

UIC RAILWAY SYSTEM DEPARTMENT  
**CES Las Vegas 2024**  
**Technical Report**

May 2024



INTERNATIONAL UNION  
OF RAILWAYS

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# Introduction

## by François Davenne, Director General of UIC

**The International Union of Railways (UIC)** is the worldwide railway organisation, with over 200 members in 95 countries from every continent, representing 2,783 billion passenger.km, 8,991 tonne.km, 801,357 route.km and 6,013 million rail staff. UIC brings together the vast majority of European railway operators, major railway operators from every other continent, universities, research institutes and associations, such as AAR<sup>1</sup> or RSSB<sup>2</sup>. UIC has developed synergies with around 100 leading institutions, such as the World Bank, international standardisation organisations (ISO, IEC, CEN-CENELEC, ETSI), railway authorities (ERA<sup>3</sup>, etc.), railway regulators (FRA<sup>4</sup>) and the Intergovernmental Organisation for International Carriage by Rail (OTIF<sup>5</sup>).

Adapting to climate change is becoming a major global concern, and its urgency has just been highlighted by the IPCC<sup>6</sup>. As a result, **UIC published its “Vision of Rail in 2030”**, encouraging the allocation of funds for investment in the **improvement of railway infrastructure, rolling stock and services**, as well as **innovation to decarbonise operations**, in order to drastically **increase the number of trains, and the number of passengers and freight carried worldwide**.

**This is why CES Las Vegas is so important for UIC.**

I would like to warmly thank Gary Shapiro, who in a visionary way, strongly supported the presence of UIC at CES in Las Vegas. Thus, UIC has been active at CES Las Vegas and CES Government since 2017, participating in conferences and panels, delivering keynote speeches, and supporting the promotion of rail. In 2024, UIC increased its presence at CES even further.

Thanks to CES Las Vegas 2024, it is possible for railway stakeholders from all over the world to identify the main trends in innovation.

Thus, I have the pleasure to present the second edition of the UIC technical report on CES Las Vegas.

We want to publish this technical report annually in order to inform railway stakeholders about the main trends in innovation, as well as identifying specific innovations to monitor for a potential transfer to the railways. This year, we have added an academic bibliography as a help for those in the railway sector wishing to transfer CES to the rail industry.

We hope you will appreciate our report on [shop.uic.org](https://shop.uic.org).

We look forward to your comments and encouragement on [shop.uic.org](https://shop.uic.org).

<sup>1</sup> AAR: Association of American Railroads

<sup>2</sup> RSSB: Rail Safety and Standards Board (UK)

<sup>3</sup> ERA: European Union Agency for Railways

<sup>4</sup> FRA: Federal Railroad Administration (USA)

<sup>5</sup> OTIF: The Intergovernmental Organisation for International Carriage by Rail (OTIF)'s raison d'être is the provision of a unified railway law for international trains. For this purpose, OTIF has implemented suitable procedures for cooperation between the state level and the railway economic sector level. See OTIF Bulletin 3/2028 pages 5 and 6 "OTIF: A CONCEPT OF LEGISLATIVE HARMONISATION BASED ON PARTNERSHIP" available at [https://otif.org/fileadmin/new/5-Media/5B-Bulletin/2018/Bulletin\\_3\\_2018\\_EN.pdf](https://otif.org/fileadmin/new/5-Media/5B-Bulletin/2018/Bulletin_3_2018_EN.pdf)

<sup>6</sup> Intergovernmental Panel on Climate Change (IPCC) (2023), "Urgent climate action can secure a liveable future for all". [online] Available at [https://www.ipcc.ch/report/ar6/syr/downloads/press/IPCC\\_AR6\\_SYR\\_PressRelease\\_en.pdf](https://www.ipcc.ch/report/ar6/syr/downloads/press/IPCC_AR6_SYR_PressRelease_en.pdf) (Accessed 20 March 2023)

<sup>7</sup> UIC (2021), "Design a Better Future". [online] Available at <https://uic.org/IMG/pdf/uic-design-a-better-future-vision-of-rail-2030.pdf> (Accessed 1 November 2021)

# Preface

by Mr. Sanjiv Bhutani - Chairman of the UIC  
International Railway Research Board (IRRB)



**The modern railway**, building its position in all regions of the world, must not only develop internally but also seek inspiration and solutions that can be adapted **to become an important part of the new mobility culture**. In this context, it is not only important to follow and analyse trends and mega-trends, but also to carefully analyse both innovations and developed technologies for end users for inspiration or simple adaptation to the needs and expectations of rail users.

**The railway**, based essentially on organic development using incremental innovations, needs to devote more effort, **in collaboration with innovators** and the financial sector, **to searching for disruptive, architectural, or even radical innovations**.

The **Consumer Electronics Summit (CES)** in Las Vegas (USA), **designed as a global stage for innovations**, is, in fact, one of the places where such inspiration can be drawn. This annual event, indeed is one of the most powerful technology events in the world. CES showcases companies including manufacturers, developers and suppliers of hardware, content, technology delivery systems etc. The trade show also includes a conference programme where global business leaders and pioneers address the most relevant industry issues. **CES is a testing ground for disruptive technologies and a meeting place for global innovators**.

**The International Union of railways (UIC), in coordination with its International Railway Research Board (IRRB), is developing Regional Competence Hubs (RCHs) to support the development of railways in all UIC regions viz.** North America, Latin America, Africa, Middle East, Asia-Pacific and Europe.

**CES is one of the sources from where RCH would draw inspiration to find key success factors** in a rapidly changing World through innovative solutions **to meet the expectations of customers**.

Networking of partners is another important element in the pursuit of development through research and innovation. The **UIC Regional Competence Hubs, which are stakeholder partnerships** for the development of individual regions in a way that **matches their vision and development policies as well as the capabilities and current abilities of the railways**, should also be present where such networking brings experts from the railway sector into alliance with academia and at the same time, seeks appropriate partnerships with innovators on a global basis.

Globally, at CES, the most valuable and recognisable brands do business, it is where they meet new partners and the sharpest minds in the electronics and emerging technology industry to present their latest launches and boldest breakthroughs. It is also **the event that allows sectors like railways to look around, and find inspiration, partners or a reference point for their own ambitions and plans both** in the short term and in terms of foresight and vision based on a goal that will **not only be an upgrade but also be a radical change**.

**The presence of UIC in the CES** not only boosts the visibility of this global association for railway development but it **is also meaningful from the point of view of looking for partnerships for the UIC Regional Competence Hubs**.

**The second edition of the UIC Report, entitled “CES Las Vegas 2024 Technical Report,” follows the success of the publication relating to CES Las Vegas 2023. It provides a valuable source of inspiration and has been enriched with references to the state of scientific knowledge** by identifying peer-reviewed scientific publications relating to the technological innovations presented at this year's Consumer Electronic Summit. I am sure all the stake holders shall immensely get benefitted from it.

# The authors

**Francis Bédel** and **Christian Chavanel** are the authors of this report, assisted by **Jean-Michel Evanghelou**, **Gilbert Reveillon** and **Paul Plummer**.

## Francis Bédel

Francis Bédel took responsibility of the UIC IT service in 2015 and held the position of UIC Chief Digital Officer during the development of the UIC Digital Platform. The UIC Digital Platform aims at supporting UIC members with their digital activities and developments on a worldwide basis, and follows the philosophy: “Share, Open, Connect”. He held these responsibilities till 2021.

Francis Bédel started his career at French Railways SNCF in 1982, filling such roles as traffic manager and manager of freight stations. In 1990, he joined SNCF’s IT Department to work on the rollout of a national project aimed at redesigning the management of freight wagons and, from 1993 to 1997, was responsible for the operation of Freight IT local bases. Francis Bédel took charge of International Affairs for Freight IT at SNCF and, among other things, was responsible for European interoperability projects and the relationship with the European Commission.

Francis was RAILDATA President from 2013 until the end of 2016. He has also been active in many other international activities and projects.

Today, Francis works as a Digital Strategy Advisor.

For over 20 years, Francis has been personally committed to volunteer social activities, predominantly humanitarian missions in Western Africa focusing on childhood and education, and has chaired an association which manages residences for young people in the Parisian area since 2019.

## Christian Chavanel

Christian Chavanel is a railway professional with more than 35 years’ experience in international development, project management, operations, maintenance, safety, standardisation and regulatory affairs in the rail sector.

He is an engineer and a graduate of an Executive MBA (ESSEC & Mannheim). He holds an MIT certificate on ‘Artificial Intelligence and its implications for Business Strategy’, and an MIT certificate on ‘Cybersecurity Leadership for Non-Technical Executives’.

He has notably held the positions of:

- Head of a consulting mission for SNTF (Société Nationale des Transports Ferroviaires) in Algiers;
- Interoperability & Standardisation Director at SNCF (from 2014 to June 2019);
- Expert at OTIF in Bern (2014-2019);
- Chair of CEN-CENELEC Sector Forum Rail (2016-2019);
- COO (SNCF Regional Transportation);
- PMO (SNCF Regional Transportation);
- Head of Paris Gare de Lyon station;
- Infrastructure District manager.

Today, he is UIC Director of the Railway System and UIC Africa Coordinator.

## Jean-Michel Evanghelou

Jean-Michel Evanghelou is Director of Telecom, Signalling and Digital Applications, as well as Director of Financial Controlling and Project Operations at UIC. During his career, he has held various director positions within the Orange Group and afterwards joined Nortel Networks, where he had different roles in the international business, serving as Vice-President for various telecom technologies and segments. He has also served as Director of the Railway Business Unit of Kapsch Group. Jean-Michel graduated as engineer from the Ecole Centrale of Paris.

## Gilbert Reveillon

CEO Mobile LOOV Sarl

CEO – Managing Director at Finances, Digital Transformation & eCommerce, Paris, France

- Harvard Business School, FinTech online, Alumni April 2021;
- PhD Maître de Conférences (Associate Professor) at Institut Mines Telecom, 2013;
- Master of Business Administration MBA HEC Montréal (Finances, CAD), 1991;
- Seasoned CEO in High Tech, Aviation, HS Train (Eurostar) & Services (Accor, BNPP);
- CES Las Vegas “Innovation Awards” 2014 and 2015 (Digital Health, Wearable Tech);
- Serial Investor / Business Angel in the digital ecosystem (French Tech);
- JV & Partnerships France, UK, Germany, USA (Boston, NYC, Silicon Valley), China (Peking U).

Skills in:

- International Business Development for Global Fortune 500 & state-of-the-art start-ups, including CDO EU;
- Alliances;
- Managed 350 start-ups & 30 incubators: Master Programme Innovation for IMT-TEM;
- Cross-border France-EU-China-UK-USA-CAD investment projects in Innovation and Technology (IoT, Quantum Computing & Q Sensing, Digital Transformation, AI & MLearning, Industry 4.0, AV & VR, Blockchain & Cryptos, Cybersecurity, IS, FinTech, M&A);
- Seminar & international keynote speaker;
- Washington DC, NYC, Boston, Shenzhen, Beijing, Shanghai, Wuhan, HKG, Tokyo, Luxemburg, Geneva;
- London, Paris, etc.;
- World Bank, IMF, UN, UIC, CES & CES Government (as Chair Europe), ANDESE, (PhD EU Awards);
- Club GIS, etc.;
- CCE (Conseiller du Commerce Extérieur – Foreign Trade Advisor for the French Government), President ICT & Digital Economy (white paper to DGT & Ministry of Economics & Foreign Affairs and French Parliament).

