FORWARD LOOKING USE CASES, THEIR REQUIREMENTS AND KPIS/KVIS

Deliverable D1.1

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6GSNS

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SHORT ABSTRACT	This deliverable contains a uniform description of the use cases that are to be implemented and applied within the scope of TARGET-X. The benefits that are to be achieved through application of the use cases are collected and utilized determine the value proposition of the use cases. Furthermore, the deliverable contains the draft of a Methodological Assessment Framework (MAF) which employs Key Performance Indicators (KPI) and Key Value Indicators (KPI) to quantify the value proposition of the use cases from a technical, an economic and a societal perspective.

KEY WORDS	Manufacturing, Energy, Automotive, Construction, Economical and Societal Evaluation
CONTRIBUTOR(S)	Maximilian Brochhaus (Fraunhofer IPT) Manuel Pitz (RWTH-ACS), Benish Khan (RWTH-ACS) Pierre Kehl (Fraunhofer IPT) Mahdi Darroudi (Neutroon) Lucas Manassés Pinheiro de Souza (RWTH-WZL) Marit Zöcklein (CCR) Victoria Jung (CCR)

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Executive Summary

Within the research project TARGET-X, innovative beyond 5G use cases will be implemented and applied on large scale trial sites in the verticals manufacturing, robotics, energy, automotive, and construction. One of the main barriers for adoption of 5G/6G is the lack of clarity about the benefits that can be enabled using the technology. Even though, it can already be demonstrated selectively, that certain benefits in automation or process optimization can be achieved, a precise approach that is applicable across different domains is currently missing. Therefore, the conceptualization of a methodological assessment framework which enables a uniform assessment of the added value of 5G use cases in the project's verticals is one of the objectives of TARGET-X.

The deliverable at hand describes the 5G use cases and the requirements of each vertical of the research project. It also includes a description of the first draft of the methodological assessment framework as well as preliminary sets of key performance indicators (KPI) and key value indicators (KVI) that will be employed to quantify the benefits that can be achieved through implementation and application of the use cases.

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List of Acronyms and Abbreviations

ACRONYM/ABBREVIATION	EXPLANATION
6G-IA	6G Smart Networks and Services Industry Association
AI	Artificial Intelligence
CAM	Cooperative Awareness Message
CAV	Connected and Autonomous Vehicle
CPM	Collective Perception Message
CV	Connected Vehicles
CWS	Collison Warning System
DENM	Decentralized Environmental Notification Message
DETNET	Deterministic Network
E2E	End-to-End
GNSS	Global Navigation Satellite System
GUI	Graphical User Interface
HMI	Human Machine Interface
KPI	Key Performance Indicator
KVI	Key Value Indicator
LCA	Life Cycle Assessment
MAF	Methodological Assessment Framework
ML	Machine Learning
NTP	Network Time Protocol
OEE	Overall Equipment Efficiency
OPEX	Operational Expenditures
OSI	Open Systems Interconnections

PLC	Programmable Logic Controller
PQOS	Predictive Quality of Service
PTP	Precision Time Protocol
QOS	Quality of Service
ROS	Robot Operating System
TOV	Tele-operated Vehicle
TRL	Technology Readiness Level
TSN	Time-Sensitive Networking
UE	User Equipment
URLLC	Ultra Reliable and Low Latency Communication

1 Introduction

TARGET-X is an interdisciplinary research project that aims at contributing to the acceleration of the digital transformation of the verticals manufacturing, energy, automotive, and construction using 5G. As communication, networking, and data transmission play a decisive role in shaping the digital transformation successfully, 5G-based communication can be considered as one of the key enablers of successful end-to-end digitalization that adds value and contributes to progress. The key objectives of TARGET-X are to explore which features of 5G-technology need to be developed further on the path to 6G (beyond 5G), install trial sites and prototypes to conduct illustrative and application oriented- research, and develop solutions for a quick ramp up of 5G-based use cases for a low-cost- integration of 5G into existing as well as new processes. In this way, TARGET-X will provide insights into the necessary further development of 5G-technology that can be utilized for the development of 6G. The installation of the trial sites will contribute to the strengthening of the leading role of European industry and research in the realm of mobile communication, enabling technological sovereignty and independence from non-European technology providers.

