5GLOGINNOV

The 5G-LOGINNOV project: how 5G can reshape port logistics

White paper

www.5g-loginnov.eu

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LIST OF ABBREVIATIONS AND ACRONYMS

Abbreviation	Meaning
5GPPP	The 5G Public Private Partnership
5G NSA	5G Non Standalone
5G SA	5G Standalone
AI	Artificial Intelligence
API	Application Programming Interface
AR/VR	Augmented Reality/Virtual Reality
BM	Business Models
CAD/CAM	Connected Automated Driving / Connected and Automated Mobility
CAN	Controller Area Network
CCAM	Cooperative, Connected and Automated Mobility
CV	Connected vehicle
C-V2X	Cellular vehicle-to-everything communication
DL	Downlink

DOI	Digital Object Identifier
EAMS	Enterprise Asset Management System
EC	European Commission
Edge Computing	encompasses various decentralised computing approaches
ETSI	European Telecommunications Standards Institute
FAIR	Findable, Accessible, Interoperable and Reusable
FOT	Field Operational Test
GDPR	General Data Protection Regulation
GNSS	Global Navigation Satellite System
GPS	Global Position System
HTTPS	Hyper Text Transfer Protocol (HTTP) over Secure Socket Layer (SSL)
IT	Information Technology
IoT	Internet of Things
ITO	Intelligent Traffic Offload
ITS	Intelligent Transportation Systems
JSON	JavaScript Object Notation
KPI	Key Performance Indicator
LCMM	Low Carbon Monitoring Management
LL	Living Lab
MEC	Multi-Acces Edge Computing
MNO	Mobile Network Operator
M1M	Many-to-One-to-Many
NGFWs	Next-Generation Firewalls
NSA	Non-Standalone
NFV-MANO	Network Function Virtualisation (NFV) - Management And Network Orchestration (MANO)
OBU	On-Board-Units
OT	Operational Technology
ORDP	Open Research Data Pilot
OSM	Open-source MANO
PCT	Piraeus Container Terminal
POPD	Protection Of Personal Data

PU	Public
QoE	Quality of Experience
REST	Representational state transfer
SME	Small and Medium Enterprise
TAVF	Test track for Automated and connected driving
TMT	Technical Management Team
TMS	Traffic Monitoring System
TRxP	Transmission Reception Point
UE	User Equipment
UL	Uplink
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle
V2X	Vehicle-to-everything
VIN	Vehicle Identification Number
VSaaS	Video Surveillance as a Service
WP	Work Package

EXECUTIVE SUMMARY

Given the growing global demand for freight transportation, the advent of 5G communication networks presents a promising technological solution. Alongside complementary technologies, 5G facilitates the seamless gathering, integration, and dissemination of vast datasets from various origins. However, for the widespread adoption of innovative products and services enabled by 5G, engagement from diverse stakeholders across the logistics value chain is essential. This paper examines strategies for evaluating stakeholders' expectations and real needs during the business model development process and the subsequent implementation of solutions within the framework of the 5G-LOGINNOV project.
In particular, here's a structured overview of the document's contents:

1. **main achievements of the project in Section 2**: this section will likely summarise the significant accomplishments of the project, such as technological advancements, successful implementations, and key milestones reached.
2. **description of the testbeds and project developments vis a vis "inheritance" in Section 3**: this section will provide a detailed description of the three testbeds used in the project, outlining the infrastructure, technologies, and solutions developed within each testbed. It will also discuss how these developments build upon existing technologies and innovations.
3. **comparison between MEC and Edge Computing, cybersecurity, slicing and AI in Subsection 3.4**: subsection 3.4 will delve into specific technological choices and considerations made during the project. It will likely discuss the rationale behind choosing between Multi-access Edge Computing (MEC) and Edge Computing, address cybersecurity concerns related to Private Networks, elaborate on the implementation of network slicing, and explore the integration of Artificial Intelligence (AI) technologies.
4. **performance comparison of use cases with 5G NSA (Hamburg and Athens) and 5G SA (Koper) in Subsection 3.4:** this subsection will analyze and compare the performance of various use cases implemented within the project using 5G Non-Standalone (NSA) and 5G Standalone (SA) architectures. It may highlight differences in efficiency, reliability, and other relevant metrics between the two architectures.
5. **Impact on existing business models(Section 4)**: section 4 will assess the influence of 5G-enabled technologies and solutions on existing business models within the logistics industry. It may discuss how traditional models are disrupted or enhanced by the adoption of 5G and related innovations.
6. **new players in the 5G-based ports environment (Section 5)**: section 5 will explore the emergence of new stakeholders and actors in the context of 5G-enabled ports and logistics environments. It may identify new roles, partnerships, and opportunities created by the adoption of 5G technologies.
7. **long term business model perspective and exploitation of the project results (Section 5)**: this section will provide insights into the long-term sustainability and viability of the business models developed within the project. It may discuss strategies for commercialisation, scalability, and ongoing exploitation of project outcomes.
8. **main recommendations and lessons learned (Section 6):** section 6 will present key recommendations derived from the project experience and lessons learned during the implementation process. It may offer insights for future projects, best practices, and areas for further research and development.

By following this outline, the document effectively addresses the outlined topics and provides a comprehensive analysis of the 5G-LOGINNOV project's objectives, outcomes, and implications for the logistics industry.

1 5G-LOGINOV IN BRIEF

5G-LOGINNOV is a Horizon 2020 Innovation Action with 39 months duration, started in September 2020. The project involved 15 partners representing different stakeholders' categories, such as logistics, automotive and telecom industry actors, infrastructure operators, research institutes, SMEs, and start-ups. The 5G-LOGINNOV central innovation was to build a first-class European industrial supply side for 5G core technologies and new IoT-5G devices and – at the same time – to promote the emergence of new market players, such as SMEs and start-ups. Being part of the third 5G PPP[1] phase implied supporting the development of a lead market involving cooperation models with key vertical sectors. The project impacted the logistics industry for which tests have been developed and 5G-enabled services were evaluated. Furthermore, it contributed to the emergence of global standards and globally harmonised frequency bands for 5G. The project supported the generation of new 5G-enabled technologies for logistics operations in 3 real-life port-city areas that constitute the 5G-LOGINNOV Living Labs (LLs) in Athens, Hamburg, and Koper, with different scopes. Athens LL mainly dealt with technologies for real-time tracking and enhanced visibility of 5G yard-trucks for service optimization, job allocation and predictive maintenance; Hamburg addressed the usage of 5G to improve port operations, specifically for connecting the Hinterland to the port's facilities; Koper focused on 5G-enabled technologies to improve the automation of logistics processes in ports and to support mission critical services in the port area.
The study presented in this document has the following objectives:

- To analyse the current and future market linked to 5G core technologies, especially the main innovative approaches used in port logistics projects and the 3 Living Labs' current scenarios in terms of actors' attitude towards most innovative practices to define stakeholders' needs, gains and pains, and interaction.
- To identify the main gaps linked to the adoption of 5G technologies to improve logistics and transportation operations in ports by reviewing current and past projects and by engaging the 5G-LOGINNOV Living Labs.
- To assess the products and services currently used in Living Labs to define the potential benefits from their usage on business models and operations.
- To define 5G-enabled business opportunities to current and new actors and for emerging in the market, by engaging in the business modelling process both the new entrants (the 5 start-ups that won the 5G-LOGINNOV Open Call for Start-Ups[2]) and the established actors (the initial partners of the project, including SMEs)

2 KEY INSIGHTS

5G technology presented a transformative opportunity for the logistics industry, particularly in the realm of port and dry port operations. By leveraging the advanced capabilities of 5G, stakeholders can unlock new avenues for improved efficiency, cost reduction, and operational optimization. The main insights from 5G-LOGINNOV can be categorised into three main key areas**: technical, operational**, and **business**.

From a technical standpoint, 5G's high-speed data transfer, low latency, and massive connectivity enabled the creation of new and improved services and products that foster enhanced operations. This is particularly essential for ports situated in urban areas, where seamless integration with the surrounding environment is essential. The ability to transmit large amounts of data in real time allowed for precise tracking and monitoring of cargo, containers, and assets, optimising movements and minimising bottlenecks.

[1] https://5g-ppp.eu/
[2] https://5g-loginnov.eu/open-call/

Operationally, the synergy between 5G, Internet of Things (IoT) devices, and artificial intelligence (AI) opened up new paradigms in port operations. The vast array of data gathered from these interconnected systems paved the way for exploring concepts such as synchromodality and the physical internet. Synchromodality involves the intelligent and dynamic selection of transportation modes and routes based on real-time data, while the physical internet envisions a seamless, open, and interconnected logistics system akin to the physical internet.

From a business perspective, 5G's characteristics, included low latency, high bandwidth, and the ability to integrate public and private networks, enhanced existing business models. Port managers and logistics operators can leverage these capabilities to improve their performance and introduce a holistic view of sustainability encompassing operational, economic, environmental, and social aspects. Moreover, 5G enabled the integration of complementary technologies beyond those currently in use, as identified through stakeholder surveys.

Notably, 5G's disruptive potential extends beyond enhancing existing business models. It paves the way for the emergence of new business models aligned with the "Many-1-Many" (M1M) paradigm (See Section 5). This paradigm envisions a dynamic ecosystem where multiple stakeholders can collaborate seamlessly, enabling the creation of innovative services and solutions that transcend traditional boundaries.

3 LIVING LABS AND PROJECT KEY RESULTS

The implementation of 5G technology in ports can bring about several benefits, enhancing communication, efficiency, and overall operations. Here are some of the advantages of 5G mobile communication in ports as found in 5G-LOGINNOV for all three living labs.

3.1 Athens

As part of the 5G-LOGINNOV project, the Athens LL (at Piraeus Port, the largest Port terminal in Greece) developed a set of use cases and platforms (Figure 1) which communicate over the private 5G NSA network with different types of end devices (5G-Trucks, 5G-Cranes, 5G-IoT, 5G UEs and 5G-enabled sensor telemetry). 5G technology enabled the use case innovations exploiting the eMBB service and low latency transmissions of 5G, including NFV-MANO based applications and service orchestration, a private compute continuum platform involving edge and far-edge computing innovative solutions, computer vision and AI-enabled video and data analytics.