## Paul Plummer

Professor Paul Plummer is Director of the University of Birmingham Centre for Rail Research and Education (BCRRE) and lead for the UK Rail Research and Innovation Network (UKRRIN). He also holds various rail industry positions. Formerly he has been Chief Executive of Rail Delivery Group (RDG), Group Strategy Director at Network Rail, President of European Infrastructure Managers (EIM) and Chief Economist at what is now the Office of Rail and Road (ORR).

## Authors' Biographies

### Dr John Easton

Dr John Easton is an Associate Professor in the University of Birmingham's School of Engineering, specialising in topics related to the applications of digital systems in rail, data modelling, machine learning and cyber security in industrial systems. He is the immediate past chair of the IET's Railway Technical Network (2018-2021) and currently chairs the Railway Engineers Forum (REF), which serves as an interface between railway special interest groups: IET, IMechE, ICivE PWI, CLIT and CIRO. John sits on RSSB's Data and Information Systems Interface Committee (DISIC) as the academic representative and is a member of the UK Department for Transport's College of Experts.

### Dr Qian Fu

Dr Qian Fu is a Research Fellow at the Birmingham Centre for Railway Research and Education within the University of Birmingham's School of Engineering. His expertise lies in big data and analytics, with a particular focus on the development and implementation of advanced methods and open-source research software for integrating, analysing and managing data across diverse transport systems. He has worked in close collaboration with partners such as Network Rail and RSSB, and received the Turing Postdoctoral Enrichment Award for his work. He is an active member of the Royal Statistical Society and the Society of Research Software Engineering.



# 1. Context

The Consumer Electronic Show (CES) held in Las Vegas is an annual global event showcasing the latest trends and innovations in electronics, software, artificial intelligence, etc.

CES Las Vegas 2021 was cancelled because of Covid-19.

CES Las Vegas 2022 was a hybrid event, with more than 4,400 booths, hybrid conferences and around 45,000 visitors.<sup>8</sup> China and GAFAM were not present, and there were no presentations on public transport or the railways.

CES Las Vegas 2023 hosted more than 3,200 companies, including over 1,000 start-ups. 115,000 visitors from 140 countries and 4,800 media attended the event.<sup>9</sup>

In 2024, **CES Las Vegas 2024** broke records:

- There were over 4,300 exhibitors, including 1,400 start-ups;
- Over 135,000 visitors, including over 40% from outside the US, and over 5,000 media attended the event;
- 250 conferences with than 1,000 speakers took place;
- 27,000 articles and content worldwide were published, generating some 270 billion global impressions for the #CES2024 hashtag,<sup>10</sup> including 170 millions for the sole Web village with #CES2024Web3TF Hashtag.

## CES Las Vegas 2024

**UIC** has been active at CES Las Vegas and CES Government since 2017, participating in conferences and panels, delivering keynote speeches and supporting the promotion of rail. In 2024, UIC increased its presence at CES even further.

For the second time, **UIC had its own booth** and was present to promote and advocate for railway digitalisation and fostering rail as the backbone of new transport mobility.

In addition, **UIC** was a **partner of “the CES 2024 Web 3 Global Village Pavilion – Creating a faster, safer and more sustainable future”**, and was involved in different activities.<sup>11</sup>

The official kick-off of the “CES 2024 Web3TF village” has been performed by Don UPSON, Chairman CES GovTech GBEF with a special focus on cybersecurity issues for infrastructures which remains a sensitive issue for UIC and its Members.

Laurent Bili, French ambassador to the USA, visited the Village on 10 January 2024.

Francis Bédel moderated a panel on Artificial Intelligence (AI) and cybersecurity applied to rail, with four keynote speakers:

- Jean-Michel Evanghelou (UIC) on ‘*Railway cybersecurity*’;
- Christian Chavanel (UIC) on ‘*AI applied to railway sector*’;
- Fabrice Morénon (SNCF Hubs & Connections) on ‘*AI revolution and railway stations*’;
- Wong-Sang Lee (Hundai Rotem) on ‘*AI, cyber security & eco-friendly railway mobility*’.

We take this opportunity to warmly thank Gilbert Reveillon for hosting UIC in his Village, close to other partners, including French CCE and Delupac.

Mobility was one of the key trends for CES Las Vegas 2024, and UIC was able to ensure that rail was present and could be considered a key actor for future green mobility.

UIC intends to be present and even more visible and more active in 2025, in order to promote and advocate for rail as the backbone of future mobility, for both passengers and goods.

<sup>8</sup> Les Echos (2023), “Tech : le CES fait sa (vraie) rentrée après la pandémie”. [online] Available at <https://www.lesechos.fr/tech-medias/hightech/le-ces-fait-sa-vraie-rentree-apres-la-pandemie-1893691> (Accessed 4 January 2023)

<sup>9</sup> Forbes (2023), “#CES2023 | Ce que l’on peut retenir du salon de Las Vegas ?”. [online] Available at <https://www.forbes.fr/business/ces2023-i-ce-que-lon-peut-retenir-du-salon-de-las-vegas/#:~:text=Les%20chiffres%20cl%C3%A9s&text=Le%20salon%20s'est%20termin%C3%A9,de%20plus%20de%20140%20pays> (Accessed 11 January 2023)

<sup>10</sup> Forbes (2024), “#CES2024 | Ce que l’on peut retenir du salon de Las Vegas ?”. [online] Available at <https://www.forbes.fr/technologie/adr-contrib-ces2024-i-ce-que-lon-peut-retenir-du-salon-de-las-vegas/> (Accessed 15 January 2024)

<sup>11</sup> UIC (2024), “UIC at CES Las Vegas 2024”. [online] Available at [https://www.linkedin.com/posts/uicrail\\_ces2024-ces2024w3tf-ces2024web3tf-activity-7150450190921912320-HPXW?utm\\_source=share&utm\\_medium=member\\_ios](https://www.linkedin.com/posts/uicrail_ces2024-ces2024w3tf-ces2024web3tf-activity-7150450190921912320-HPXW?utm_source=share&utm_medium=member_ios) (Accessed 12 January 2024)



## 2. Main trends

CES Las Vegas 2024 was a continuation of CES 2023:

- It used to focus on consumer electronics, from large screens TVs to various connected objects;
- As last year, organisers developed this year what they called marketplaces, i.e. fairs that are **increasingly B to B**, whereas the fair was originally much more B to C;
- As in 2023, the **automotive sector** confirmed its **leading position** at the show, with a focus on electric and autonomous vehicles;<sup>12</sup>
- As in 2023, **microchip manufacturers** were present.

New sectors made their debut at CES Las Vegas 2024, such as L'Oréal, Essilor and Delubac.<sup>13</sup>

The CES Las Vegas 2024 conference programme highlighted advances in digital health, Generative Artificial Intelligence (AI), sustainability, gaming, vehicle tech, cybersecurity, the future of money, space tech, etc. (CES 2024 a)<sup>14</sup>. Artificial Intelligence was everywhere.<sup>15</sup>

In this context, the keynote speeches (CES 2024 a)<sup>16</sup> addressed:

- The benefits of blending the real and digital worlds, including the emerging **industrial metaverse** by Siemens (CES 2024 b)<sup>17</sup>;
- **Sustainable, accessible and inclusive beauty tech** by L'Oréal (CES 2023 a)<sup>18</sup>;
- **Brand loyalty in the age of always on** by C-Space (CES 2024 c)<sup>19</sup>;
- How Walmart is enabling the **next generation of retail**, which will reflect on their people culture, beyond the advances powered by artificial intelligence and machine learning (CES 2023 b)<sup>20</sup>:
  - **Roles of silicon and software in making AI more accessible**, by Intel (Intel 2024)<sup>21</sup>,
  - Tech to make **healthcare more proactive, predictive and personalised** (Intel and Elevance Health),
  - Tech innovations **improving the productivity and sustainability of the construction industry** by HD Hyundai (CES 2023 c)<sup>22</sup>,
  - Usage of **devices in the AI age**, by Qualcomm and Nasdaq (CES 2023 d)<sup>23</sup> (Qualcomm 2024)<sup>24</sup>.

<sup>12</sup> Forbes (2024), "#CES2024 | Ce que l'on peut retenir du salon de Las Vegas ?". [online] Available at <https://www.forbes.fr/technologie/adr-contrib-ces2024-i-ce-que-lon-peut-retenir-du-salon-de-las-vegas/> (Accessed 15 January 2024)

<sup>13</sup> Forbes (2024), "#CES2024 | Ce que l'on peut retenir du salon de Las Vegas ?". [online] Available at <https://www.forbes.fr/technologie/adr-contrib-ces2024-i-ce-que-lon-peut-retenir-du-salon-de-las-vegas/> (Accessed 15 January 2024)

<sup>14</sup> CES (2024 a) – "CES 2024 Keynotes". [online] Available at <https://www.ces.tech/sessions-events/keynotes.aspx> (Accessed 7 January 2024)

<sup>15</sup> Consumer Technology Association (2024), "Tech Trends to Watch 2024", slide 14. [online] Available at <https://cdn.ces.tech/ces/media/pdfs/2024/ces-tech-trends-pres0.pdf>, (Accessed 8 January 2023)

<sup>16</sup> CES (2024 a) – "CES 2024 Keynotes". [online] Available at <https://www.ces.tech/sessions-events/keynotes.aspx> (Accessed 7 January 2024)

<sup>17</sup> CES (2024 b), "Siemens Keynote, CES 2024 : Combining Real, Digital Worlds". [online] Available at <https://www.ces.tech/articles/2023/october/siemens-keynote-ces-2024-combining-real-digital-wo.aspx> (Accessed 7 January 2024)

<sup>18</sup> CES (2023 a), "L'Oréal to Keynote at CES 2024 – Defining the Next Era of BeautyTech". [online] available at <https://www.ces.tech/news/press-releases/ces-press-release.aspx?NodeID=5d8a5073-220a-4e19-8ed3-bed94e963776> (Accessed 26 July 2023)

<sup>19</sup> CES (2024 c), "C Space Keynote : Brand Loyalty in the Age of Always On". [online] Available at <https://videos.ces.tech/detail/video/6344569683112/c-space-keynote:-brand-loyalty-in-the-age-of-always-on> (Accessed 9 January 2024)

<sup>20</sup> CES (2023 b), "Walmart to Keynote CES 2024, Revealing Its Vision for Continued Retail Disruption". [online] Available at <https://www.ces.tech/news/press-releases/ces-press-release.aspx?NodeID=87f5a236-1482-4d01-9ca9-f405f9877c6f> (Accessed 2 October 2023)

<sup>21</sup> Intel (2024), "Intel at CES 2024: Bringing 'AI Everywhere'". [online] Available at <https://www.intel.com/content/www/us/en/newsroom/resources/ces-2024.html#gs.4vf5n1> (Accessed 10 January 2024)

<sup>22</sup> CES (2023 c), "HD Hyundai, CES 2024 Keynote, on Sustainability in Construction". [online] Available at <https://www.ces.tech/articles/2023/november/hd-hyundai-ces-2024-keynote-on-sustainability-in.aspx> (Accessed 9 November 2023)

<sup>23</sup> CES (2023 d), "Qualcomm Keynote to Explore On-Device AI at CES 2024". [online] Available at <https://www.ces.tech/articles/2023/november/qualcomm-keynote-to-explore-on-device-ai-at-ces-20.aspx> (Accessed 20 November 2023)

<sup>24</sup> Qualcomm (2024), "How We Will Interact with Our Devices in the AI Age". [online] Available at <https://www.qualcomm.com/company/events/ces> (Accessed 10 January 2024)

As usual, public transport was quite absent from this edition. However, the rail sector was represented by UIC for the second time with a dedicated booth.