The deliverable at hand is an outcome of the first work package ("Methodological Assessment Framework") of the research project which focuses on the exchange of ideas and learnings across the individual verticals preventing the research to be carried out in silos. Work packages two, three, four, and five each are dedicated to one specific vertical while work package six focuses on the technology evolution beyond the current state of the art of 5G-technology. Figure 1-1 illustrates the cross vertical- interaction of the individual work packages of TARGET-X.

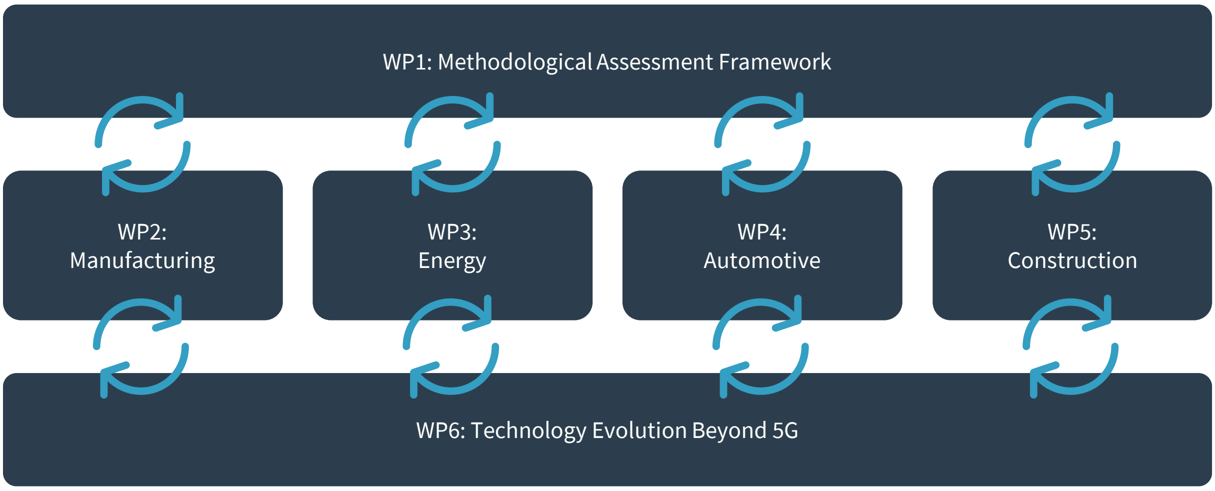

Figure 1-1: Cross-vertical interaction in TARGET-X

1.1 Objective of the document

In order to create a comprehensive and holistic description of all TARGET-X use cases, the deliverable at hand contains a detailed description of the use cases that will be implemented and applied in each vertical. For each use case, different requirements are listed that must be fulfilled for a successful application of the use case. In addition, a first version of a methodological assessment framework (MAF) is drafted aiming at a uniform assessment of the value proposition of each use case. The value proposition is assessed from two perspectives. On the one hand, technical and economic factors are evaluated. On the other hand, societal value that is achieved through implementation and application of the use cases is evaluated. Societal values, for example, include improvements of sustainability aspects. The evaluation from the technical and economic perspective is carried out by using key performance indicators (KPI) and the evaluation from the societal perspective is carried out by using key value indicators (KVI).

1.2 Trials sites and testbeds

Within TARGET-X, a total of five trial sites will be utilized to test, validate, and demonstrate the work carried out in the project. In the following section, each trial site will be described briefly. For a more detailed description of each individual trial site, please refer to the individual deliverables of the other work packages of TARGET-X.

The first trial site is located on the shopfloor of the Fraunhofer Institute of Production Technology IPT in Aachen, Germany. This trial site focusses on the implementation and application of manufacturing use cases. The trial site is described in detail in Deliverable 2.1 of TARGET-X [1].

The second trial site is located at the line-less mobile assembly laboratory at WZL of RWTH Aachen University in Aachen, Germany. This trial site focusses on the implementation and application of robotics use cases. The trial site is described in detail in Deliverable 2.2 of TARGET-X [2].

The third trial site is located on the Melaten Campus in Aachen, Germany belonging to RWTH Aachen University. This trial site focusses on the implementation and application of energy monitoring use cases and it is described in detail in Deliverable 3.1 of TARGET-X [3].

The fourth trial site is located at the IDIADA connected -vehicle hub in Santa Oliva, Spain. The focus of the activities carried out in this trial site are the implementation and application of the automotive use cases. The trial site is described in more detail in Deliverable 4.1 of TARGET-X [4].