In this direction, alongside its network infrastructure, Piraeus Container Terminal (PCT) utilizes a GPU-enabled data centre (Figure 2) that serves as a private edge computing platform. At the far-edge front, various IoT devices and sensors (e.g., UHD cameras) are deployed across various mobile Port assets, including trucks and cranes, but also on fixed Port infrastructure such as buildings. The platform adheres to the cloud-native paradigm, featuring containerized applications and services fully managed through Kubernetes. It offers comprehensive lifecycle management operations from day-0 to day-2, and leverages Port infrastructure as a service (PIaaS).

In this regard, edge-computing is well suited to handle the high volume and variety of data generated in the port environment, where rapid processing and real-time analytics are crucial for operational efficiency. Additionally, by processing sensitive port data on-site, private edge computing ensures that this critical information does not leave the port premises, thereby enhancing data security and compliance with privacy regulations. While ETSI MEC is designed to work well with mobile networks (including private ones) and also bring computation and data storage closer to the data source, its primary focus is on optimizing network operations and delivering low-latency network services. In contrast, edge computing provides broader flexibility and can handle a wider range of computing tasks, not just those tied to network optimization. This versatility of edge computing makes it the preferred choice for PCT, as it aligns more closely with its diverse operational requirements and objectives.

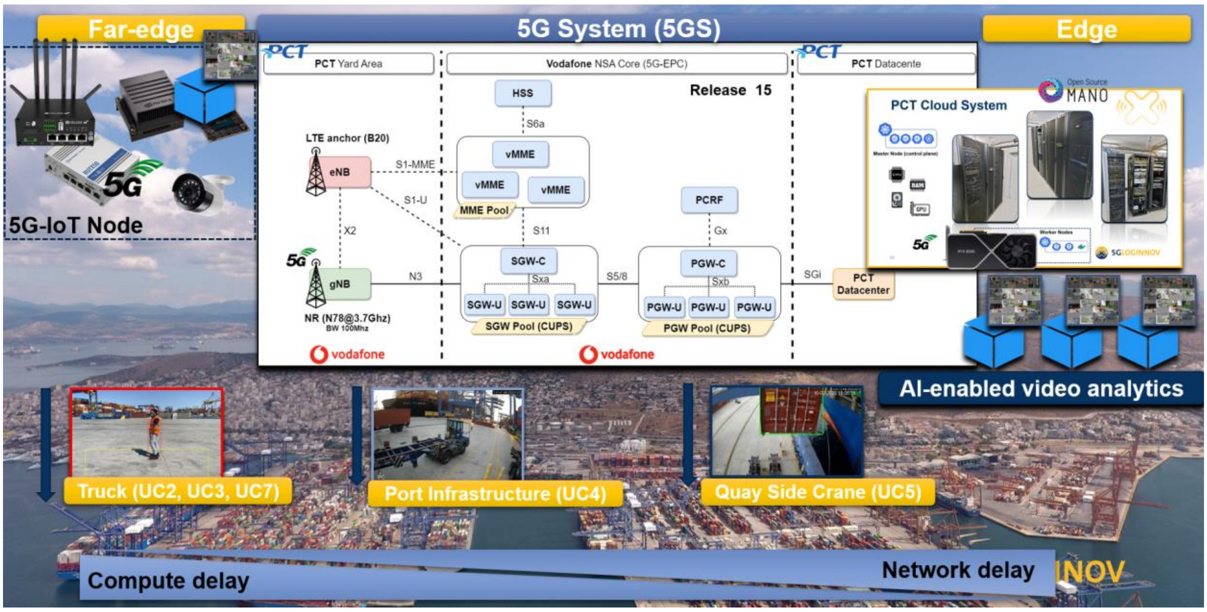

Figure 1: LL Athens - Private 5G system, far-edge and edge computing platform

In this direction, a collaborative effort in the Athens Living Lab has successfully implemented 5G technology, specifically targeting port operations both within and outside the port premises tailored to safety/security applications as well as for improving the efficiency of daily port operations (reduce costs, improve the utilization of human resources and automate logistics services) through 5G-enabled capabilities. This expansive trial included the integration of a significant number of connected port assets (Trucks, Cranes and IoT devices), which are fundamental in streamlining daily operations. Particularly, the on-premises private network provides cellular connectivity to a fleet of 200-yard trucks and 100 cranes, while the entire Port area is under comprehensive surveillance through a network of high-definition cameras.

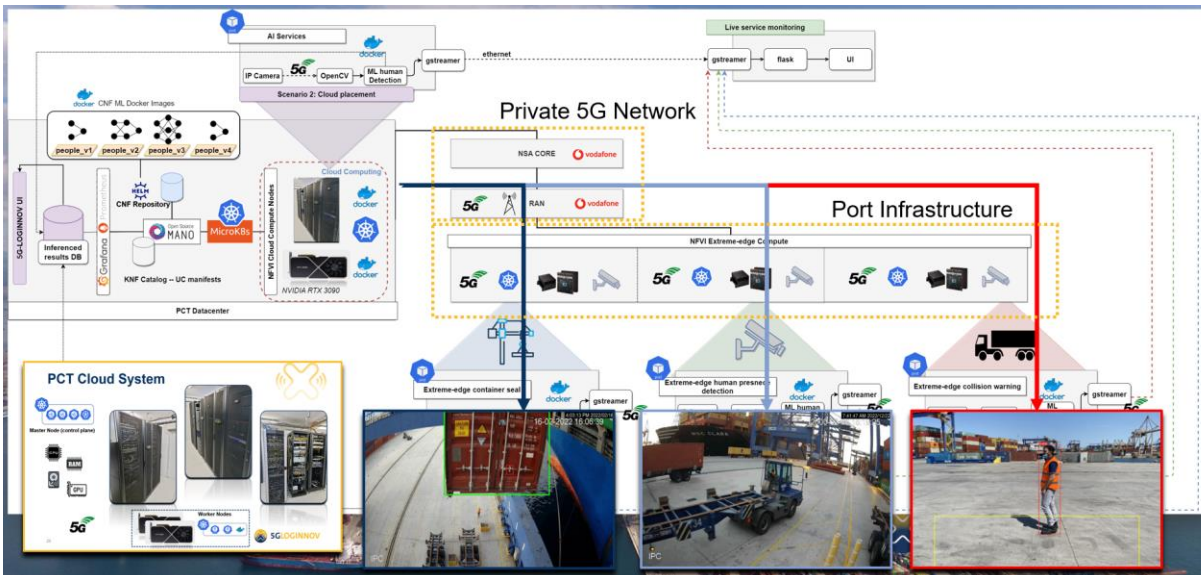

Figure 2: LL Athens - Orchestration of services across PCT port assets (Trucks, Cranes, Infrastructure)

Key take-aways include the highlights from the network perspective, highlights emanating from the use case requirements and also by the logistics actors involved in the port operations and the supply chain. The integration of mission-critical services, such as the 5G and AI-enabled collision warning system designed to prevent accidents between trucks and personnel, which is one of the main use cases in Athens LL, underscores the paramount importance of reliable network connectivity, availability and service differentiation, with advanced slicing capabilities exposed only by advanced 5G SA networks. Towards this direction, PCT has already moved from NSA network core, to a private 5G advanced SA system with the core network residing inside the Port premises (session breakout) providing a comprehensive private cellular solution.

Additionally, the application of 5G and AI video analytics, enhanced by edge computing capabilities and demonstrated in total by three use cases in Athens, showcased a strong requirement from 5G networks: the substantial need for increased uplink capacity. In response to this need, configuring 5G new radio (NR) to favour uplink transmissions-an inherent 5G network capability-emerges as a key consideration, particularly for such bandwidth-intensive services. This is particularly relevant for video analytics, where high resolution camera feeds from within the Port premises are transmitted (by uplink transmissions) to edge computing facilities, highlighting this key aspect that previous cellular network generations fail to deliver. To support the uplink intensive services at PCT, the gNB station operates in band n78 at 3.7GHz with 100MHz channel bandwidth, providing 5G connectivity to a subset of the port Piers, while more remote radio units (RRUs) are under deployment to provide Port wide high bandwith network coverage.

A substantial effort on cross LL use case integration was delivered between Athens and Koper LL and particularly, for the use case of 5G and AI enabled container seal detection. This included an AI service that detects the presence (or absence) of seals at container doors. The ML model was trained solely from data coming from PCT, and was ported to Koper LL, with zero modification or re-training. The model demonstrated similar performance. Here we emphasize the significance in port operations of the uniformity of cargo transport through standardized cargo containers. These containers possess consistent structures and features, which suggests that machine learning models trained on these similar characteristics can be effectively applied from one port to another. This transferability (also showcased through large scale trials and pilots in 5G-LOGINNOV) indicates the potential for minimal integration effort or modifications in adapting these models across different port environments.

We've also showcased that Port Terminals collaborate with various freight forwarding companies for container transportation to and from the Port via road networks. A key gap identified is the absence of a unified platform for efficient information exchange between the Port and these companies, which could streamline their collaboration. For instance, an automated system predicting the arrival times of external trucks at the port gates would be highly beneficial, considering the unpredictability of external factors like traffic congestion or accidents. In this direction, a system integrated with a majority of these companies, proportionate to the volume of inbound and outbound trucks, would significantly improve processes like the handover of containers from the Port to external trucks (and vice versa).

3.2 Hamburg

In the Living Lab (LL) Hamburg, the primary focus was on the exploitation of applications and services related to the hinterland area. This section likely highlights key insights and lessons learned from the LL's activities and experiences.