## 2.1. Main trends in 2023

### CES 2023 Tech Trends

Steve Koenig, VP Research of the Consumer Technology Association, opened CES with his “CES 2023 Tech Trends to Watch”.<sup>25</sup>

Industries were still confronting global challenges:

- Supply chains remain vulnerable;
- Semiconductor demand stubborn inflation softening;
- Labour shortages;
- Stubborn inflation and rising interest rates.

However, **the key technology themes of CES 2023 were:**

- **Enterprise tech innovations;**
- **Metaverse / Web 3.0;**
- **Transportation and mobility;**
- **Health technology;**
- **Sustainability;**
- **Gaming and services.**

#### 2.1.1. Enterprise tech Innovations

This theme covered:

- **5G and industrial IoT applications;**
- **Connected intelligence;**
- **Autonomous systems;**
- **Quantum computing;**
- Enabling **automation** and **virtualisation**.

The digital utilities underpinning the modern enterprises were:

- **Cybersecurity;**
- **The cloud;**
- **AI & robotics.**

In terms of **logistics** and **warehouse automation**, these trends were supposed to increase **productivity**, improve **worker safety** and optimise uptime and floor space.

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<sup>25</sup> Consumer Technology Association (2023), “CES 2023 Tech Trends to Watch”. [online] Available at <https://videos.ces.tech/detail/video/6318202282112/ces-2023-tech-trends-to-watch> (Accessed 4 January 2023)

## 2.1.2. Metaverse

The metaverse was closer than we thought.

The **Metaverse of Things (MoT)** was deemed to have impacts on:

- **Virtualisation** (virtual spaces, multiple access points, digital twins, individualisation of the consumer experience);
- **Immersion experience** (virtual scenarios, full immersion, VR-based experience, digital twins, shared experience).

Metaverse strategies were supposed to range from consumers (retail, competition, entertainment, social interactions) to businesses (simulation, immersive marketing, Metaverse as a Service) and mixed uses (communication, cooperation, transaction).

## 2.1.3. Transportation and mobility

This theme covered:

- Electric Vehicles (EVs) and the **evolution of the electrification ecosystem**, covering land, sea and air-transport;
- Advancement of **autonomous systems** and application;
- **Transformation of the in-vehicle experience.**

The transformation of the in-vehicle experience could be based on:

- Screenification;
- Voice control;
- 5G V2X;
- Retail and entertainment services;
- Features as a Service (FaaS) Models.

## 2.1.4. Health technology

This theme covered:

- Digital therapeutics, notably new ways to manage chronic health conditions;
- Telehealth;
- Fitness tech.

The new frontiers in Health Tech innovations were foreseen to be:

- On-demand network (24/7 virtual visits):
  - Access to online pharmacies,
  - Remote patient monitoring,
  - Fitness/wellness platforms,

- Mental wellness:
  - Stress relief,
  - Anxiety management,
  - Monitoring depression,
- Virtual reality applied to:
  - Fitness,
  - Therapeutic treatments,
  - Physician training.

### 2.1.5. Sustainability and Environmental and Social Governing (ESG)

Sustainability innovations were based on:

- Smart grid;
- **Supply chain;**
- Agriculture/Food tech;
- **Clean air and water;**
- **Alternative energy;**
- Minimising packages;
- **Recycling technologies;**
- Reducing use of rare earth metals.

The farm of the future was based on:

- Intelligent silos;
- **Drones** and soil detectors;
- Satellite and 5G connections;
- Connected farmers;
- **Farming robots;**
- Offsite analysis platforms.

### 2.1.6. Gaming and services

Gaming was based on the latest technological developments.

## 2.2. Main trends in 2024

Jessica Boothe and Brian Comiskey, respectively Director of Research and Director of Thematic Programs of the Consumer Technology Association, opened CES with “*Tech Trends to Watch 2024*”<sup>26</sup>.

**In comparison to CES 2023, we saw no major breakthroughs.**

CES 2024 is a continuation of previous trends in innovation.

From a railway point of view, the only surprising innovations were transparent screens and transparent solar cells, with potential transfers to railway sector which we will discuss in Section 3 of this report.

There is a **global connectivity acceleration**, with 5.4 billion people connected to the Internet today and 1 billion more expected to come online by 2027.

It is essential to have a **special focus on Gen Z** (11-26 years old): 86% of Gen Z in the USA say tech is essential to their lives; and 90% of the global Gen Z reside in emerging markets.

**Digital infrastructure evolves through Li-Fi, IoT, edge computing and next telecom generation.**

Therefore, the **cloud** and **cybersecurity** will continue to be crucial.

**AI** and **robotics** will benefit from this main trend.

That is why the main trends shaping the near future will be **AI, sustainability and inclusivity with impacts on food, mobility, gaming, fintech, health and content.**

**Consumers’ AI concerns** cover privacy, disinformation, safety and job loss.

The **convergence between health and wellness** remains a key factor of innovation.

Bigger, better and faster **battery storage solutions** for electric vehicles (EVs) have been numerous, with potential benefits for the rail sector.

**As seen in 2023, the railway sector should continue to carefully monitor potential transfers to railways:** 5G use cases and industrial IoT applications; connected intelligence; autonomous systems; quantum computing; cybersecurity; Artificial Intelligence (AI); robotics; the Metaverse of Things (MoT); immersion experience; electrification ecosystems; transformation of the in-vehicle experience; smart grids; applications for supply chains; solutions for clean air and water; alternative energies; recycling technologies; and drone technologies and applications.

**In addition, the railway sector should carefully consider edge computing, battery storage solutions, transparent screens and transparent solar cells.**

### 2.2.1. Enterprise tech innovations

This theme covers:

- 5G and industrial IoT applications;
- Connected intelligence;
- Autonomous systems;
- Quantum computing;
- Enabling automation and virtualisation.

<sup>26</sup> Consumer Technology Association (2024), “*Tech Trends to Watch 2024*”. [online] Available at <https://cdn.ces.tech/ces/media/pdfs/2024/ces-tech-trends-pres0.pdf>. (Accessed 8 January 2023)

The digital utilities underpinning modern enterprises are:

- Cybersecurity;
- The cloud;
- AI & robotics.

In terms of **logistics** and **warehouse automation**, these trends will increase **productivity**, improve **worker safety** and optimise uptime and floor space.

### 2.2.2. Metaverse

The metaverse is closer than we think.

The Metaverse of Things (MoT) will impact:

- **virtualisation** (virtual spaces, multiple access points, digital twins, individualisation of the consumer experience);
- **immersion experience** (virtual scenarios, full immersion, VR-based experience, digital twins, shared experience).

Metaverse strategies will range from consumers (retail, competition, entertainment, social interactions) to businesses (simulation, immersive marketing, Metaverse as a Service) and mixed uses (communication, cooperation, transaction).

### 2.2.3. Transportation and mobility

This theme covers:

- Electric Vehicles (EVs) and the **evolution of the electrification ecosystem**, covering land, sea and air transport;
- Advancement of **autonomous systems** and application;
- Transformation of the in-vehicle experience.

The transformation of the in-vehicle experience will be based on:

- Screenification;
- Voice control;
- 5G V2X;
- Retail and entertainment services;
- Features as a Service (FaaS) Models.

### 2.2.4. Health technology

This theme covers:

- Digital therapeutics, notably new ways to manage chronic health conditions;
- Telehealth;
- Fitness tech.

The new frontiers in Health Tech innovations are:

- On-demand network (24/7 virtual visits):
  - Access to online pharmacies,

- Remote patient monitoring,
- Fitness/wellness platforms,
- Mental wellness:
  - Stress relief,
  - Anxiety management,
  - Monitoring depression,
- Virtual reality will be applied to:
  - Fitness,
  - Therapeutic treatments,
  - Physician training.

### 2.2.5. Sustainability and Environmental and Social Governing (ESG)

Sustainability innovations are based on:

- Smart grid;
- Supply chain;
- Agriculture/food tech;
- Clean air and water;
- Alternative energy;
- Minimising packages;
- Recycling technologies;
- Reducing use of rare earth metals.

The farm of the future will be based on:

- Intelligent silos;
- **Drones** and soil detectors;
- Satellite and 5G connections;
- Connected farmers;
- Farming robots;
- Offsite analysis platforms.



## 2.2.6. Gaming and services

Gaming will be based on the latest technological developments.

In addition, it is important to consider two keynote speeches:

- Olivier Zipse: Chair of the Board of Management, BMW: *“How the Future of Mobility Can Merge the Real and Virtual Worlds”*, 4 January 2023;<sup>27</sup>
- Carlos Tavares, CEO, Stellantis: *“The Future of Sustainable Mobility”*, 5 January 2023.<sup>28</sup>

**Of all these main trends, the railway sector should carefully monitor potential transfers to railways:** 5G use cases and industrial IoT applications; connected intelligence; autonomous systems; quantum computing; cybersecurity; Artificial Intelligence (AI); robotics; the Metaverse of Things (MoT); immersion experience; electrification ecosystems; transformation of the in-vehicle experience; smart grids; applications for supply chains; solutions for clean air and water; alternative energies; recycling technologies; and drone technologies and applications.

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<sup>27</sup> Zipse, Olivier. (2023). *How the Future of Mobility Can Merge the Real and Virtual Worlds*. [online] Available at: <https://videos.ces.tech/detail/videos/ces-2023-keynotes/video/6318212504112/bmw-keynote?autoStart=true>

<sup>28</sup> Tavares, Carlos. (2023) *The Future of Sustainable Mobility*. [online] Available at: <https://videos.ces.tech/detail/videos/ces-2023-keynotes/video/6318254987112/stellantis-keynote?autoStart=true>

### 3. Innovations which could be applied to the rail sector

As explained above, the only surprising innovations were **transparent screens** and **transparent solar cells**.

**Regarding transparent screens**, an awarded innovation is described below.

#### Transparent solar cells

The solid, opaque layers of silicon photovoltaic (PV) cells limit their use on transparent surfaces.

However, perovskite-based solar cells could facilitate solar cells on transparent surfaces. Perovskites are crystalline minerals, able to convert light into voltage. Perovskites are ink-like materials which can be finely printed on glass, sometimes as transparent or tinted composites.

Thus, while current silicon PV cells are mainly implemented on rooftops, perovskite-based solar cells could be incorporated into windows and walls. Consequently, these transparent perovskite-based solar cells could both drastically increase the potential implementations of solar cells and reduce the sprawl of solar farms.