The fifth trial site is located at the Reference Construction Site at Campus Melaten in Aachen, Germany. This trial site is dedicated to the implementation and application of the construction use cases and it is described in more detail in Deliverable 5.1 of TARGETX [5].

1.3 Structure of the document

The deliverable at hand is structured in the following way. After the introduction was given in the first chapter, the individual use cases of each vertical are explained in chapter 2. Each explanation starts with a general description of the use case also containing an illustration of the system architecture on which the use case is based. After the general description of the use case, the benefits that are to be achieved through implementation and application of the use case are described. These benefits represent the value proposition of the use case which is employed later for the assessment of the use cases. Next, the technical requirements of the use cases are described. For this purpose, functional, performance, and complimentary requirements are listed, characterizing each use case from a network requirements perspective. The complementary requirements supplement the performance requirements with further details, such as the message sizes or an estimate of the UEs involved, while the performance requirements define the basic properties of the network. After the use case descriptions, chapter 3 contains the elaboration on the KPI/KVI-based MAF. The chapter starts with a presentation of the first draft of the MAF and an explanation of the basic principle behind it. Afterwards, overarching technical and economic goals are derived from the benefits of each use case. After the derivation of the technical and economic goals, KPI for measuring the degree of fulfillment of the goals are determined. The same procedure is then repeated for the definition of societal goals. For the measurement of the fulfillment of these goals, KVIs are determined. Finally, chapter 4 summarizes the content of the deliverable. In addition, a critical reflection as well as an outlook on the next steps in the second year of TARGET-X are given.

1.4 Terms and definitions

Various functional network requirements were defined for recording the requirements of the individual use cases. These are described in Table 1. The listed requirements are used to describe the use cases and their respective requirements in chapter 2. The functional requirements were defined based on the requirements formulated in [6].

Table 1: Network Requirement Explanation

Network Requirement	Explanation
Network configuration management	Requirement for monitoring and managing the system that is provisioned for the 5G trials. This is essential to allow, e.g., specifying application service properties such as QoS demands, collecting network-related performance metrics and deploying software in the Edge cloud by authorized applications.
Fault management	Requirement to supervise the network and display and track alarms efficiently, allowing users to manage network problems quickly and effectively
Mobility management support	Requirement for end devices, such as a mobile robot platform, with the mobility demands that fit to the limited-size space of a factory
Security management	Requirement for communication services to guarantee their confidentiality and data integrity, while providing privacy of both robotics-related end devices and applications.
End-to-end (E2E) QoS support	Requirement for communication services with Quality of Service demands in terms of latency, reliability and/or average throughput, covering all required segments of the 5G system (e.g., access and core networks)
Deterministic latency	Requirement for having the possibility to react on critical events detected, such as resonant vibration of the workpiece
Energy efficiency support	Requirement for user equipment with a limited battery capacity which indicates the necessity to consume energy optimally. Therefore, the 5G system shall minimize energy consumption with respect to communication
Localization services	Requirement for tracing workpieces or workpieces on pallets on the shop floor and inside machines. Localization ideally operates independently from the UE type

2 Use Cases of TARGET-X Verticals

In this chapter, the different use cases from the TARGET-X verticals are described in detail. For each use case there is an assignment to one or more of the use cases classes closed-loop control, monitoring, or analytics. The use case classes have been defined according to [14] and will be expanded as the project progresses. Afterwards, a general description is given outlining the overall concept of the use case and its objective. Next, the expected benefits by implementation of the use case are addressed. The benefits are described from two perspectives enabling an evaluation of the added value through implementation of a use case from two different points of view. The first perspective is the technical and economic perspective which takes the technical and the economic benefits of use case into consideration. These benefits can be expressed with KPI. The second perspective for benefit evaluation is the societal perspective. With this perspective, additional benefits of the application of a use case that do not directly address technical or economic goals can be evaluated. The societal benefits for instance include sustainability related aspects or aspects of digital inclusion. The societal benefits will be expressed with KVI according to [8]. It should be mentioned at this point that the use cases are evaluated from the perspective of the users of these use cases. Accordingly, the key figures used (KPI and KVI) do not describe the performance of the 5G network, but rather the performance of the use cases in the respective verticals.