1. ***Ultra-fast Data Speeds and Low Latency:*** 5G offers significantly faster data speeds compared to previous generations of mobile communication. This allows for quick and reliable data transfer, enabling faster communication between devices and systems within the port. For example, Hamburg Port Authority owns a road network of 130 kilometres inside the port and has information panels VMS as well as several traffic light controlled intersections. During rush hour in truck delivery towards container terminals, which are located all over the city, incidents have to be monitored and reported to the port's traffic management centre and, in especially, all impacts on traffic flow, congestions or accidents have to be exchanged with the traffic authorities of the City of Hamburg and the traffic management centre of Lower Saxony in charge of the connecting motorways. 5G technology also provides low latency, minimising delays in data transmission. This is essential for real-time services and coordination of activities in ports, such as tracking the movement of vessels, managing container operations, and ensuring the safety of personnel.

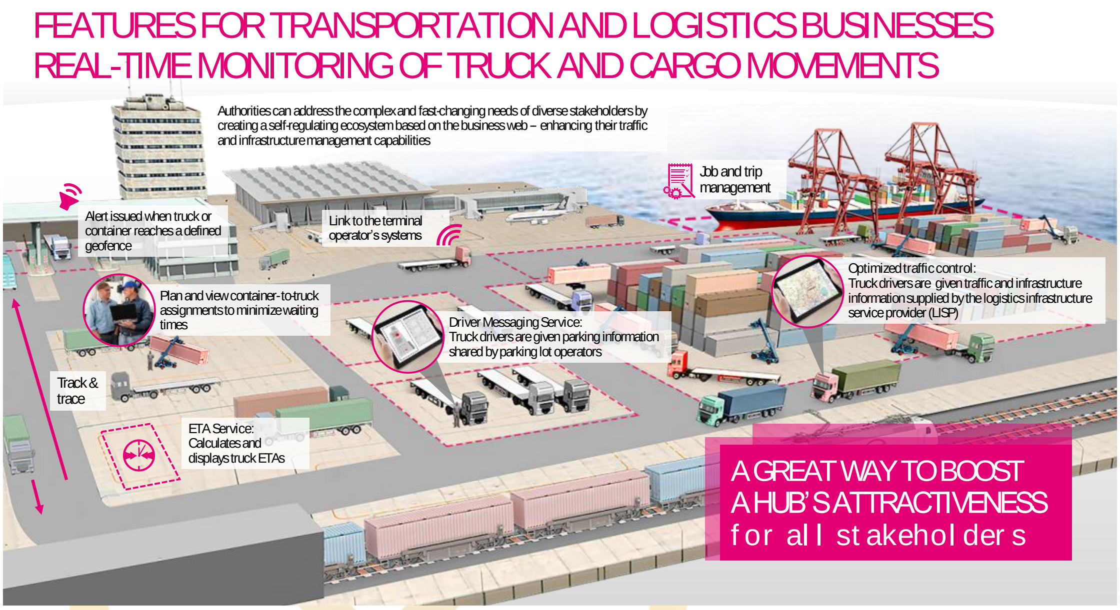

Figure 3: How 5G enables data sharing and messaging in a multi-stakeholder eco-system of port logistics

2. Increased capacity: **Error! Reference source not found.**Figure 3 depicts that besides data speeds and low latency, increased capacity characterizing 5G networks can support a higher number of connected devices simultaneously. In a port environment, where numerous sensors, cameras, and other IoT devices are deployed for monitoring and control, this increased capacity ensures seamless connectivity and efficient data exchange. For Hamburg, this feature is of special importance as the urban near hinterland of Hafen-City has to handle truck delivery and cruise terminal logistics in an densely populated urban road infrastructure used by tourist buses and private passenger cars.

3. Facilitating Smart Port Initiatives: The implementation of 5G aligned with the concept of smart ports, where advanced technologies are employed to improve efficiency, reduce costs, and enhance overall port performance as well as the reduction of traffic related negative environmental impact. For this, 5G enables the deployment of sensors for environmental monitoring in and around the port. This includes monitoring air and water quality, noise levels, and other environmental parameters, contributing to sustainable and eco-friendly port operations. In Hamburg, this started with the 5G-Monarch project for monitoring water quality with a AR/VR measurement tools and was crucial also for 5G-LOGINNOV. Here, the project found that Time-to-Green information given to truck platoons driving in Hamburg's test track for autonomous driving based on 5G cellular C-V2X infrastructure saved 67% standstill times and 17% carbon emissions relative to driving without platoon and Time-to-Green shared information.

In 5G-LOGINNOV test site of Hamburg, the following main achievements were attained:

- By using 5G based telematic devices in urban logistics fleets such as taxis and Amazon delivery vans, it was possible not only to monitor the carbon footprint caused by dense urban traffic situations but also to share the relevant traffic flow information with low latency and ultra fast data speeds in such a way that traffic management actions can be taken to support the decarbonization of Hamburg's city traffic.

- Additionally, by implementing cellular V2X communication, it could be shown that time-to-green data send via 5G and mobile edge computing were able to manage a mini-platoon of two vehicle in such a way that vehicles can keep stable distance and manoeuvre smoothly with little standstill, thus, much less pollution Hamburg's busy traffic. The implemented 5G Loginnov services of a) Floating Truck Emission Data, b) Automated Truck Platooning and c) Dynamic Environmental Controlled Traffic Management prooved significant carbon reductions of 17% and even 60% less standstill compared to the situation without the three implemented 5G-LOGINNOV services.

- All three use cases were presented successfully to Hamburg's traffic authorities and stakeholders. Technical design and use case scenarios were anchored in the testfield for autonomous and connected driving TAVF, further details see in https://tavf.hamburg/en/. The successful implementation of the use cases, in especially the significant reduction of carbon emissions, noise and standstill, created a new awareness of benefits I.T.S. services will bring to citizens, fully in line with the Hamburg I.T.S. policy directive. But compared to before, the project enabled pilot partners to quantify the carbon footprint including baseline and carbon reductions for impact assessment. Usually, environmental impact is qualitative only, thus not accessible to emission trading systems in transport as baseline and improvement have to be measurable and fully transparent – with regards to carbon baseline and reduction.

- In 5G-LOGINNOV, this was achieved by using standardized energy analysis as defined in ISO-23795-1 standard and to apply it to all three telematic devices on board of the vehicle: 1. smartphones with T-Systems LCMM technology, 2. Tec4u Car-PC and 3. Continental IoT devices. By collecting and analysing 250 trips on the testfield and more than 100.000 trips in the city by the Hamburg's SME partners e-Shuttle (Amazon delivery) and UZE (taxi fleets), Hamburg's authorities and TAVF shareholders learned to quantify the amount of carbon saving Autonomous Driving and Platooning will bring to the city.

- Based on these results, it became possible to present the estimated carbon savings Hamburgs I.T.S. policy will bring to the decarbonization strategy of the city during the I.T.S. World Congress in Suzhou China. This is shown in Figure 4, where the equivalent of tree plants necessary to save 10 tons of CO_2 per year is given based on an fuel consumption average of 8 liter diesel per 100 km, 150 km daily mileage and 350 days of taxi operation.

- For the TAVF shareholders, results of 5G platooning and dynamic traffic management were considered similarly of great importance as this enables policymakers to quantify the carbon savings of the planned 10.000 e-shuttle operation foreseen by Hamburg's Public Transport owned New Mobility Service company. This is shown in Figure 5.

Figure 4: Measured carbon savings and climate impact based on 5G-Loginnov Floating Truck Emission Data

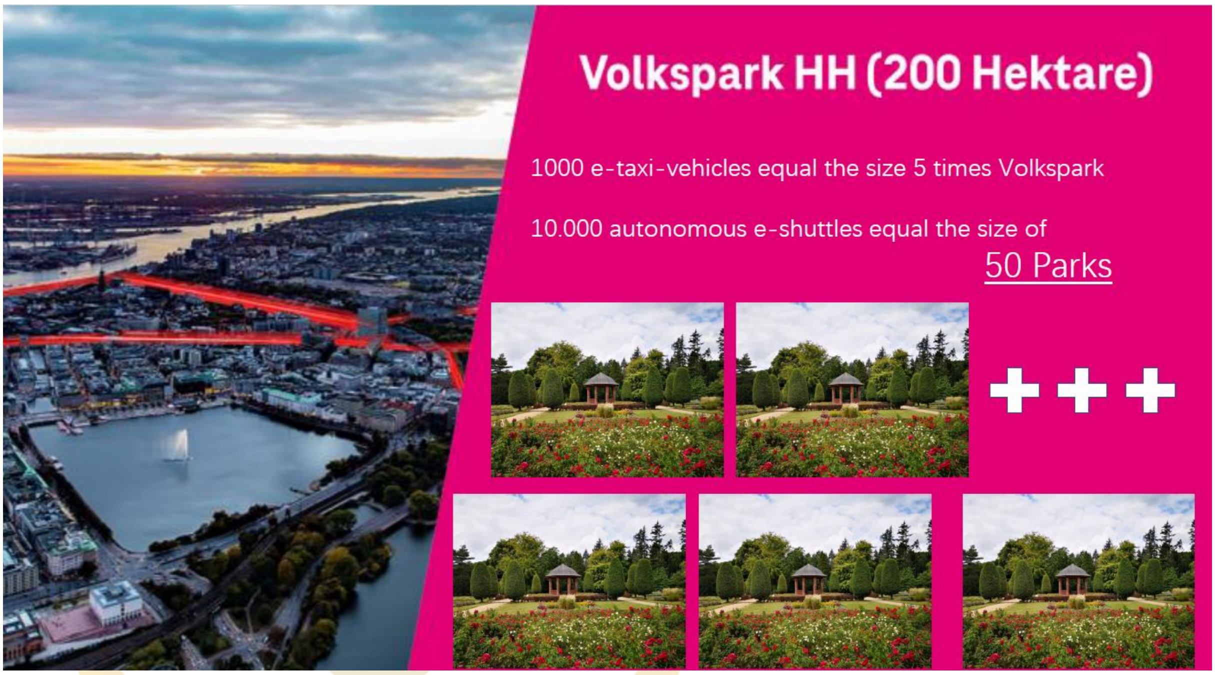

Figure 5: Autonomous e-shuttle carbon savings for the decarbonization strategy of Hamburg's municipality

In summary, the adoption of 5G mobile communication in ports such as Hamburg can lead to a transformative impact, revolutionising communication, automation, and efficiency in various aspects of port operations.