“Technical efficiency levels for silicon-based cells top out below 30%, while perovskite-only cells have reached experimental efficiencies of around 26%.”<sup>29</sup>

In addition, “Solar cells that combine traditional silicon with cutting-edge perovskites could push the efficiency of solar panel to new heights. [...] If deployed on a significant scale, [such] perovskite tandem cells could produce more electricity than the legacy solar cells at a lower cost”.<sup>30</sup>

According to Panasonic<sup>31</sup>, “large-scale demonstration materials could be ready in 2025” and market uptake could occur within five years.

At this stage, it is important to keep in mind that “perovskites are notorious for degrading when exposed to high temperatures, moisture and bright light”.<sup>32</sup>

<sup>29</sup> MIT Technology Review (2024), “Super-efficient solar cells: 10 Breakthrough Technologies 2024”. [online] Available at <https://www.technologyreview.com/2024/01/08/1085124/super-efficient-solar-cells-breakthrough-technologies/> (Accessed 8 January 2024)

<sup>30</sup> MIT Technology Review (2024), “Super-efficient solar cells: 10 Breakthrough Technologies 2024”. [online] Available at <https://www.technologyreview.com/2024/01/08/1085124/super-efficient-solar-cells-breakthrough-technologies/> (Accessed 8 January 2024)

<sup>31</sup> Nature (2024), “Three Sustainable Japanese Technologies to Watch”. [online] Available at <https://www.nature.com/articles/d42473-023-00174-w>

<sup>32</sup> MIT Technology Review (2024), “Super-efficient solar cells: 10 Breakthrough Technologies 2024”. [online] Available at <https://www.technologyreview.com/2024/01/08/1085124/super-efficient-solar-cells-breakthrough-technologies/> (Accessed 8 January 2024)

### 3.1. Accessibility

#### Motionsleep By 10minds co. ltd.



The motion pillow has been combined with the vital ring to enhance the sleep experience for individuals who snore or encounter breathing discomfort. It not only intelligently detects snoring sounds, but also accurately measures oxygen saturation levels. Through the movement of 7 airbags, it dynamically adjusts the positions of the head and back, creating a comfortable breathing environment and reducing snoring. The product has been further enhanced with an increased number of airbags, the vital ring for oxygen saturation measurement, circadian rhythm lighting and a space-saving charging system, all contributing to improved performance and usability, and adding a touch of sophistication.<sup>33</sup>

**Could be of interest for night trains (premium passengers)**

#### GUIDi – AI smart belt to guide the visually impaired By AI Guided Limited



GUIDi is an AI smart belt that empowers the visually impaired by implementing MEMS and AI technology within wearable devices. We help users manage their own personal and highly intelligent navigation system, independent of the Internet or GPS. The device works using dual wide-angle cameras, a customised edge AI module with sensor integration, a haptic navigation system and voice command. The accompanying mobile app features voice command support and over-the-air updates, ensuring continuous improvement and cutting-edge functionality.<sup>34</sup>

**Important for visually impaired passengers in stations**

#### OOrion App By OOrion



OOrion is a specialised mobile app for visually impaired individuals, assisting the user in identifying, locating and navigating elements such as objects and text in their surroundings. It uses image recognition algorithms, fully developed internally, and needs no other equipment than a simple smartphone camera. It operates offline and is entirely compatible with Siri and VoiceOver, the iPhone's screen reader.<sup>35</sup>

**Important for visually impaired passengers in stations**

<sup>33</sup> CES 2024. *Motionsleep*. [online] Available at: <https://www.ces.tech/innovation-awards/honorees/2024/best-of/m/motionsleep.aspx>

<sup>34</sup> CES 2024. *GUIDi*. [online] Available at: <https://www.ces.tech/innovation-awards/honorees/2024/honorees/g/guidi-ai-smart-belt-to-guide-the-visually-impaired.aspx>

<sup>35</sup> CES 2024. *Oorion App*. [online] Available at: <https://www.ces.tech/innovation-awards/honorees/2024/honorees/o/oorion-app.aspx>

## 3.2. Artificial Intelligence

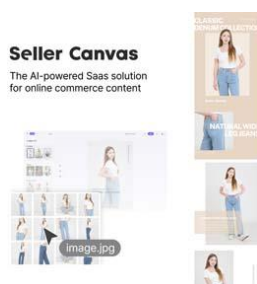
### Gun Detection System By Bosch



The Gun Detection System from Bosch is the first to pair video and audio AI to prioritise proactive security and safety involving guns at schools. The near-invisible system offers a multi-layered approach to increase the security and safety of campuses, while enabling a smooth, frictionless flow and welcoming atmosphere that promotes learning.<sup>36</sup>

**Could apply to stations**

### Seller Canvas By STUDIO LAB



Seller Canvas revolutionises e-commerce marketing by assisting companies, sellers and marketing agencies in need of commerce content. It has an AI marketing content creation tool and an automated photo robot. With vision AI, a robot arm and a self-driving body, the photo robot analyses the model, product and surroundings, and shoots the perfect photo op. Beyond just photography, the platform automates the entire content creation cycle by analysing and utilising user-uploaded product, model photos for image editing and commerce copywriting. Seller Canvas can effortlessly generate and design a wide range of promotional content – from landing pages and advertisements, to short videos.<sup>37</sup>

**Interesting for stations and passenger experience**

### DeCloakVision By Decloak Intelligences Co.



DeCloakVision is an innovative privacy-enhancing surveillance system that protects individuals' privacy while enabling the targeted observation and tracking of specific activities. This system employs decentralised AI models, harnessing differential privacy and homomorphic encryption tech for secure, anonymous tracking without compromising identities or public privacy. DeCloakVision's multimodal deep neural network (DNN) model ensures high efficiency in human image processing tasks and accuracy in recognition tasks, while providing differentially private de-identification and quantum safe encryption to safeguard image data. The system seamlessly integrates with existing surveillance infrastructure and presents a robust remedy for mass surveillance challenges, all while protecting individual privacy rights.<sup>38</sup>

**Applicable to stations**

<sup>36</sup> CES 2024. *Gun Detection System*. [online] Available at: <https://www.ces.tech/innovation-awards/honorees/2024/best-of/g/gun-detection-system.aspx>

<sup>37</sup> CES 2024. *Seller Canvas*. [online] Available at: <https://www.ces.tech/innovation-awards/honorees/2024/best-of/s/seller-canvas.aspx>

<sup>38</sup> CES 2024. *DE CLOAK Vision*. [online] Available at: <https://www.ces.tech/innovation-awards/honorees/2024/honorees/d/decloakvision.aspx>

## Trip.PASS – Mobile passport platform By Lordsystem



Trip.PASS is a groundbreaking platform that merges financial and tourism services, with a keen focus on digital security and personal privacy. According to Interpol, officials worldwide conducted 1.7 billion searches for lost passports in 2021. Trip.PASS Mobile Passport addresses this issue by securely authenticating digital identities and preventing passport theft and fraud. The platform offers a wide array of online-to-offline services, such as payments, tax-free shopping and transportation, all fortified with advanced security measures. Its mobile-based financial services offer a secure and streamlined travel experience. By setting a new standard in digital security, Trip.PASS revolutionises both global tourism and cybersecurity.<sup>39</sup>

**Of interest for ticketing**

## D-ID Creative Reality Studio and mobile app By D-ID

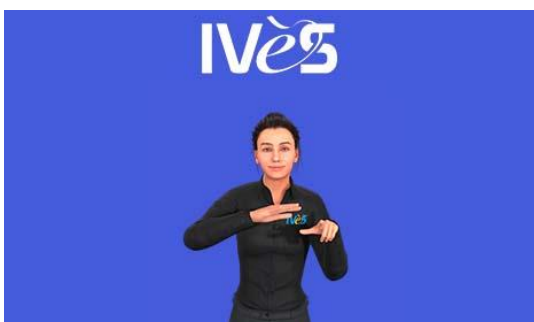


D-ID's Creative Reality Studio dramatically reduces the time, hassle and costs of video production, allowing for the creation of highly personalised, AI-generated media for marketing, customer experience, corporate training, AI assistants and more. It has a new subscriber every 3 seconds and over 150 million videos generated.

Powered by D-ID's industry-leading API, the mobile app features the core functionalities of the Creative Reality Studio, allowing millions of new users to create videos for social media content, messaging apps and email. It allows users to generate videos of digital people based on a single image and either a written script or an audio recording.<sup>40</sup>

**For training and web application design**

## IRIS By IVès



IRIS, much like a chatbot, operates as a computer program powered by Artificial Intelligence (AI). Its primary function is to facilitate real-time communication by enabling our virtual avatar, IRIS, to provide immediate responses to inquiries posed by internet users. Whether it's answering questions or engaging in conversations, IRIS leverages AI to understand and interpret user queries, ensuring swift and accurate interactions. This innovative technology marks a significant advancement in bridging the communication gap, particularly for users who rely on sign language as their primary means of communication.<sup>41</sup>

**Of interest for customer information**

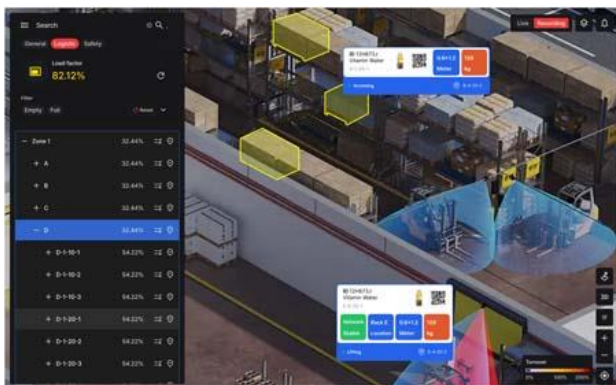
<sup>39</sup> CES 2024. *Trip.PASS-Mobile passport platform*. [online] Available at: <https://www.ces.tech/innovation-awards/honorees/2024/best-of/trip-pass-mobile-passport-platform.aspx>

<sup>40</sup> 44 CES 2024. *D-ID Creative Studio and Mobile App*. [online] Available at: <https://www.ces.tech/innovation-awards/honorees/2024/honorees/d-id-creative-reality-studio-and-mobile-app.aspx>

<sup>41</sup> CES 2024. *IRIS*. [online] Available at: <https://www.ces.tech/innovation-awards/honorees/2024/honorees/i/iris.aspx>



## WATA AI Warehouse Management Platform with AI Vision Kit By WATA Inc



AI Warehouse Management Platform harnesses an AI vision kit that merges LiDAR, Vision, AIoT and edge servers to capture and instantly map data in rapidly evolving industrial settings, creating a 3D environment that is identical to reality. By replacing outdated systems unable to adapt to dynamic industrial environments, the platform facilitates real-time field data integration, enhancing real-time, reality-enhanced DX. Integrating AI Vision Kit with the platform brings innovation to the logistics processing of traditional warehouses. It provides integrated control and monitoring to prevent industrial accidents in settings where humans, robots and heavy machinery collaborate, all while enhancing individual task efficiency.<sup>42</sup>