2.1 Manufacturing

The manufacturing vertical of TARGET-X is divided into the two application domains 5G for cloud native production and 5G for mobile robotics. Within this vertical, novel approaches to employ 5G for the realization of critical inline quality assurance monitoring scenarios, environmental condition monitoring, tracking of devices in manufacturing processes, and remote control of mobile robots are developed to exploit and test the potentials that 5G offers. In the following, the individual use cases of the manufacturing vertical are described in detail.

2.1.1 Use Case 1: Inline Quality Assurance for Machining

2.1.1.1 Description

The thematic focus of this use case is on closed-loop control. For implementation of the use case, the programmable logic controller (PLC) of a milling machine is connected to a remote station for condition monitoring. The milling process that the machine is used for is monitored by different sensors that acquire data on the workpiece, work tool as well as from the machine control. In this way, an inline quality control system is established to continuously check if important process parameters are within the specified and required tolerances. The connection from the PLC located at the shopfloor to the remote station is created via 5G. The exact way the connection is realized has not yet been determined, for example a realization with class B CC-Link IE TSN is possible. For implementation of the use case, three consecutive steps are to be conducted. At first, the communication pipeline is set up in the uRLLC testbed, which is described in more detail in [1], using the technical setup described above. In the next step, first test runs are conducted to test the achievable performance of the system. After conduction of the test runs and evaluation of the results, the connection from the machine integrated PLC to the remote station used to enable the remote condition monitoring application is evaluated. Figure 2-1 shows the systematic architecture of the described use case. The use case is described in more detail in [1].

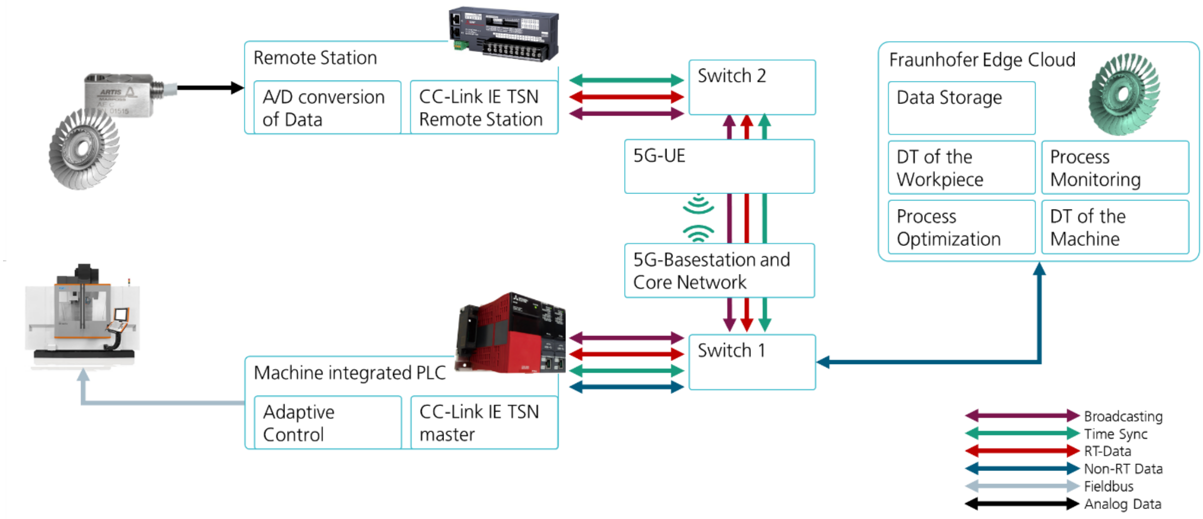

Figure 2-1: System Architecture Diagram for the Inline Quality Assurance for Machining Use Case [1]

As shown in Figure 2-1, a direct connection between the machine integrated PLC, a remote station and an edge cloud is created by employing TSN-switches that are connected via 5G. For the use case realization, additional software is required for the orchestration of the involved communication participants.

2.1.1.2 Benefits of the Use Case

From a technical and economical perspective, the direct communication between the machine integrated PLC to the remote station for condition monitoring offers the benefit, that increased insights into the process are gathered and underlying mechanism of the process can be understood more deeply. This enables the identification of optimization approaches to increase the overall process efficiency, reduce tool wear, and save material. The implementation of the optimization approaches will also result in reduction of the costs, enabling a reduction of OpEx for the use case.