3.3 Koper

Living Lab (LL) Koper is located in the Port of Koper, one of the most dynamic ports in Europe and a front-runner of innovation. Five project partners, LUKA KOPER (LK), INTERNET INSTITUTE (ININ), TELEKOM SLOVENIJE (TSLO), VICOMTECH (VICOM) and CONTINENTAL (CONTI), were focusing on exploitation of applications and services that are based on 5G-assured Industry 4.0 scenarios and included use cases related to port control, logistics, remote automation, and port security.

Utilising Public and Private 5G Infrastructures with Edge and Slicing Support
LL Koper focused on development and demonstration of novel 5G technologies targeting future European ports (e.g., cloud-native and MEC driven infrastructures, MANO-based services and network orchestration, Industrial IoT, vehicle telemetry, AI/ML based video analytics, drone-based security monitoring etc.) and cutting-edge prototypes tailored to the needs of port operation. A novel 5G technologies and cutting-edge prototypes were implemented, tested and verified in the LL Koper, which were tailored for the particular port environment. These include a 5G NSA system deployed over public infrastructure extended with a private core network deployed at the port Edge and base stations operating on band n7 (20 MHz of spectrum) and n78 (100 MHz of spectrum), 5G SA systems as fully private mobile network infrastructure operating on band n78 (20 MHz of spectrum) with the support for 5G slicing and assured QoS, MANO-based services and network orchestration, Industrial IoT devices, AI/ML based video analytics, drone-based and wearable camera-based security monitoring, etc. To add additional added value to the deployed 5G systems, cloud infrastructure in the port was extended with the AI capabilities (GPU compute) and three groups of uses cases with several demonstrators were investigated and verified in the port operational environment with the target to optimise logistic processes, ensure port security and workers safety (Figure 6).

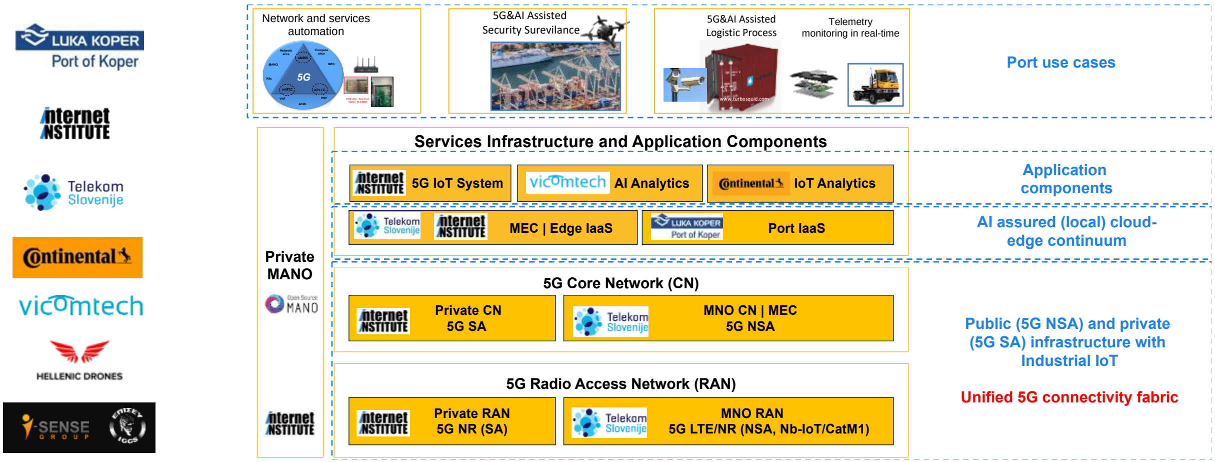

Figure 6: LL Koper - Deployed system capabilities following a modular design approach.

Development of New 5G IoT Devices
The deployment of 5G capabilities in the Port of Koper presented both developmental and operational challenges. The scarcity of high-end 5G devices and industrial-grade IoT gateways capable of supporting 5G in NSA and SA mode hindered 5G deployment initially (Figure 7). Thus, one of the targets of the project was to develop 5G-capable industrial and telematics devices brought to the project by Continental and the INTERNET INSTITUTE, finally integrated into operational port trucks. These devices provide real-time telemetry data crucial for optimizing operational flow and predictive maintenance of port assets, along with far-edge compute capabilities for continuous 5G network monitoring.

Having real-time information and visibility about the operational status of port assets, such as yard trucks, is key to optimizing operational flow and predicting maintenance. The 5G IoT device developed by Continental allows for the collection of telemetry data both via the vehicle CAN interface (e.g., fuel consumption) and from the on-board GNSS module (speed, acceleration, standstill time, etc.), which is collected in real-time in the backend system for interpreting data and calculating operational KPIs.

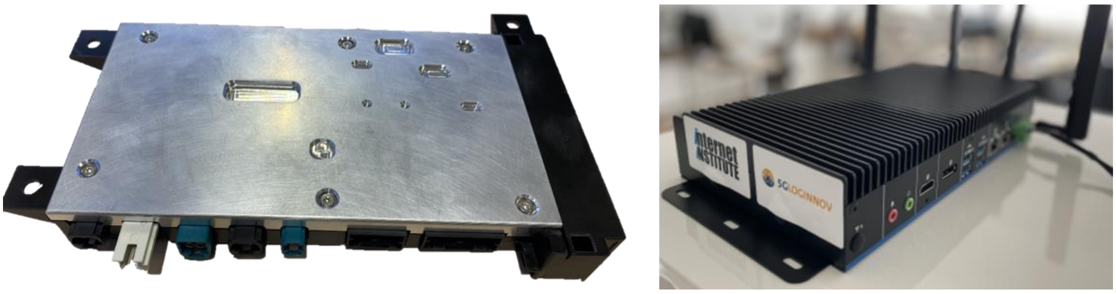

Figure 7: LL Koper – Developed Telematics IoT device (left) and Industrial 5G GW (right).

To support 5G operation in SA mode, ININ developed a dedicated gateway that supports advanced 5G SA functions such as eMBB and mMTC slicing. These functions enable LL Koper to deliver assured bandwidth with slicing support and low latency for eMBB applications, as well as M2M connectivity for mMTC applications. ININ's 5G GW platform also incorporates a centralized cloud-based management and device monitoring platform that was extended with cloud-native capabilities and options for MANO/OSM-based orchestration. This allowed us to deploy, configure, and manage 5G-based IoT network functions and services in a flexible and scalable way, using container-based technologies and optional orchestration mechanisms. The new gateway platform also incorporates advanced functions, such as compute and storage capabilities that can be used for running containerized applications (e.g., running 5G test automation systems qMON) at the far-edge. Prepared gateway system was used to support several use cases in the LL Koper (UC5, UC6, UC3) and to support automation of 5G performance monitoring of the deployed NSA and SA mobile networks in the LL Koper.

Spectrum Needs for Smart Ports

To verify the proposed 5G design, developed components, and implemented use cases, intensive testing and verification of the deployed smart port capabilities were conducted during the duration of the 5G-LOGINNOV project. This included drive testing and continuous monitoring of the deployed networks and services in the port. The test results showed that the performance and suitability of the 5G NR system depend on the channel bandwidth and the application requirements. For applications that are not bandwidth-intensive, such as sensor readings and real-time telemetry collection, the system can provide adequate service quality using 20 MHz of spectrum. However, for bandwidth-intensive applications like video streaming and cloud computing, the 5G system requires more spectrum to achieve higher throughput and lower latency.

The results indicate that using 50 MHz of spectrum can increase the uplink throughput up to 258 Mbps (using 2x2 MIMO), which represents a significant improvement compared to 20 MHz of spectrum (uplink throughput up to 57 Mbps using 2x2 MIMO). However, even this may not be sufficient to fully utilize the potential of 5G technology for future smart port operations. Therefore, we recommend using 100 MHz of dedicated spectrum or more for private 5G deployments in the port to assure more advanced and diverse applications and services for future smart port use cases.

State-of-the-art 5G Security

As ports represent one of the most essential critical infrastructures for the European economy, they need protection against the latest cybersecurity threats. As such, state-of-the-art 5G security capabilities were investigated and enforced on the private 5G system in LL Koper. These capabilities included also secure 5G UE registration with encrypted SUPI/IMSI identity using asymmetrical encryption (public and private system keys) and data plane integrity. Additionally, a dedicated 5G SA-capable USIM module were used and prepared with the public asymmetric key derived from the private key used on the 5G core network side to ensure the highest level of security for the services and use-cases employed in the port (Figure 8).

Security function	5G SA	4G/NSA
Encrypted (SUPI/IMSI) (private network registration)	✓	✗
Temporary identity GUTI	✓	✓
Control plane privacy	✓	✓
Control plane integrity	✓	✓
Data plane privacy	✓	✓
Data plane integrity	✓	✗

Figure 8: LL Koper - Private 5G SA network supporting advanced 5G security services.

5G Devices Ecosystem
By the end of the project in Q4 2023, a breakthrough on the consumer devices (support for 5G SA operation) side was noticed as several Tier-1 producers of smartphones (e.g., Apple) opened their ecosystem to support private 5G network deployments without the need for additional agreements with smartphone producers. However, niched 5G SA devices (e.g., wearable cameras for security personnel) still lacked 5G support in the market. We believe that the availability of specialized 5G equipment for port and industrial environments is essential for 5G breakthroughs in these vertical industries segments in the future.