**For application in warehouse management**

## 3.3. Cybersecurity

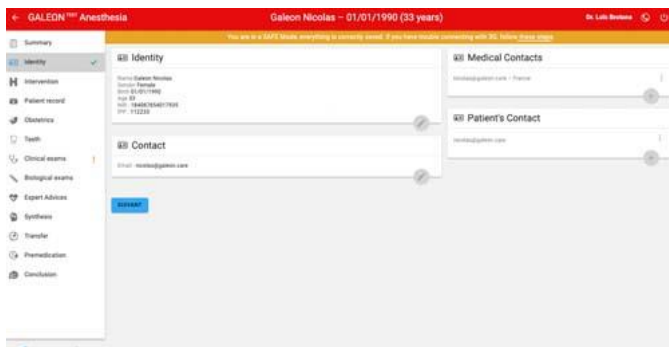
### Offline Identification By Akidaia



Akidaia has created an offline access control solution, while for over 30 years existing solutions like badges, mobile apps, QR codes and biometrics have always needed to be connected to a database of authorised users. By decentralising access rights, Akidaia eliminates heavy and expensive infrastructure, protects companies and institutions from cyber-attacks and provides a security solution for temporary sites, such as construction sites, and isolated areas like technical facilities or industrial sites.<sup>43</sup>

**Applicable to stations and isolated sites**

### Galeon Hacker Defence Protection (HDP) By Galeon



Galeon HDP is the first electronic health record that has resisted two cyber-attacks and saved lives. 40 million hospital records were compromised this year in the US. Galeon Hacker Defence Protection (HDP) instantly detects and prevents cyber-attacks, protecting patients and hospital assets. During an attack, Galeon HDP switches to SAFE MODE. It closes all compromised access and monitors traffic to allow caregivers access to patient files. It helps hospitals to keep running and avoid months of disruption, degraded services, and data and money losses.<sup>44</sup>

**Applicable to stations**

<sup>42</sup> CES 2024. WATA AI Warehouse management platform with AI vision kit. [online] Available at: <https://www.ces.tech/innovation-awards/honorees/2024/honorees/w/wata-ai-warehouse-management-platform-with-ai-vision-kit.aspx>

<sup>43</sup> CES 2024. Offline Identification. [online] Available at: <https://www.ces.tech/innovation-awards/honorees/2024/honorees/o/offline-identification.aspx>

<sup>44</sup> CES 2024. Galeon Hacker Defence Protection (HDP). [online] Available at: [https://www.ces.tech/innovation-awards/honorees/2024/honorees/g/galeon-hacker-defense-protection-\(hdp\).aspx](https://www.ces.tech/innovation-awards/honorees/2024/honorees/g/galeon-hacker-defense-protection-(hdp).aspx)

## DFS-aided Cyber Security Camera By Microsystems, Inc.



Drop Free Screen (DFS) is the world's first camera cover glass for cyber security cameras with the most advanced security functions: electronic liquid screening for improving cyber security and drop free glass for improving camera visibility. DFS, operated by a single electrowetting-on-dielectric (EWOD) technology, has outstanding advantages such as low thickness (200µm), low power consumption (1mW) and robust operation (>100,000 cycles). For the first time, DFS is applied to a camera to protect personal privacy from cyber security threats and provide a safe monitoring environment without compromising camera size and battery life.<sup>45</sup>

**Applicable to stations**

## 3.4. Digital Imaging

### LG 4K Transparent OLED T By LG Electronics Inc.



The world's first 77-inch UHD transparent OLED TV reflects users' taste and personality while pursuing a non-standard interior. It has a customisable design in which metal shelves and frame are combined to resemble furniture. This product offers flexible installation options using LG's Zero Connect technology, suitable for centre room, window-front or traditional TV set-ups. It supports various mounting methods, including wall and floor stands. Motorised contrast enhancement technology selectively displays essential elements, enhancing transparency and the 3D effect. For immersive content like movies, it employs shading technology, creating a dual viewing experience that transitions to a black screen when needed.<sup>46</sup>

**Of interest for stations**

## 3.5. Drones and unmanned systems

### Parkie (Parking Robot) By HL Mando



Our innovative autonomous driving robot valet parking solution is rewriting the world of smart buildings and smart city development. It easily adapts to suit any car and can be installed in any structure without additional construction. Our design, based on the latest autonomous driving and robotics technology, does not just provide 24/7 valet parking that is both fast and safe, it also allows building owners and developers to increase value by adding up to 30% more parking spaces to a location.<sup>47</sup>

**Of interest for car parks in main stations**

<sup>45</sup> CES 2024. *DFS-aided Cyber Security Camera*. [online] Available at: <https://www.ces.tech/innovation-awards/honorees/2024/honorees/d/dfs-aided-cyber-security-camera.aspx>

<sup>46</sup> CES 2024. *LG 4K Transparent OLED T*. [online] Available at: <https://www.ces.tech/innovation-awards/honorees/2024/best-of/lq-4k-transparent-oled-t.aspx>

<sup>47</sup> CES 2024. *PARKIE (Parking Robot)*. [online] Available at: [https://www.ces.tech/innovation-awards/honorees/2024/best-of/p/parkie-\(parking-robot\).aspx](https://www.ces.tech/innovation-awards/honorees/2024/best-of/p/parkie-(parking-robot).aspx)



### 3.6. Embedded technologies

#### FreePower for Countertop By Aira, Inc.



FreePower can turn any countertop into a wireless charger. From bar tops at a restaurant to your kitchen island or home office desk, this embedded technology seamlessly integrates into surfaces of all kinds. FreePower gives users complete spatial freedom to place devices anywhere within the charging zone and can accommodate multiple devices at the same time.<sup>48</sup>

**For customer experience in stations**

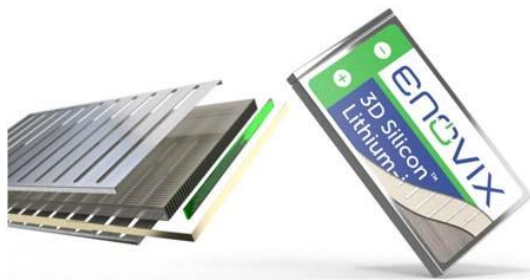
#### Porta Solution By CONPORTLAB



Porta Solution is an innovative IoT suite designed to fulfil the industrial requirements for seamless “on-site equipment integration” and “remote high-level system connectivity”. It consists of Porta CON, a lightweight programmable industrial IoT gateway embedded with industry-standard protocols, Porta Studio, a cloud-based no-code development platform that eliminates the need for expensive PLCs, and Porta IoT Link, a cloud-centric API service that enables easy integration and management of on-site IoT systems as if they were native to the cloud. Together, these components empower clients to deploy optimal IoT data collection and control systems across various settings.<sup>49</sup>

**Of interest for stations and warehouses**

#### Enovix BrakeFlow Technology By Enovix Corporation



In order to power the technologies of the future, we need better batteries. However, significant increases in battery energy density can be accompanied by increased risk of an internal short, which can lead to a fire or thermal runaway. Enovix BrakeFlow™ technology ushers in a new level of safety in next generation high energy density lithium-ion battery technology. BrakeFlow is a unique safety system located inside the battery cell. While most safety features are located outside of the battery pack, BrakeFlow acts as a safety resistor at the busbar junction inside the cell and reduces the risk of overheating.<sup>50</sup>

**Might be of interest in several areas**

<sup>48</sup> CES 2024. *FreePower for Countertop*. [online] Available at: <https://www.ces.tech/innovation-awards/honorees/2024/honorees/f/freepower-for-countertop.aspx>

<sup>49</sup> CES 2024. *Porta Solution*. [online] Available at: <https://www.ces.tech/innovation-awards/honorees/2024/honorees/p/porta-solution.aspx>

<sup>50</sup> CES 2024. *ENOVIS BrakeFlow Technology*. [online] Available at: <https://www.ces.tech/innovation-awards/honorees/2024/honorees/e/enovix-brakeflow-technology.aspx>

**IDYLLIC Chipless RFID**  
By Idyllic Technology



An ultra-low-cost RFID technology halfway between barcodes and conventional RFID.<sup>51</sup>

**Applicable for maintenance yards**

**LG 65-inch 4K OLED Zero Connect TV (Model: OLED65M4)**  
By LG Electronics Inc.



LG's 65-inch M4 provides for seamless transmission of high-quality audio and 4K 120Hz video, allowing users to customise their space with no need to worry about wires or clutter. The M4 serves as LG's pinnacle 4K OLED benefitting from LG's over a decade of OLED market leadership. Featuring LG's Most Advanced OLED AI Processor which was designed specifically for OLED, the M4 offers new enhanced picture processing and features that takes its OLED picture and consumer usability to the next level.<sup>52</sup>

**For stations**

**MT6825**  
By MediaTek



MediaTek is working to bring reliable connectivity everywhere with its MT6825 chipset that supports two-way satellite communications. MediaTek's MT6825 chipset can be easily integrated into smartphones and other connected devices. Consumers can enjoy peace of mind knowing that they can send messages and share their location even when cellular coverage is unreliable or completely unavailable. Even more importantly, users can request lifesaving assistance in emergency situations. Today, the MT6825 powers the first commercially available 3GPP NTN devices on the market, including the Motorola satellite link and Cat S75 smartphone.<sup>53</sup>

**Of interest for remote workers**

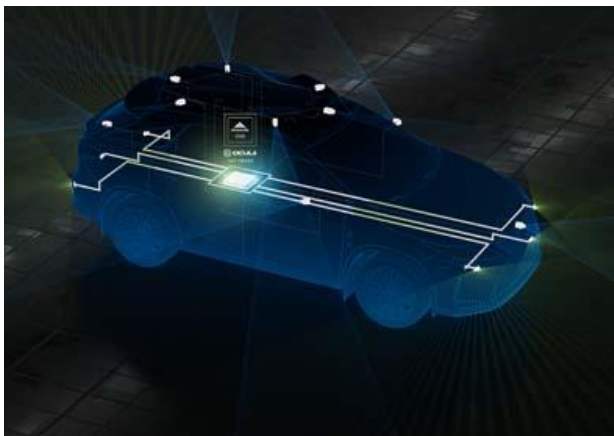
<sup>51</sup> CES 2024. *IDYLLIC Chipless RFID*. [online] Available at: <https://www.ces.tech/innovation-awards/honorees/2024/honorees/i/idyllic-chipless-rfid.aspx>

<sup>52</sup> CES 2024. [online] Available at: [https://www.ces.tech/innovation-awards/honorees/2024/honorees/l/lg-65-inch-4k-oled-zero-connect-tv-\(model-oled65m4.aspx](https://www.ces.tech/innovation-awards/honorees/2024/honorees/l/lg-65-inch-4k-oled-zero-connect-tv-(model-oled65m4.aspx)

<sup>53</sup> CES 2024. *MT6825*. [online] Available at: <https://www.ces.tech/innovation-awards/honorees/2024/honorees/m/mt6825.aspx>

## Centrally Processed 4D Imaging Radar Architecture

By Ambarella



Ambarella announced the world's first centralised 4D imaging radar architecture, which for the first time allows both central processing of raw radar data and deep, low-level fusion with other sensor inputs – including cameras, lidar and ultrasonics. It combines Ambarella's highly efficient 5nm CV3-AD685 AI central domain controller system-on-chip (SoC) and its Oculii™ adaptive AI radar software. This breakthrough architecture's optimised hardware and software provides the industry's best AI processing performance per watt, for the lowest possible energy consumption, along with the most accurate and comprehensive AI modelling of a vehicle or robot's surroundings.<sup>54</sup>