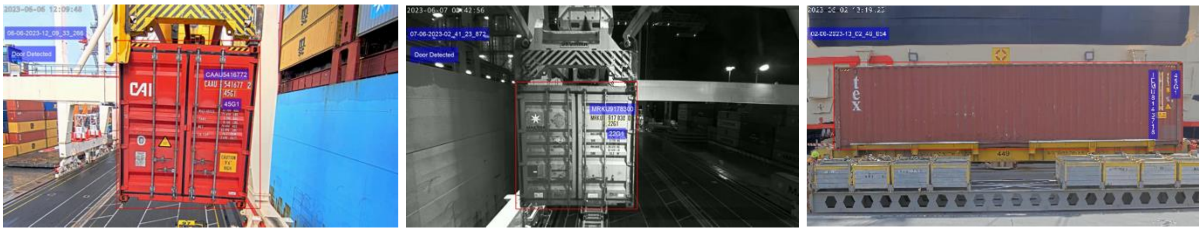

Figure 9: LL Koper – AI-assured logistic process automation

Dedicated Spectrum for 5G Networks in the Port
Finally, based on the achived project results, Luka Koper made a strategic decision to pursue dedicated frequency spectrum for private 5G network deployment in the port. In December 2023, they applied for a national tender in Slovenia where they were successful and were awarded 20 MHz of dedicated spectrum in the n40 band (2300 MHz). This spectrum is planned to be used for building initial coverage of the private 5G network in the port area. Additionally, it is expected that the n77 band (3800 MHz – 4200 MHz), with at least 100 MHz of available spectrum, will be released by 2025 by the Slovenian regulator. This band will be utilised in addition to the n40 band to assure the required private network capacities for the most demanding and bandwidth-intensive smart port use cases, such as real-time UHD video streaming applications supporting security and other logistic automation processes(Figure 9).

3.4 Technical notes

3.4.1 Clarification of the “choice” between MEC and Edge Computing, the nonexistence of cybersecurity for Private Networks, slicing and AI

In this section, some distinctions between Multi-Access Edge Computing (MEC) and Edge Computing are described as follows:

1. **Edge Computing**:
   - **Concept**: Edge computing is a network model that aims to bring IT resources (such as storage and computing power) closer to the data source and end-users.

- **Deployment**: It involves placing computing and storage resources at the “edge” of the network, near the end-users. This can be on customer premises or at the base of cell towers.
- **Use Cases**: Edge computing is used in scenarios that require high real-time performance, such as autonomous driving and factory robots.
- **Benefits**: By processing data locally, edge computing reduces latency, ensures faster network speeds, and provides more reliable connections.
- **Hardware**: It can occur on various hardware, including traditional server racks, routers, or WiFi hotspots.
- **General Concept**: Edge computing is a broader term that encompasses various deployment models.

2. **Multi-Access Edge Computing (MEC)**:
    - **Standard Architecture**: MEC is a specific standard architecture within edge computing.
    - **ETSI Standard**: MEC is developed by the European Telecommunications Standards Institute (ETSI).
    - **Focus**: MEC is centered on communication from mobile devices (such as 5G terminals and IoT devices) in the local environment.
    - **Mobile Communication**: It was specifically designed with mobile communication in mind.
    - **Guiding Principles**:
        - MEC applications should have a virtualization platform (based on ETSI’s NFV architecture).
        - Deployment can happen at radio nodes, aggregation points, and the edge of the core network.
        - APIs in a MEC environment should be simple and controllable.
        - MEC systems must handle variations in available compute, storage, and network resources.
        - MEC applications can be relocated between external clouds and MEC hosts while meeting requirements.
    - **5G**: MEC leverages 5G technology for ultra-high-speed communication, low latency, and multiple simultaneous connections.
    - **Use Cases**: MEC enables innovative services, such as virtual reality (VR) and mixed reality (MR) experiences.

In summary, while edge computing is a broader concept, MEC specifically focuses on mobile communication and adheres to ETSI standards. Both play essential roles in optimising network performance and enabling exciting applications in the era of 5G communication.
In Hamburg, the MEC was used in the context of collision alert for Vulnerable Road Users risking to crash at an intersection with the automated vehicle platoon which was operated in the Testfield for Autonomous and Connected Driving. As all use cases in Hamburg were based on 5G NSA mobile communications, the choice for a commercial MEC adhering ETSI standards was mandatory. Given the nonexistence of cybersecurity for Private Networks, slicing and AI, the roll-out of Private Networks in the public road network domain of the hinterland was not viable in the Hamburg pilot.

3.4.2 Difference on the performance of the same use cases with 5G NSA (Hamburg and Athens) and 5G SA (Koper)

5G Private Campus Networks are organized in terms of **cybersecurity**, **network slicing**, and **AI in the following way**:

1. **Cybersecurity for 5G Private Campus Networks**:
    - **Challenges**: Protecting private 5G networks can be challenging due to increased complexity and the expanding attack surface. As private networks connect with various devices, services, and networks (including IT, OT, and IoT), the risk of cyber threats rises.

    - **Zero Trust Approach**: Adopting an end-to-end **Zero Trust** approach is crucial. It involves comprehensive visibility and context-rich monitoring to deliver enterprise-grade security for 5G.
    - **Ecosystem Collaboration**: Collaboration across the industry is essential. Integrating best-of-breed security platforms with trusted 5G partners ensures robust security solutions.
    - **Example**: Palo Alto Networks collaborates with NVIDIA to create a scalable private 5G security solution that optimizes AI-powered applications for speed, latency, security, and efficiency.
2. **Network Slicing for 5G Private Campus Networks**:
    - **Concept**: Network slicing allows the creation of virtual private 5G networks that are flexible, secure, and scalable.
    - **Diverse Requirements**: Different use cases demand specific network slices. For example, an industrial automation application may require low latency, while a healthcare application needs high reliability.
    - **Impact on Network Design**: The diversity of slicing requirements affects how networks are built and managed.
3. **AI in 5G Private Campus Networks**:
    - **Optimizing Applications**: AI can enhance 5G network performance by optimizing resource allocation, reducing latency, and improving efficiency.
    - **Security**: AI-powered cybersecurity solutions can detect and prevent threats in real time.
    - **Intelligent Traffic Offload (ITO)**: Solutions like ITO accelerate virtual next-generation firewalls (NGFWs) for secure traffic management.

In summary, securing private 5G networks involves collaboration, robust security practices, tailored network slices, and leveraging AI for enhanced performance and protection.

For Hamburg, the near hinterland road network has public networks which allow to fully rely on the cybersecurity architecture, slicing and AI-Big Data software components of the 5G NSA network.

In the context of 5G NSA, slicing played an essential role in enabling the coexistence of 5G and existing 4G LTE networks. Slicing allowed operators to allocate resources efficiently while ensuring seamless connectivity and optimal performance for both types of networks. By dynamically allocating resources based on demand and application requirements, slicing enhanced network flexibility, scalability, and efficiency in 5G NSA deployments. For ensuring VRU security when operating driverless vehicle platoons or remote car sharing services, the 5G NSA architecture for slicing and cybersecurity is recommended except for very complex port areas such as security gates of terminals with special requirements of imaging, drones, etc.

AI algorithms analysed large volumes of network data in real-time to identify patterns, predict network congestion, and optimize resource allocation. This helped ensure optimal network performance and quality of service for users. Big Data analytics enabled operators to gather insights from diverse data sources, including network performance metrics, user behavior patterns, and application data. These insights can inform decision-making processes related to network planning, optimization, and troubleshooting. AI-driven automation played a key role in managing network slices, orchestrating resources, and dynamically adapting to changing network conditions in 5G NSA environments.

Slicing enabled efficient resource utilization and service differentiation provided by the 5G networks, while AI and Big Data technologies empowered operators to optimise network performance, enhanced user experience, and streamlined network management processes.

Together, these components facilitate the seamless integration of 5G NSA with existing infrastructure, paving the way for enhanced connectivity, innovative services, and new business opportunities.

4 5G-ENABLED BUSINESS MODELS

5G in ports has different tasks and priorities, when looking at automation inside the port area or in the near hinterland. For Hamburg, terminal operation and container slot booking is advanced and basically, drones operated in reserved and restricted flight zones (U-Spaces) offer new business opportunities for private campus networks, currently under discussion in pilot projects of Deutsche Telekom and Port of Hamburg. For traffic management and autonomous mobility (CCAM), the 5G-LOGINNOV project partners T-Systems, Continental, tec4u and Swarco succeeded to prove the positive impact of the piloted use cases and presented with great interest of participants in stakeholder and customer meetings.

Nevertheless, in the complex eco-system of public entities, logistics service providers, road authorities, MNO, ICT companies and new actors such as start-ups, SME, etc., business ownership and return-of-invest time and cost frames are still unclear. The developed business scenarios, products and services cover many aspects, but cannot easily identify the main driving factors to scale up the market towards successful revenue models and revenue sharing.

The primary focus of the business models (BMs) in the Athens Living Lab is to enhance safety conditions and optimize port operations by leveraging data exchange platforms enabled by 5G technology. These BMs are designed to improve working conditions for port personnel and streamline resource planning.

The implementation of 5G technology facilitates real-time and low-latency data collection and exchange through IoT sensors and high-definition cameras installed on vehicles and infrastructures. The emphasis is on safety, technology integration, optimization, and user impact within the port environment, with broader benefits for stakeholders in the logistics and transportation industry.

Key activities and resources required include deploying the 5G network, developing, training, and testing AI-enabled systems, and installing high-definition cameras on vehicles and port infrastructures.

The main partners involved in the development phase include network and telecom operators, IT providers, research institutes, hardware providers, and vehicle providers.

Economically, expenses mainly stem from development costs, surveillance device installation, operation, maintenance, administrative costs, and scale-up expenses for market adoption. Revenue sources post-project include cost savings from process optimization, improvements in yard personnel's work quality, and revenue from usage fees and licenses paid by interested stakeholders.

The primary focus of the business models (BMs) in the Hamburg Living Lab lies in optimizing port operations and reducing emissions across various use cases. These BMs harness the capabilities of 5G technology, enabling real-time data exchange and analysis.