**Applicable for ATO**

## SiWx917

By Silicon Labs



SiWx917 is a single-chip solution that is Matter-ready, includes an integrated applications processor, and offers industry-leading energy efficiency, making it ideal for battery-powered or energy-efficient IoT devices with always-on cloud connectivity. The SiWx917 SoC is ideal for ultra-low power IoT wireless devices using Wi-Fi®, Bluetooth, Matter and IP networking for secure cloud connectivity. The SiWx917 is also ideal for asset tracking, smart homes, smart cities, medical, industrial, health and fitness applications. SiWx917 was developed to radically reduce energy consumption in Wi-Fi IoT networking, while delivering more compute, faster AI/ML, and robust security to solve the challenges of the future.<sup>55</sup>

**To be considered for spare parts management**

## 3.7. Headphones

### Mymanu CLIK Pro – Immersive translation earbuds

By CEH Technologies Ltd t/a Mymanu



Mymanu Clik 2, the world's most powerful translation earbuds, enable users to communicate seamlessly in 50+ languages in person or online. Our proprietary translation system, accessible offline, via Wi-Fi, eSim, combined with high-fidelity sound technology, aptX Codec, promises a truly immersive experience in cross-cultural communication to break down the language barriers.<sup>56</sup>

**Of interest for stations / customer information**

<sup>54</sup> CES 2024. Centrally processed 4D imaging radar architecture. [online] Available at: <https://www.ces.tech/innovation-awards/honorees/2024/honorees/c/centrally-processed-4d-imaging-radar-architecture.aspx>

<sup>55</sup> CES 2024. SiWx917. [online] Available at: <https://www.ces.tech/innovation-awards/honorees/2024/honorees/s/siwx917.aspx>

<sup>56</sup> CES 2024. Mymanu CLIK Pro – Immersive translation earbuds. [online] Available at: <https://www.ces.tech/innovation-awards/honorees/2024/honorees/m/mymanu-клик-pro-immersive-translation-earbuds.aspx>

## Timekettle X1 Interpreter Hub By Timekettle



Introducing the Timekettle X1 Interpreter Hub, a groundbreaking translator like never seen before. Combining the convenience of a handheld translator with a screen, speaker and a hands-free experience with wireless translator earbuds, the X1 Interpreter Hub revolutionises how we communicate. With unique functions, such as voice calling with real-time interpretation and user-friendly set-up in meeting rooms, the Timekettle X1 Interpreter Hub takes communication to a new level. Say goodbye to language barriers and embrace a seamless, effortless translation experience with the X1 Interpreter Hub.<sup>57</sup>

**Of interest for stations / customer information**

## 3.8. In-vehicle entertainment

### Interactive Transparent Window By AUO Corporation



The AUO Interactive Transparent Window creates an amazing visual experience in the cockpit by seamlessly integrating transparent displays into side windows and controllers. This window fulfils a range of needs, from basic entertainment functions and online meetings to interactive AR/MR experiences, extending beyond the cabin environment. Additionally, the window proactively enhances safety by issuing warnings to passengers if they attempt to open the door without noticing approaching vehicles, leveraging connectivity with side mirror cameras. With the Interactive Transparent Window, vehicles evolve from conventional transportation to all-round third living spaces, enhancing the aspects of entertainment and safety.<sup>58</sup>

**For passenger trains**

### Rollable RSE By AUO Corporation



The AUO Rollable Rear Seat Entertainment (RSE) is an innovative product that can change the landscape of rear cabins and the invariable RSE settings in vehicles. The invention of the Rollable RSE aims to offer vehicle manufacturers more flexible interior designs and enable passengers to enjoy a more all-round third living space.<sup>59</sup>

**For passenger trains**

<sup>57</sup> CES 2024. *Timekettle X1 Interpreter Hub*. [online] Available at: <https://www.ces.tech/innovation-awards/honorees/2024/honorees/t/timekettle-x1-interpreter-hub.aspx>

<sup>58</sup> CES 2024. *Interactive Transparent Window*. [online] Available at: <https://www.ces.tech/innovation-awards/honorees/2024/best-of/interactive-transparent-window.aspx>

<sup>59</sup> CES 2024. *Rollable RSE*. [online] Available at: <https://www.ces.tech/innovation-awards/honorees/2024/honorees/r/rollable-rse.aspx>



### 3.9. Mobile devices

#### Motorola defy satellite link By Bullitt Satellite



The Motorola defy satellite link uses Bullitt Satellite technology to provide direct-to-satellite true two-way messaging for those situations when you lose mobile coverage, when the networks are disrupted, or if a more discrete form of communication is preferred.

Not much larger than a car key fob, this incredibly affordable, easy-to-use device links your smartphone directly to geostationary satellites 22,300 miles up in space.

It also has satellite enabled SOS and a location sharing “Check In” button, so friends, family or co-workers can follow and stay in touch, no matter where their route takes them.<sup>60</sup>

**Of interest for outdoor workers**

#### Beetle: Portable Radar for Daily Life Safety By HL Klemove



HL Klemove

Named after its compact size and rounded shape, HL Klemove’s Beetle is a portable radar sensor for daily safety. Various risks may arise even when walking or riding a bike, and people may not be aware of them. Beetle makes movement safer by detecting and forewarning of potential dangers in blind spots. Beetle is so compact that it can be easily carried anywhere, anytime. Beetle ensures safe operation even in harsh weather conditions.<sup>61</sup>

**For outdoor workers**

#### “Rulerless” 3D measurement application By Mitsubishi Electric Corporation



Rulerless is a mobile application system that contributes to early recovery and reconstruction from flood damage caused by heavy rains and floods. In the past, damage assessment has required dispatching personnel to the site, which has in turn made damage assessment time-consuming. This application enables the measurement of damage conditions, etc., necessary for damage certification, using only a smartphone, leading to prompt support for disaster victims. In addition, operational efficiency can be improved by using this for equipment inspection and equipment delivery/installation simulations.<sup>62</sup>

**For equipment and outdoor inspections**

<sup>60</sup> CES 2024. *Motorola defy satellite link*. [online] Available at: <https://www.ces.tech/innovation-awards/honorees/2024/honorees/motorola-defy-satellite-link.aspx>

<sup>61</sup> CES 2024. *Beetle: portable radar for daily life safety*. [online] Available at: <https://www.ces.tech/innovation-awards/honorees/2024/honorees/b/beetle-portable-radar-for-daily-life-safety.aspx>

<sup>62</sup> CES 2024. *“Rulerless” 3D measurement application*. [online] Available at: <https://www.ces.tech/innovation-awards/honorees/2024/honorees/r/rulerless-3d-measurement-application.aspx>

### OtterBox Hardline Series By Otter Products



OtterBox Hardline Series for iPad is a relentless line of defence for technology in hazardous working environments. Hardline Series is a device-integrated, protective iPad case that is UL-certified for the US and Canada, plus IECEx and ATEX internationally. The Hardline Series includes a case for iPad Air (5th generation), device integration and third-party certification, a charging station, and hand and breakaway shoulder straps. With protection from drop, electrostatic discharge, chemical resistance, extreme temperature environments and flame-resistance, this industrial-grade product is rigorously tested and certified by UL Solutions to meet eight types of protection to deliver enhanced safety on the jobsite.<sup>63</sup>

**Of interest for workers in hazardous environment**

### Live Activities By United Airlines



The Live Activities iOS mobile app feature (similar feature coming soon to Android devices) helps United customers stay informed in real-time. Without even unlocking their iPhone, customers can see live flight updates, such as flight number, on-time status, inbound aircraft status, estimated departure and more, right on the lock screen or in the dynamic island on iPhone 14 Pro and iPhone 14 Pro Max. When it's time to board the aircraft, customers can open their boarding pass directly from their lock screen to easily scan. The technology ultimately puts all the flight information a customer may need at their fingertips.<sup>64</sup>

**Passenger experience**

## 3.10. Smart cities

### RoWok™ by SJW Robotics By SJW Robotics (Appetronix)



A fully autonomous robotic restaurant that cooks delicious, made-to-order meals with zero onsite employees.<sup>65</sup>

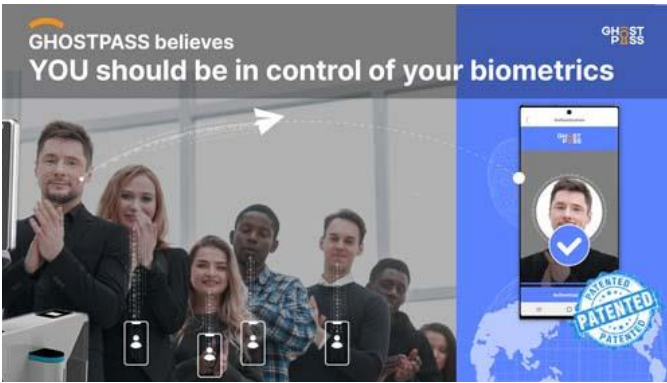
**For stations and passenger experience**

<sup>63</sup> CES 2024. *OtterBox Hardline Series*. [online] Available at: <https://www.ces.tech/innovation-awards/honorees/2024/honorees/o/otterbox-hardline-series.aspx>

<sup>64</sup> CES 2024. *Live Activities*. [online] Available at: <https://www.ces.tech/innovation-awards/honorees/2024/honorees/l/live-activities.aspx>

<sup>65</sup> CES 2024. *RoWok™ by SJW Robotics*. [online] Available at: <https://www.ces.tech/innovation-awards/honorees/2024/best-of/r/rowok%e2%84%a2-by-sjw-robotics.aspx>

**Decentralised remote biometric authentication solution**  
**By GHOSTPASS Inc.**



Ghostpass Inc. is a self-distributed biometric authentication solution company that monitors and controls large amounts of biometric information by storing it individually on users' smart devices, rather than storing it in bulk in the cloud (central server), eliminating privacy concerns. Our innovative solution is to send biometric data detected by the authentication request to the user's smartphone for authentication. This allows users to fully own the sovereignty of biometric information, and provides approximately 70-90% cost savings and strong security compared to traditional server methods.<sup>66</sup>

**Could apply for secured access**

**SQPV Glass**  
**By inQs Co., Ltd.**

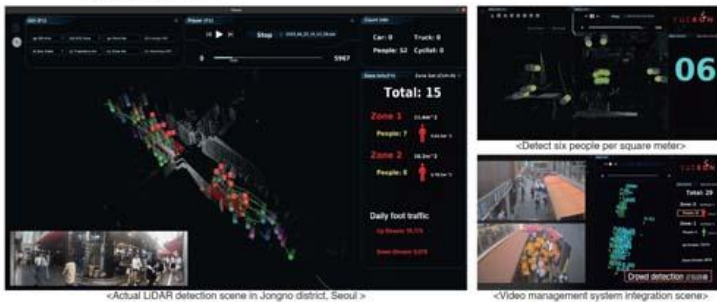


inQs has developed the most advanced and efficient energy harvesting clear solar glass (SQPV glass) in the world today. This innovative glass not only generates electricity from sunlight, but can also harnesses energy from invisible light, even in dimly lit indoor settings or on a cloudy day. SQPV glass can effectively convert light into electricity by layering nanomaterials that contribute to the generation of various types of electricity in a structure sandwiched between two sheets of conductive glass. It can harvest light from both sides of the glass. This technology outperforms any other existing solution, producing more power per unit.<sup>67</sup>

**For stations**

**Smart Crowd Analytics based on LiDAR**  
**By Vueron Technology Co., Ltd**

 **The Seoul Metropolitan Government has selected**  
 The very first smart city crowd management system based on ultra-precise object detection



Smart Crowd Analytics, the world's first LiDAR smart city solution introduced by Seoul City, analyses people flow in narrow alleyways, ensuring safety through real-time congestion analysis for prompt decision-making by operators to prevent accidents. With a daily average of over 10,000 people per site, it deploys alerts to citizens when certain risk events occur. This affordable solution costs less than US\$0.01 per person and facilitates rapid and widespread deployment. The solution has now been expanded to airport queue management and shows great potential for application in various industries.<sup>68</sup>

**For safety issues in stations**

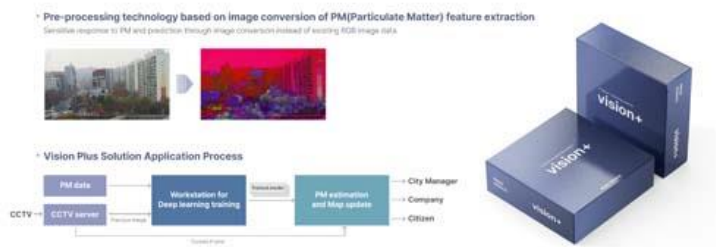
<sup>66</sup> CES 2024. *Decentralised Remote biometric authentication solution*. [online] Available at: <https://www.ces.tech/innovation-awards/honorees/2024/honorees/d/decentralized-remote-biometric-authentication-solu.aspx>

<sup>67</sup> CES 2024. *SQPV Glass*. [online] Available at: <https://www.ces.tech/innovation-awards/honorees/2024/best-of/s/sqpv-glass.aspx>

<sup>68</sup> CES 2024. *Smart Crowd Analytics based on LiDAR*. [online] Available at: <https://www.ces.tech/innovation-awards/honorees/2024/honorees/s/smart-crowd-analytics-based-on-lidar.aspx>



**Vision Plus**  
By DEEPIVISIONS Co., Ltd



Vision Plus is an AI-powered particulate matter (PM) monitoring solution using image data. Our patented deep learning algorithms analyse images to precisely calculate PM concentrations. Unlike conventional devices with cost and efficiency constraints, our innovation taps into existing CCTV systems, eliminating the need for additional installations and expanding monitoring to numerous locations.

Vision Plus drives environmental sustainability by pinpointing pollution sources and assessing the effectiveness of pollution control measures. Accurate, real-time data empowers informed decision-making. Our cutting-edge technology is dedicated to improving quality of life and fostering healthier living environments.<sup>69</sup>

**For smart stations and buildings**

**3.11. Sustainability**

**Aircore EC (latest generation)**  
By Infinitum



Infinitum's latest generation Aircore EC is disrupting the motor industry with its innovative patented PCB stator and integrated Variable Frequency Drive (VFD). Using lighter weight, reusable materials and modular design, Infinitum's motor generates the highest torque density in the industry, at a fraction of the carbon footprint and noise of traditional motors. With no iron, 66% less copper and 90+% efficiency, it sustainably powers commercial and industrial applications, such as HVAC fans, pumps and materials handling equipment with less energy and waste – while helping to decarbonise some of the highest emitting sectors in the world today.<sup>70</sup>

**Of interest for HVAC**

**Hydrolux2.0 (metallic alloy for hydrogen storage)**  
By HYDROLUX Inc.



Hydrolux 2.0 is an advanced hydrogen storage alloy that ensures safe and efficient hydrogen storage at room temperature and low pressures. Its versatility makes it suitable for various applications, including large commercial hydrogen-powered vehicles and portable fuel cells used in emergency power systems. Rooted in AB2-type TiMn2-series technology, it offers easy initial activation, guaranteeing reliable hydrogen storage and release for a wide range of applications.<sup>71</sup>

**For hydrogen trains**

<sup>69</sup> CES 2024. *Vision Plus*. [online] Available at: <https://www.ces.tech/innovation-awards/honorees/2024/honorees/v/vision-plus.aspx>

<sup>70</sup> CES 2024. *Aircore EC (latest generation)*. [online] Available at: [https://www.ces.tech/innovation-awards/honorees/2024/honorees/a/aircore-ec-\(latest-generation\).aspx](https://www.ces.tech/innovation-awards/honorees/2024/honorees/a/aircore-ec-(latest-generation).aspx)

<sup>71</sup> CES 2024. *Hydrolux2.0 (metallic alloy for hydrogen storage)*. [online] Available at: [https://www.ces.tech/innovation-awards/honorees/2024/honorees/h/hydrolux2-0-\(metallic-alloy-for-hydrogen-storage\).aspx](https://www.ces.tech/innovation-awards/honorees/2024/honorees/h/hydrolux2-0-(metallic-alloy-for-hydrogen-storage).aspx)

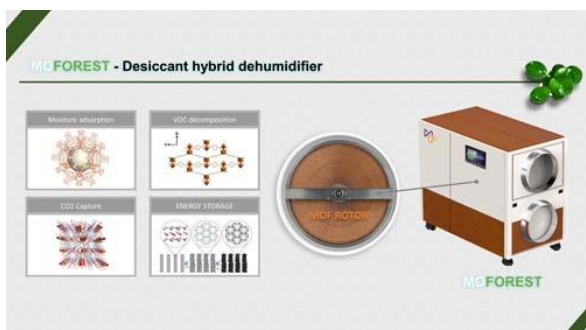
### WOTA BOX By WOTA Corporation



The WOTA BOX is the world's first portable water recycling plant that can recycle greywater (from showers and handwashing) to be used for the same purpose again, on-site. It is powered by WOTA's autonomous control technology for water treatment. Because the system can recycle over 98% of used water, users only need a small amount of water to shower multiple times (25 gallons can provide up to 100 showers). The WOTA BOX is useful during times of emergency and in settings where water is not abundantly available, such as camp sites, sporting events and festivals in remote locations.<sup>72</sup>

**Could apply to stations**

### MOForest By AEOL Korea



MOForest is an all-in-one air conditioning system designed to provide cooling, ventilation, dehumidification and air purification functionalities for zero-energy buildings (ZEB) at up to 30% less energy consumption. Tackling a longstanding obstacle in ZEB commercialisation, MOForest boasts strengthened dehumidification capabilities to effectively manage indoor humidity levels. MOForest leverages our proprietary Metal Organic Framework (MOF) technology, which maximises energy recovery, minimises consumption and elevates ZEB standards.<sup>73</sup>

**For HVAC applications**

## 3.12. XR technologies

### ROUTi-AR By SLZ Inc.



ROUTi-AR is a software solution developed for the construction industry that allows users to inspect, design and manipulate end-to-end layout Building Information Modelling (BIM) data directly on construction sites through an AR overlay and obstacle-avoiding design automation algorithms. ROUTi-AR enables users to export BIM data, intuitively design MEP (mechanical, electrical, plumbing) layouts on-site, and then import the newly-created design directly into their original BIM model. It is the only application that can import new AR design data back into the original BIM model, as other construction technology solutions require designing component routes one at a time on a design workstation.<sup>74</sup>

**For BIM**

<sup>72</sup> CES 2024. WOTA BOX. [online] Available at: <https://www.ces.tech/innovation-awards/honorees/2024/honorees/w/wota-box.aspx>

<sup>73</sup> CES 2024. MOForest. [online] Available at: <https://www.ces.tech/innovation-awards/honorees/2024/honorees/m/moforest.aspx>

<sup>74</sup> CES 2024. ROUTi-AR. [online] Available at: <https://www.ces.tech/innovation-awards/honorees/2024/honorees/r/routi-ar.aspx>

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The railway has been undergoing significant technological advancements in recent years. By embracing these advancements, the railway industry can enhance accessibility, safety, efficiency and sustainability, ensuring a seamless and sustainable future for railways.<sup>75</sup> This chapter provides, from an academic perspective, an overview of the latest technologies and innovations in the railway sector, highlighting the theoretical and applied research underpinning the aforementioned innovations. References to relevant literature are provided to guide further exploration of each topic.

### 4.1. Accessibility in railways

Accessibility in railways has become increasingly important to accommodate passengers with diverse needs, including those with disabilities and reduced mobility. Various technologies have been developed to improve the accessibility for rail passengers, such as:

- **Innovative accessible facilities:** Implementation of innovative facilities within railway stations and trains to facilitate easy boarding and alighting for passengers with reduced mobility;<sup>76</sup>
- **Real-time passenger information systems:** Providing real-time information on train schedules, platform changes and service disruptions through mobile apps and digital displays to assist passengers in planning their journeys;<sup>77,78</sup>
- **Assistive technologies:** Integration of assistive technologies like tactile paving, audio announcements and visual signage to aid passengers with visual or hearing impairments.<sup>79</sup>

### 4.2. Artificial Intelligence (AI) in railway operations

AI technologies are revolutionising railway operations through various means such as optimising maintenance, scheduling and safety protocols.<sup>80,81,82</sup> Key applications of AI in railways include:

- **Predictive maintenance:** Utilising machine learning algorithms to analyse sensor data from railway infrastructure and rolling stock, enabling predictive maintenance to prevent breakdowns and improve reliability;<sup>83,84</sup>
- **Smart signalling systems:** Implementing AI-powered signalling systems that dynamically adjust train schedules based on real-time traffic conditions, enhancing operational efficiency and reducing delays;<sup>85,86</sup>

<sup>75</sup> Steele, H. and Roberts, C. (2022). Towards a Sustainable Digital Railway. *Sustainable Railway Engineering and Operations*, Emerald Publishing Limited. 14: 239-263.

<sup>76</sup> Piccioni, C., Ricci, S. and Polis, K. (2022). Accessibility to passenger trains: review and tests of innovative solutions. IRSA 2021: Tagungsband, *Proceedings: 3rd International Railway Symposium Aachen*, RWTH Aachen University.

<sup>77</sup> Kurup, S., Golightly, D., Clarke, D. and Sharples, S. (2021). Passenger information provision: Perspectives from rail industry stakeholders in Great Britain. *Journal of Rail Transport Planning & Management*, 19: 100264.

<sup>78</sup> Zorić, P., Mikulčić, M., Musa, M. and Kuljanić, T. M. (2022). Analysis of available information and communication solutions and Services for railway passenger information in the EU. 5th EAI International Conference on Management of Manufacturing Systems, Springer.

<sup>79</sup> Fernando, N., McMeekin, D. A. and Murray, I. (2023). Route planning methods in indoor navigation tools for vision impaired persons: a systematic review. *Disability and Rehabilitation: Assistive Technology*, 18(6): 763-782.

<sup>80</sup> Bešinović, N., Donato, L. D., Flammini, F., Goverde, R. M. P., Lin, Z., Liu, R., Marrone, S., Nardone, R., Tang, T. and Vittorini, V. (2022). Artificial Intelligence in Railway Transport: Taxonomy, Regulations, and Applications. *IEEE Transactions on Intelligent Transportation Systems*, 23(9): 14011-14024.