Each use case within these business models involves the development of the 5G network, applications, data collection and analysis platforms, and communication systems. Key partners include network operators, IT service providers, research institutes, and vehicle suppliers. Customer relationships entail co-creation during implementation and testing, with future adoption facilitated through subscription and usage fees.

The main costs associated with these initiatives include the development and integration costs of monitoring systems, along with HR expenses for compliance with data management policies. Revenue streams encompass usage and licensing fees, as well as the optimization of port operations and management.

By participating in the test track of autonomous and connected driving with its public shareholders from City and Port Authority of Hamburg, this obstacle was successfully removed (Figure 10). Within its I.T.S. 2030 policy directive, the decarbonization policy and Germany's selected digital mobility innovation hub, the project's partners enter into the first phase of commercialization. Hamburg's public transportation affiliate company New Mobility Solutions has the objective to roll out flexible shuttle services with autonomous vehicles as a complement to the traditional public transportation system. The research project ALIKE should be the first to integrate a fleet of fully electric and autonomous shuttles into public transportation. These shuttles, the HOLON Mover and the ID. Buzz AD from Volkswagen Commercial Vehicles, are equipped with a self-driving system from Mobileye see https://new-mobility-solutions.de/en/projects/

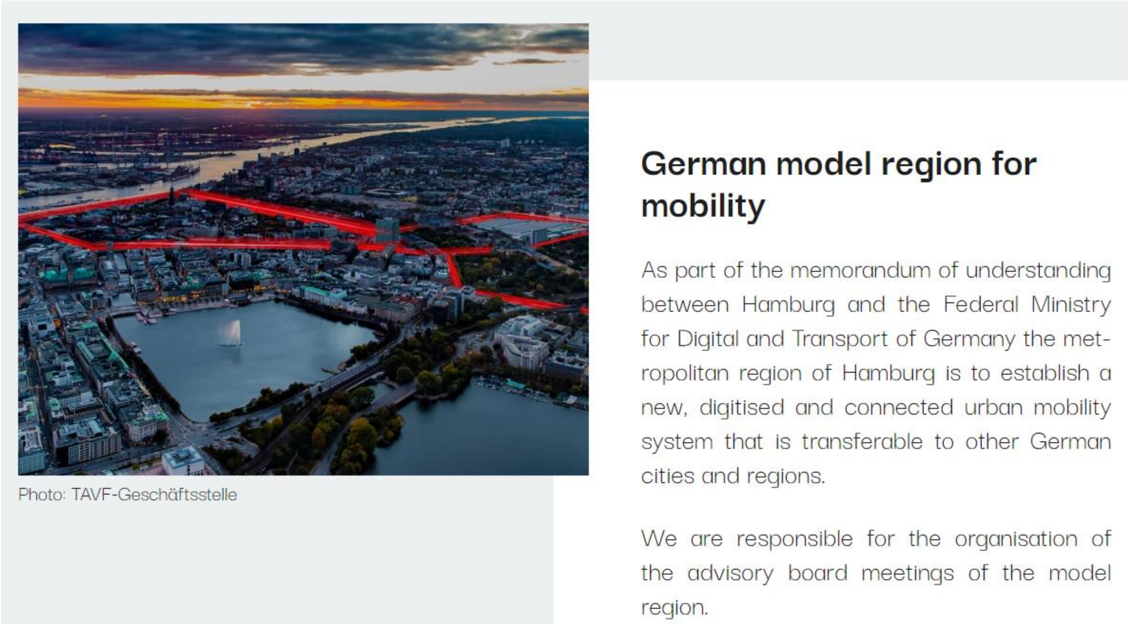

Figure 10: New-Mobility-Solutions GmbH – a municipal Public Transport affiliate for digital mobility

The business models in the Koper Living Lab leverage 5G technology across three main areas: enhancing communication, optimizing operations, and improving security within the port environment.

Activities include developing the 5G network, integrating systems with existing port platforms, and conducting training sessions for end-users. Key resources involve expertise from IT and TELCO operators, ICT competencies, and access to intellectual property.

Costs encompass 5G network development, integration of innovative services, HR expenses for R&D personnel, and administrative and legal costs. Initial revenues originate from European funding, followed by licensing or usage fees from external parties.

For further details, refer to Report 5GLOGGINOV D4.3 Achievements with new actors and opportunities, which provides a summarized Business Model Canvas adopted by each Living Lab.

In conclusion, the introduction of 5G infrastructure transcends its role as a mere enabler for individual applications. It catalyzes experimentation and the introduction of side technologies. Furthermore, it contributes to the meta business model through a Many-to-One-to-Many (M1M) system. These advancements pave the way for further exploitation and innovations, as elaborated in Section 5.

5 FURTHER EXPLOITATION AND LONG TERM INNOVATION PERSPECTIVES

5.1 Existing business models and how they are affected by 5G

Existing public transport business models can be expanded with 5G enabled autonomous driving technology in several promising ways:

1. Micro-transit solutions:

Self-driving shuttles: Deploy smaller autonomous vehicles to address "first-mile" and "last-mile" connectivity issues. These can connect users to existing bus or train stations, covering areas where traditional routes are inefficient.

On-demand services: Implement app-based systems where users can hail autonomous vehicles for point-to-point travel within designated areas. This caters to flexible schedules and personalized routes, potentially filling gaps in existing public transport networks.

2. Increased efficiency and cost reduction:

Optimized routing and scheduling: Leverage autonomous vehicle capabilities for real-time traffic data analysis. This allows for dynamic route adjustments, reducing travel times and operational costs.

Reduced manpower: Autonomous vehicles can address driver shortages and optimize personnel allocation. This frees up resources for other crucial aspects of public transport, like maintenance and infrastructure development.

3. Expanding service reach:

Nighttime and weekend operations: Introduce autonomous vehicles for extended public transport operations during off-peak hours. This caters to shift workers, night owls, and improves overall accessibility.

Demand-responsive services: Implement autonomous vehicles in low-demand areas where fixed routes might be impractical. This caters to underserved communities and increases the reach of public transport.

Challenges to be considered:

Technology readiness: Full self-driving capabilities are still under development. Extensive testing and regulatory frameworks need to be established before widespread public deployment.

Public perception and trust: Concerns regarding safety and data privacy need to be addressed effectively to gain public acceptance for autonomous vehicles in public transport.

Further considerations:

Integration with existing infrastructure: Autonomous vehicles need to seamlessly integrate with traffic management systems, pedestrian crossings, and designated drop-off zones.

Data management and cybersecurity: Robust systems are crucial to ensure data security and privacy of passenger information collected during autonomous operations.

By addressing these challenges and pursuing strategic implementation, autonomous driving technology holds immense potential to revolutionize public transportation. It can lead to a more efficient, accessible, and sustainable public transport system, catering to the evolving needs of modern society.

In the Alike[9] and Ahoi [10] projects, reliable connectivity and precise positioning will play a crucial role and are currently under preparation to be made available for New Mobility Solutions with supporting project set ups linked to Hamburg’s digital lighthouse (Figure 11). The same holds for using LCMM and standardized carbon monitoring tools for decarbonizing urban transport.

Figure 11: New-Mobility-Solutions linked to Hamburg's digital lighthouse

5.2 Impact evaluation

The 5GLOGINNOV project adopted a rigorous approach to assess the potential impact of various use cases related to the implementation of 5G technology in logistics operations. The methodology employed a combination of qualitative and quantitative analyses, integrating data from previous deliverables (see deliverable D4.3) and literature reviews of relevant EU projects.
First, a multi-criteria evaluation was conducted to identify relevant micro-criteria, drawing from a wide range of documents and deliverables produced within the 5GLOGINNOV project. These micro-criteria represented the key aspects to be considered in the impact analysis. Subsequently, an impact matrix was created by assigning scores to each use case based on the frequency with which the micro-criteria were mentioned in specific deliverables (D1.4 and D3.4). This approach allowed for the quantification of the relative importance of different factors for each use case. The results of the multi-criteria analysis provided an assessment of the potential impact of the various use cases, taking into account multiple perspectives and considerations. To further deepen the analysis, environmental, social, and economic scenarios were explored. Through this lens, the use cases were ranked based on their overall impact, with higher-scoring use cases identified as having a greater influence within their respective domains (environmental, social, or economic).
This holistic approach enabled a comprehensive evaluation of the potential implications of 5G adoption in logistics operations, considering a wide range of criteria and scenarios. The higher-ranked use cases were deemed to have the greatest potential to generate significant impact within their respective domains, driving innovation and progress in the logistics sector. Moreover, this approach can be easily replicated to other projects.

5.3 5G infrastructure and side technologies implementation

In order to evaluate the impact of 5G technologies, an assessment on selected Stakeholders was conducted (see deliberable D3.4). This survey shows the emersion of two main impacts.

The primary impact of 5G-LOGINNOV lies in the increased implementation level of the tested technologies within the project's scope. By rigorously evaluating and demonstrating the practical applications of 5G-enabled solutions, the project paves the way for wider adoption and integration of these cutting-edge technologies in logistics operations. This includes advancements in areas such as real-time tracking, autonomous transportation, predictive maintenance, and enhanced supply chain visibility.

However, the implications of 5G-LOGINNOV extend beyond the direct implementation of the tested technologies. The project also holds the potential for a secondary impact: an increased implementation level of complementary or "side" technologies. The successful deployment of 5G in logistics operations creates a conducive environment for the adoption of other emerging technologies that can leverage the capabilities of 5G networks. These side technologies may include advanced analytics, artificial intelligence, Internet of Things (IoT) devices, and augmented reality/virtual reality (AR/VR) applications. By enabling seamless connectivity, low latency, and high data transfer rates, 5G acts as a catalyst for the integration of these technologies into logistics processes, unlocking new levels of operational efficiency, automation, and data-driven decision-making.