<sup>81</sup> Ficzero, P. (2023). The role of artificial intelligence in the development of rail transport. *Cognitive Sustainability*, 2(4).

<sup>82</sup> Whig, P., Velu, A., Nadikattu, R. R. and Alkali, Y. J. (2024). Role of AI and IoT in Intelligent Transportation. *Artificial Intelligence for Future Intelligent Transportation*, Apple Academic Press: 199-220.

<sup>83</sup> Rahimi, M., Liu, H., Cardenas, I. D., Starr, A., Hall, A. and Anderson, R. (2022). A review on technologies for localisation and navigation in autonomous railway maintenance systems. *Sensors*, 22(11): 4185.

<sup>84</sup> Phusakulkajorn, W., Núñez, A., Wang, H., Jamshidi, A., Zoeteman, A., Ripke, B., Dollevoet, R., De Schutter, B. and Li, Z. (2023). Artificial intelligence in railway infrastructure: current research, challenges, and future opportunities. *Intelligent Transportation Infrastructure*, 2: liad016.

<sup>85</sup> Dai, X., Zhao, H., Yu, S., Cui, D., Zhang, Q., Dong, H. and Chai, T. (2021). Dynamic scheduling, operation control and their integration in high-speed railways: A review of recent research. *IEEE Transactions on Intelligent Transportation Systems*, 23(9): 13994-14010.

<sup>86</sup> Torralba, A., García-Castellano, M., Hernandez-Gonzalez, M., Garcia-Martin, J. P., Pérez-Mira, V., Fernandez-Sanzo, R., Jacome-Moreno, A. and Gutierrez-Rumbao, F. J. (2020). Smart railway operation aid system for facilities with low-safety requirements. *IEEE Intelligent Transportation Systems Magazine*, 13(3): 253-267.

- **Automatic Train Operation (ATO):** Deployment of AI-driven ATO systems for autonomous train control, enabling precise speed and braking control while maximising energy efficiency.<sup>87</sup>

### 4.3. Cybersecurity in railway networks

With the increasing digitisation of railway infrastructure, cybersecurity has emerged as a critical concern to safeguard against potential cyber threats and attacks.<sup>88,89</sup> Key initiatives in railway cybersecurity include:

- **Secure communication protocols:** Implementation of secure communication protocols and encryption techniques to protect data transmitted between onboard systems, trackside infrastructure and control centres;<sup>90</sup>
- **Intrusion Detection Systems (IDS):** Deployment of IDS to monitor network traffic and detect anomalous behaviour indicative of cyber-attacks, allowing for timely response and mitigation measures;<sup>91</sup>
- **Cybersecurity training and awareness:** Providing specialised cybersecurity training programmes for railway personnel to enhance awareness and readiness in identifying and responding to cyber threats.<sup>92</sup>

### 4.4. Digital imaging in railway inspection

Digital imaging technologies are revolutionising railway inspection processes, enabling accurate and efficient monitoring of infrastructure and rolling stock. Key applications include:

- **LiDAR scanning:** Utilising LiDAR (Light Detection and Ranging) technology for high-resolution 3D scanning of railway tracks, bridges and tunnels to conduct aerial inspections, assess structural integrity and identify defects such as track misalignment and vegetation encroachment;<sup>93</sup>
- **Drone surveillance and drone-based maintenance tasks:** Employing drones equipped with high-definition cameras and thermal imaging sensors to conduct aerial inspections of railway infrastructure, offering comprehensive coverage and rapid detection of anomalies. Additionally, drones could also be employed for various maintenance tasks such as cleaning, applying anti-corrosion coatings and inspecting catenary systems, which could help minimise the need for manual inspections in hazardous environments and enhance operational efficiency;<sup>94,95,96</sup>
- **Computer vision systems:** Implementing computer vision algorithms to analyse digital images and videos captured during railway inspections, enabling automated defect detection and classification.<sup>97,98</sup>

<sup>87</sup> Zhu, C., Lu, J. and Li, X. (2023). Review of Studies on Energy-Efficient Train Operation in High-Speed Railways. *IEEJ Transactions on Electrical and Electronic Engineering*, 18(3): 451-462.

<sup>88</sup> Thomas, R. J., Chothia, T. and Ordean, M. (2022). Cyber security in the rail sector-an integrated approach. *World Congress on Rail Research*.

<sup>89</sup> Kiviharju, M., Lassfolk, C., Rikkonen, S. and Kari, H. (2022). A cryptographic and key management glance at cybersecurity challenges of the future European railway system. *14th International Conference on Cyber Conflict: Keep Moving! (CyCon)*, IEEE.

<sup>90</sup> Rother, B., Golałowski, F., Ansar, Z., Kuzhiyelil, D., Resch, S., Hametner, R. and Pathak, P. (2022). Analysis of Safety-Critical Communication Protocols for On-Premise SIL4 Cloud in Railways. *International Conference on Reliability, Safety, and Security of Railway Systems*, Springer.

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<sup>94</sup> Askarzadeh, T., Bridgelall, R. and Tolliver, D. D. (2023). Systematic Literature Review of Drone Utility in Railway Condition Monitoring. *Journal of Transportation Engineering, Part A: Systems*, 149(6): 04023041.

<sup>95</sup> Li, J., Peng, Y., Tang, Z. and Li, Z. (2023). Three-Dimensional Reconstruction of Railway Bridges Based on Unmanned Aerial Vehicle–Terrestrial Laser Scanner Point Cloud Fusion. *Buildings*, 13(11): 2841.

<sup>96</sup> Krajčec, S. *Drones #2: Revolutionizing Railways – How Drones are Transforming the Railway Industry*. [online] Available at: [https://www.systra.com/canada/expert\\_insights/drones-2-revolutionizing-railways-how-drones-are-transforming-the-railway-industry/](https://www.systra.com/canada/expert_insights/drones-2-revolutionizing-railways-how-drones-are-transforming-the-railway-industry/) [Accessed March 2024].

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<sup>98</sup> Petrović, A. D., Banić, M., Simonović, M., Stamenković, D., Miltenović, A., Adamović, G. and Rangelov, D. (2022). Integration of computer vision and convolutional neural networks in the system for detection of rail track and signals on the railway. *Applied Sciences*, 12(12): 6045.



## 4.5. Embedded technologies for railway systems

Embedded technologies play a crucial role in enhancing the functionality and performance of railway systems, enabling real-time monitoring, control and data analysis. Key advancements include:

- **Wireless sensor networks (WSN):** Deploying WSN for distributed sensing and monitoring of railway infrastructure, including track conditions, temperature and vibration levels, to detect anomalies and prevent failures;<sup>99</sup>
- **Embedded systems for train control:** Integrating embedded systems into trains for autonomous operation, collision avoidance and energy management, enabling efficient and safe transport;<sup>100</sup>
- **Edge computing platforms:** Utilising edge computing platforms onboard trains and at railway stations to process sensor data locally, reducing latency and enabling real-time decision-making for operational optimisation.<sup>101</sup>

## 4.6. In-vehicle entertainment systems

Headphones and in-vehicle entertainment systems are becoming increasingly popular onboard trains, offering passengers a personalised and immersive travel experience. Key features include:

- **Noise-cancelling headphones:** Equipping trains with noise-cancelling headphones to reduce ambient noise and improve passenger comfort during travel, especially on busy or noisy routes;<sup>102</sup>
- **Interactive multimedia content:** Enhancing onboard trains with wireless audio/video streaming capabilities enables passengers to access entertainment options through their smartphones or dedicated onboard systems. Offering a diverse range of interactive multimedia content – including music, podcasts, audiobooks, movies, games and educational programmes – through these systems significantly enhances the passenger experience. This enhancement can be particularly noticeable during long journeys, as it helps to reduce perceived travel time.<sup>103,104</sup>

## 4.7. Mobile technologies and smart cities integration

The integration of mobile devices and smart city initiatives with railway systems is transforming urban mobility and transport networks. Key developments include:

- **Mobile ticketing and payment solutions:** Introducing mobile ticketing applications and contactless payment options for seamless fare collection and passenger convenience;<sup>105</sup>
- **Integration with smart city infrastructure:** Leveraging smart city infrastructure such as IoT sensors, traffic management systems and urban mobility platforms to optimise train schedules, improve connectivity and enhance the overall passenger experience;<sup>106</sup>
- **Location-based services:** Providing location-based services and personalised travel recommendations to passengers through mobile applications, leveraging real-time data analytics.<sup>107</sup>

<sup>99</sup> Yu, X., Fu, Y., Li, J., Mao, J., Hoang, T. and Wang, H. (2023). Recent advances in wireless sensor networks for structural health monitoring of civil infrastructure. *Journal of Infrastructure Intelligence and Resilience*: 100066.

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<sup>103</sup> Ziegler, C., Neudel, R., Pham, S. and Trout, E. (2020). Improving media streaming services for train passengers with 5G. *Proceedings of the 2020 ACM International Conference on Interactive Media Experiences*.

<sup>104</sup> Macola, I. G. (2021). Entertainment on board: the tech keeping rail passengers occupied. [online] Available at: <https://www.railway-technology.com/features/entertainment-board-tech-keeping-rail-passengers-occupied/> [Accessed March 2024].

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<sup>106</sup> Kuo, Y.-H., Leung, J. M. and Yan, Y. (2023). Public transport for smart cities: Recent innovations and future challenges. *European Journal of Operational Research*, 306(3): 1001-1026.

<sup>107</sup> Xu, G., Zhang, R., Xu, S. X., Kou, X. and Qiu, X. (2021). Personalized multimodal travel service design for sustainable intercity transport. *Journal of Cleaner Production*, 308: 127367.

## 4.8. Sustainability initiatives in railway

Railway plays a crucial role in promoting sustainable mobility and reducing carbon emissions. Key sustainability initiatives include:

- **Electrification of rail networks:** Accelerating the electrification of rail networks to reduce reliance on fossil fuels and mitigate greenhouse gas emissions from train operations;<sup>108</sup>
- **Energy-efficient technologies:** Implementing energy-efficient technologies such as regenerative braking systems, lightweight materials and aerodynamic designs to minimise energy consumption and improve overall efficiency;<sup>109</sup>
- **Modal shift strategies:** Promoting modal shift from road and air transport to railways through incentives, subsidies and infrastructure investments to reduce congestion, air pollution and carbon footprint.<sup>110</sup>

## 4.9. Extended Reality (XR) technologies for railway training and simulation

Extended Reality (XR) technologies, including virtual reality (VR) and augmented reality (AR), are being increasingly used for railway training, simulation and maintenance.<sup>111,112</sup> Key applications include:

- **VR-based training simulators:** Developing VR-based training simulators for railway personnel to simulate various scenarios such as emergency evacuation procedures, equipment maintenance and operational simulations;<sup>113</sup>
- **AR-assisted maintenance and repair:** Using AR technologies to provide maintenance technicians with real-time visual overlays and instructions, facilitating faster and more accurate repairs and reducing downtime;<sup>114,115</sup>
- **Digital twin modelling:** Creating digital twin models of railway infrastructure and rolling stock using XR technologies, enabling remote monitoring, predictive maintenance and performance optimisation.<sup>116</sup>

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