The primary and secondary impacts of 5G-LOGINNOV collectively contribute to the digital transformation of the logistics sector. As the implementation levels of both the tested and complementary technologies increase, logistics operations can expect to experience significant improvements in areas such as supply chain visibility, resource optimization, cost reduction, and environmental sustainability (Figure 12).

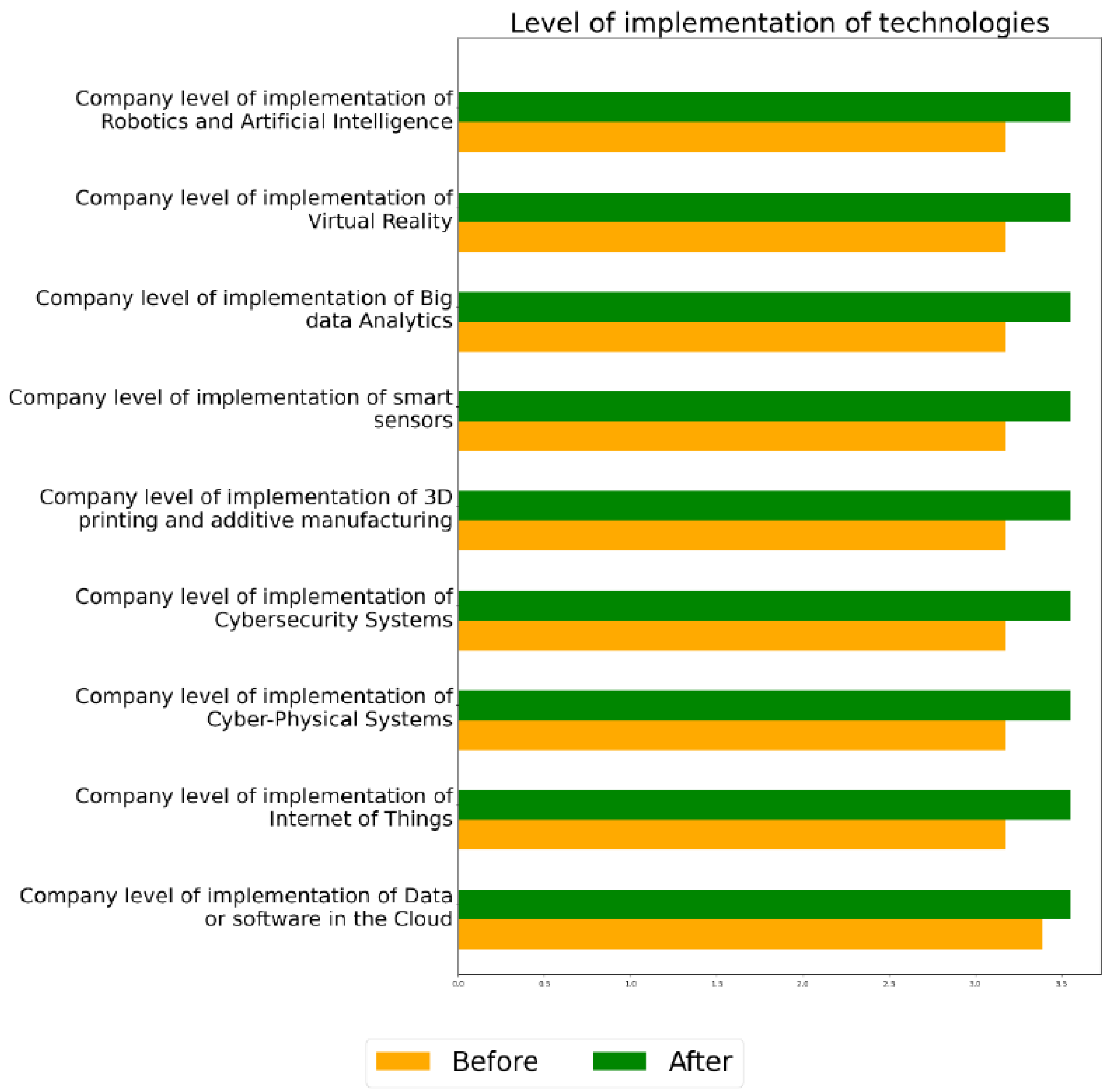

Figure 12: Example od results taken from the stakeholder assessment survey

5.4 New actors

The advent of **5G technology** is transforming ports into **smart and connected ecosystems**, enabling greater efficiency, safety, and innovation. Therefore new actors in this dynamic environment are as follows:

1. **Telecom Operators and Infrastructure Providers**:
    - **Role**: Telecom operators play a pivotal role in deploying and maintaining 5G networks within port areas. They collaborate with port authorities to ensure seamless connectivity.
    - **Impact**: Their expertise in network deployment and management is crucial for enabling reliable and high-speed communication across the port.
2. **Technology Vendors and Integrators**:
    - **Role**: Companies specializing in 5G infrastructure, edge computing, and IoT solutions contribute significantly.
    - **Impact**: They provide hardware, software, and integration services to create a robust 5G ecosystem. Examples include Ericsson, Nokia, and Huawei.
3. **Logistics and Supply Chain Companies**:
    - **Role**: These players leverage 5G to optimize cargo handling, track shipments, and enhance supply chain visibility.
    - **Impact**: Real-time data exchange improves efficiency, reduces delays, and enhances overall logistics operations.
4. **Port Authorities and Municipal Bodies**:
    - **Role**: Port authorities drive the adoption of 5G by collaborating with stakeholders, setting regulations, and ensuring security.
    - **Impact**: They oversee the transformation of ports into smart hubs, integrating technology for better management and sustainability.
5. **Shipping Companies and Terminal Operators**:
    - **Role**: These entities benefit from 5G-enabled automation, remote monitoring, and predictive maintenance.
    - **Impact**: Automated cranes, cargo-moving vehicles, and real-time condition monitoring enhance port operations.
6. **Startups and Innovators**:
    - **Role**: Smaller players bring fresh ideas and disruptive technologies to the port ecosystem.
    - **Impact**: Startups may develop niche solutions, such as AI-powered surveillance, blockchain-based documentation, or novel IoT applications.
7. **Government Agencies and Research Institutes**:
    - **Role**: They drive policy, funding, and research initiatives related to 5G adoption in ports.
    - **Impact**: Collaboration with academia and research institutes fosters innovation and knowledge exchange.
8. **Security and Cybersecurity Providers**:
    - **Role**: Ensuring the safety and integrity of 5G networks and connected devices is critical.
    - **Impact**: These players offer solutions to protect against cyber threats, secure data, and prevent unauthorized access.
9. **Environmental Monitoring and Sustainability Experts**:
    - **Role**: With 5G, real-time environmental monitoring becomes feasible.
    - **Impact**: Experts contribute to sustainable practices, reducing emissions, and minimizing the ecological impact of port operations.
10. **Data Analytics and AI Companies**:
    - **Role**: Leveraging 5G data, they provide insights for better decision-making.
    - **Impact**: Predictive analytics, anomaly detection, and optimization algorithms enhance port efficiency.

In summary, the convergence of 5G, IoT, and AI opens up exciting opportunities for various players to shape the future of smart ports. Collaboration among these stakeholders will drive innovation and propel the industry forward

5.5 The Many-to-One-to-Many (M1M) business model

As emerged from the stakeholder survey and the results of the living labs, the use of 5G technologies not only enables the optimisation of existing operations in ports and the use of strictly necessary complementary technologies, but also leads, thanks to the existence of an efficient and effective communication infrastructure, to the experimentation of other technologies.
This digital transformation process firstly enables the sharing of real-time or near-real-time data, but most importantly, it creates spaces for new actors and new business models.
Regarding the actors, space emerges for a new type of actor. Usually, the main actors are the infrastructure managers and logistics operators, supported by public stakeholders such as cities (in the case of ports in urban areas) and local authorities. The business model can be of the multi-to-one (**M-1**) or one-to-many (**1-M**) type. In this case, however, thanks to 5G technologies, the availability of data from various port actors, and the use of optimization systems, the new actor has the possibility to act as a third-party operator that purely provides digital services to support operations, in order to promote synchronization (synchromodality) and the adoption of collaborative frameworks such as the physical internet (Bruni et al., 2024; Crainic e al., 2028). This new actor de facto creates a new virtual infrastructure on top of the physical one to optimize KPIs of different type: operational (reduction of delays, use of residual capacity of operators), economic (increase in intermodality, increase in efficiency), social (reduction of accidents), and environmental (reduction of direct and indirect emissions, reduction of congestion). This business model is refereed in the literature as the Many-to-One-to-Many (**M1M**) business model (Crainic et al., 2021; Perboli et al., 2021).
In brief**, M1M** is a paradigm shift from traditional business models, enabled by emerging technologies like 5G, Internet of Things (IoT), and artificial intelligence (AI). It envisions a dynamic and collaborative ecosystem where multiple stakeholders can interact and contribute to the creation, delivery, and consumption of products and services.
The **M1M** model enables a collaborative and symbiotic relationship among stakeholders, breaking down traditional silos and fostering innovation and value co-creation. Key characteristics of the M1M business model include:

- Open and Collaborative Ecosystem: The model promotes an open and collaborative ecosystem where stakeholders can contribute their resources, expertise, and data, creating a shared value network.
- Data-Driven Insights: By leveraging 5G, IoT, and AI, the platform can process and analyze vast amounts of data from multiple sources, enabling data-driven insights and personalized solutions.
- Agility and Adaptability: The M1M model allows for rapid adaptation and iteration, enabling stakeholders to respond quickly to changing market demands, customer needs, or technological advancements.
- Value Co-Creation: The collaborative nature of the model fosters value co-creation, where stakeholders collectively contribute to the development and delivery of products and services, enhancing their overall value proposition.
- Scalability and Network Effects: As more stakeholders join the ecosystem, the value and potential for innovation increase, creating network effects and enabling scalability.

6 LESSONS LEARNT AND RECOMMENDATIONS

In reflecting on the multifaceted journey of our project, several invaluable lessons have emerged that are worth highlighting (see 5GLOGINNOV Consortium, 2024©).

- The strategic integration of startups and SMEs with niche perspectives within a broader ecosystem has proven to be a game-changer. This symbiotic relationship not only fosters innovation but also facilitates the adaptation and scalability of business models. Through this collaborative approach, startups and SMEs gain invaluable experience in navigating complex market landscapes and integrating new business models into their strategic plans. Importantly, this model exhibits replicability and holds promise for broader application across diverse sectors and industries.

- The project has shed light on the transformative power of 5G infrastructure beyond its immediate applications. While 5G is often perceived as a technological enabler for specific use cases, our experience has revealed its broader significance as a catalyst for experimentation and innovation. The introduction of 5G infrastructure has not only enabled the exploration of new applications but has also facilitated the integration of complementary technologies. This has resulted in the emergence of a meta business model, characterized by the M1M system, which underscores the interconnectedness of various technological and business elements within our project framework.

- Moreover, our project has reinforced the critical importance of adopting a global sustainability perspective. Beyond merely focusing on operational efficiency, our endeavor has emphasized the holistic consideration of environmental, social, and economic dimensions. This comprehensive approach to sustainability underscores the imperative of aligning our efforts with broader societal and environmental goals. By embracing sustainability as a guiding principle, we can drive positive impact and create value that extends far beyond individual projects or initiatives. For example, a simple estimation of carbon saving when using electric shuttle buses replacing combustion ones, gives a potential planting 1.000 hectare of trees to become carbon neutral or to roll out 1000 e-taxi and 10.000 e-shuttle buses. As the crowded city of Hamburg has not the space to plant 1.000 hectare of trees, electrification of taxi- and shuttle fleets seems much easier. Calculating the monthly costs of bus driver by 5k€, driverless shuttle services would bring Public Transport savings of 600m€ per year, enough to have aquick return-of-invest, once driverless operation is safe and operational inside 5G enabled areas of the city (Figure 13).

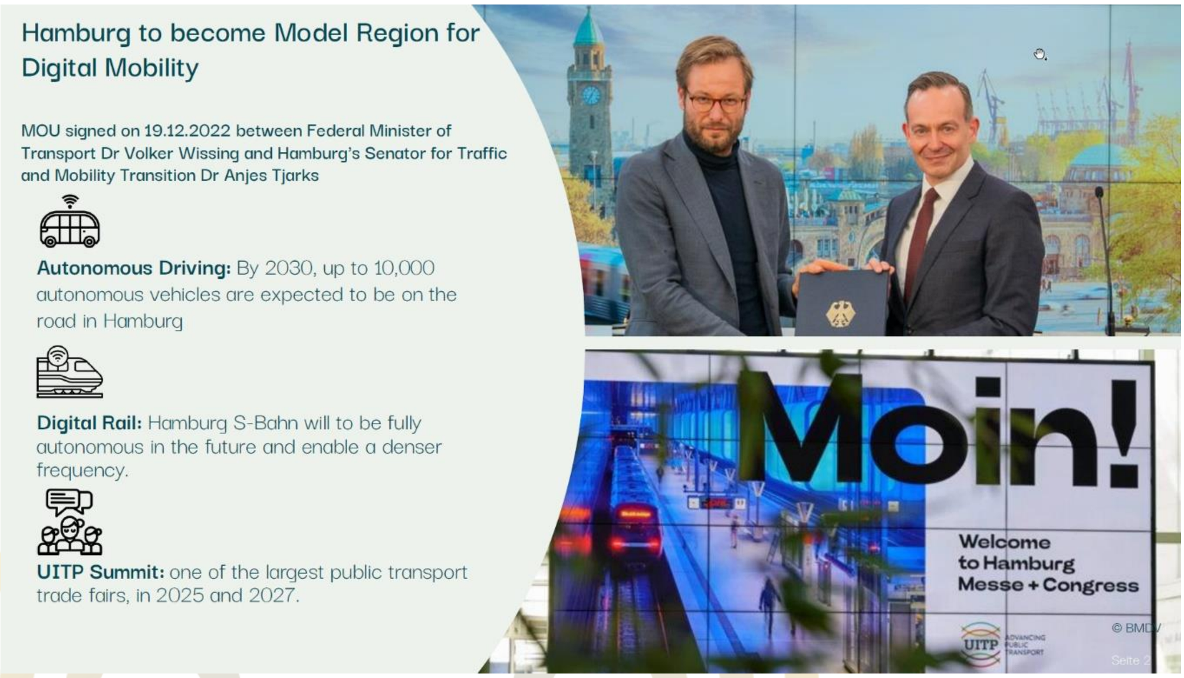

Figure 13: B2B approach in Hamburg's eco-system following the positive results of 5G-LOGINNOV

Additionally, other relevant recommendations developed from the lessons learned from the 5G-LOGINNOV project are presented below:

1. For the hinterland area, where 5G-LOGINNOV innovations were connected to the 'commercially available network,' the low latency aspect of the network was not always guaranteed. Therefore, **reliable and consistent low-latency performance in 5G networks needs to be ensured.** To achieve this and optimize latency and establish and meet specified Service Level Agreements (SLAs) it is recommended to work towards resolving license issues with Mobile Network Operators (MNOs) and implementing network slicing features. Collaboration with MNOs to address any license-related issues that hinder the consistent delivery of low latency in commercial networks is also important. This will involve streamlining the regulatory processes to facilitate MNOs in meeting the requirements for low-latency performance. To enhance low-latency performance, **developing mobile edge infrastructure, such as local base data hubs, in key regions like Hamburg** is needed. These localized data hubs will reduce data transport times and improve overall network responsiveness, addressing latency issues and supporting various latency-sensitive applications.
2. **Ensure compatibility of port infrastructure (including equipment like cranes, to support the integration of 5G hardware components).** During the project, challenges were encountered in installing 5G transponders, with cranes identified as the ideal location. However, installing 5G equipment on cranes posed difficulties, prompting consideration of using legacy Wi-Fi infrastructure as an alternative, albeit not optimal due to limited coverage per transponder. Conversely, 5G installation is more feasible due to its broader coverage and inherent system advantages, including immediate interactivity with other mobile network clients for various feature applications/services. Transitioning from legacy Wi-Fi infrastructure unlocks the full potential of 5G technology in the maritime sector, enhancing efficiency, safety, and communication. Collaboration with relevant stakeholders to establish voluntary guidelines and standards for port infrastructure upgrades is recommended, encouraging private port operators to invest in 5G-compatible equipment and facilitating the deployment of 5G hardware components within port premises. Furthermore, fostering innovation and competition in the 5G market, particularly concerning private network equipment, is deemed vital for ongoing advancements.

3. **Standardize technical interfaces to reduce complexities for service and equipment providers and foster efficient operations**: This recommendation aims to address the challenges arising from the lack of standardized technical interfaces, which requires agreements with every supplier for the integration of equipment and services. It suggests the establishment of a Technical Standards Committee to define and develop standardized technical interfaces for 5G deployment in ports and hinterland regions. The recommendation includes actions such as prioritizing open standards, conducting regular consultations, collaborating with regulatory bodies, establishing testing and certification processes, offering incentives for early adoption, organizing technology showcases, engaging in international collaborations, and providing training programs and workshops. These policies simplify operations for service and equipment providers, fostering competition and ensuring a smooth and efficient deployment of 5G technology.

4. The project partners faced some challenges when obtaining the AI and related software tools for the applications and services planned. The rapid advancement of Artificial Intelligence (AI) has created a growing demand for tools and software to support its applications and services, however, there is a noticeable lack of accessible, high-quality AI tools and software available to developers, businesses, and researchers. This gap hinders innovation and limits the widespread adoption of AI technologies. To address this issue, the following recommendations were developed: **Investment in Research and Development**; **Stimulate Open-Source Initiatives; Focus on standards and Interoperability; Intellectual Property and Licensing Reform; Ensure the availability of User-Friendly Interfaces and Documentation.** Among the recommendations, it is worth noting the **stimulation of Open-Source Initiatives.** The promotion and financial support of open-source AI projects can help democratize AI technology. It is important to encourage organizations and developers to contribute to open-source AI toolkits as well as support the creation of a centralized platform for hosting and showcasing open-source AI tools and software, making them easily accessible to the global AI community.

5. **Deployment of dedicated cloud environments (Enhance Standardization)**. During the project, challenges arouse during the integration of AI tools into existing ICT environments, including concerns regarding security and privacy. The deployment of dedicated cloud environments, such as port and mobile Infrastructure as a Service (IaaS), mandates strict adherence to internal port procedures. Notably, the manufacturer's prohibition on any infrastructure modifications for port cranes poses a significant hurdle. To mitigate these challenges this recommendation advocates for the enhancement of standardization practices. This entails promoting the adoption of standardized protocols and interfaces, facilitating seamless integration that enables diverse AI applications to collaborate effectively with existing ICT infrastructure. By fostering standardization, organizations can streamline integration processes, fostering interoperability and optimizing the functionality of AI technologies within port environments.

6. **Enhance the collaboration with Equipment Manufacturers and ensure design neutrality**. In port environments, optimizing logistics processes requires strategic equipment placements on infrastructure, such as cameras on top of cranes, to facilitate AI services without altering the crane design and manufacturer specifications. Additionally, challenges regarding equipment ownership could hinder immediate installation, impacting the ability to repair and maintain installations. Therefore, proactive engagement with equipment manufacturers is essential to develop camera placement solutions that seamlessly align with AI service requirements, preserving the original design and intended functionality of infrastructure and vehicles (e.g., cranes and trucks). These solutions should prioritize neutrality, adaptability, and non-intrusiveness to maintain the structural integrity and intended purpose of the equipment.

7. **Create a centralized knowledge repository that consolidates 5G-related references:** the creation of a knowledge base that consolidates 5G-related references like research papers, case studies, and best practices specifically relevant to ports and hinterland areas is recommended. This repository will serve as a valuable resource for stakeholders seeking guidance in their 5G deployment journey.

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