From a societal perspective primarily sustainability aspects are relevant for the use case at hand. The increased process efficiency, reduced tool wear and material savings will not only reduce operational costs but also contribute to the improvement of the ecological footprint of the process. The databased process insights offer a valuable foundation of process and product data that can be employed to calculate the ecological footprint of both the process itself and the produced product. In this way, transparency can be created using e.g., the LCA method to conduct life cycle assessments, utilizing the acquired data as input for the calculation of the ecological footprint, so that the gained information can be employed as a starting point for further optimizations with regard to the ecological footprint.

2.1.1.3 Technical Requirements

For the implementation of the use case, four functional requirements must be met. Firstly, end-to-end (E2E) quality of service is required to ensure the prioritization of data packets that are critical for the functionality of the use case. For this use case, the measurement data is critical as the employed fieldbus protocol requires a guaranteed latency of ≤ 1 ms (see Table 2). The second functional requirement is a scheduled traffic using TSN or Deterministic Networking (DetNet) enabling the transmission of measurement data and control commands between the PLC and the edge cloud with precise timing and deterministic latency. The third functional requirement is layer

2 bridging. This requirement addresses layer 2 of the Open Systems Interconnection (OSI) model which is also called the data link layer [9]. Layer 2 bridging will enable the direct data exchange between devices on the data link layer which is not yet supported by 5G since 5G communication operates at layer 3. The objective for enabling layer 2 bridging is to contribute to reaching the required latencies for the use case through deterministic communication. The fourth functional requirement is the accurate time synchronization through use of precision time protocol (PTP). In this way, a precise alignment of clocks involved in the communication is targeted. As the described functional requirements do not yet correspond to the state of the art and surpass it in some points, research will be carried out in the manufacturing vertical to test, how these requirements can be fulfilled.

Next to the functional requirements, concrete network requirements for the Inline Quality Assurance for Machining use case, have been defined which are described in the following section. The performance requirements of the use case are shown in Table 2.

Table 2: Performance Requirements of the Inline Quality Assurance for Machining Use Case

DATA FLOW	AVERAGE DATA RATES	LATENCY	AVAILABILITY
MEASUREMENT DATA	< 1 Gbit/s	≤ 1 ms	99.999 %
CONFIGURATION DATA	< 1 Gbit/s	N/A	99.99 %

Table 3 shows the complimentary requirements of the described use case.

Table 3: Complimentary Requirements of the Inline Quality Assurance for Machining Use Case

DATA FLOW	MESSAGE SIZE	TRANSFER INTERVAL	UE VELOCITY	#UE	SERVICE AREA	COMMUNICATION ATTRIBUTES
MEASUREMENT DATA	908 B	7 ms	Mobile	1 – x	50 m^2	Periodic
CONFIGURATION DATA	512 B	Aperiodic	Mobile	1	50 m^2	Asymmetrical

2.1.2 Use Case 2: Environmental Condition Monitoring

2.1.2.1 Description

The thematic focus of this use case is on monitoring and analytics. A mobile data acquisition device is integrated into a milling machine and is directly connected to a variety of sensors that measure selected parameters directly in the milling process. In this way, monitoring of both the condition of the milling machine as well as the consumption of resources (electrical power, air flow from compressors, and cooling fluid) is achieved. The measurement data is transferred via 5G to a cloud system hosting different applications like condition monitoring, process control, or a digital twin of the milling machine. The applications hosted in the cloud are employed to monitor the ecological footprint of the milling process as well as the overall condition of the milling machine.

For implementation of the process, the following steps need to be taken. First, the environmental factors that are to be monitored need to be determined. This is done by analysis of the resources consumed by the execution of the milling process (electrical power and consumables such as coolant lubricant and compressed air). After the environmental factors for monitoring are determined, the sensor platform for measurement of the required data is configured to enable data acquisition immediately from the milling process. In addition to the sensors and energy meters which can be integrated in the machine control are developed. In the following steps, the sensor platform containing the sensors and energy meters is integrated into the milling process and connected to a 5G network via an integrated 5G modem. In this way, a direct connection between the milling process and a connected cloud system hosting a variety of monitoring and analytics applications is established. In the final step, a graphical user interface (GUI) is developed to enable the visualization of the measured and analyzed data. Visualization can for example be realized with a dashboard displaying the most important data points for monitoring of the ecological footprint of the milling process as well as the overall condition of the milling machine. Figure 2-2 shows the systematic architecture of the described use case. The use case is described in more detail in [1].

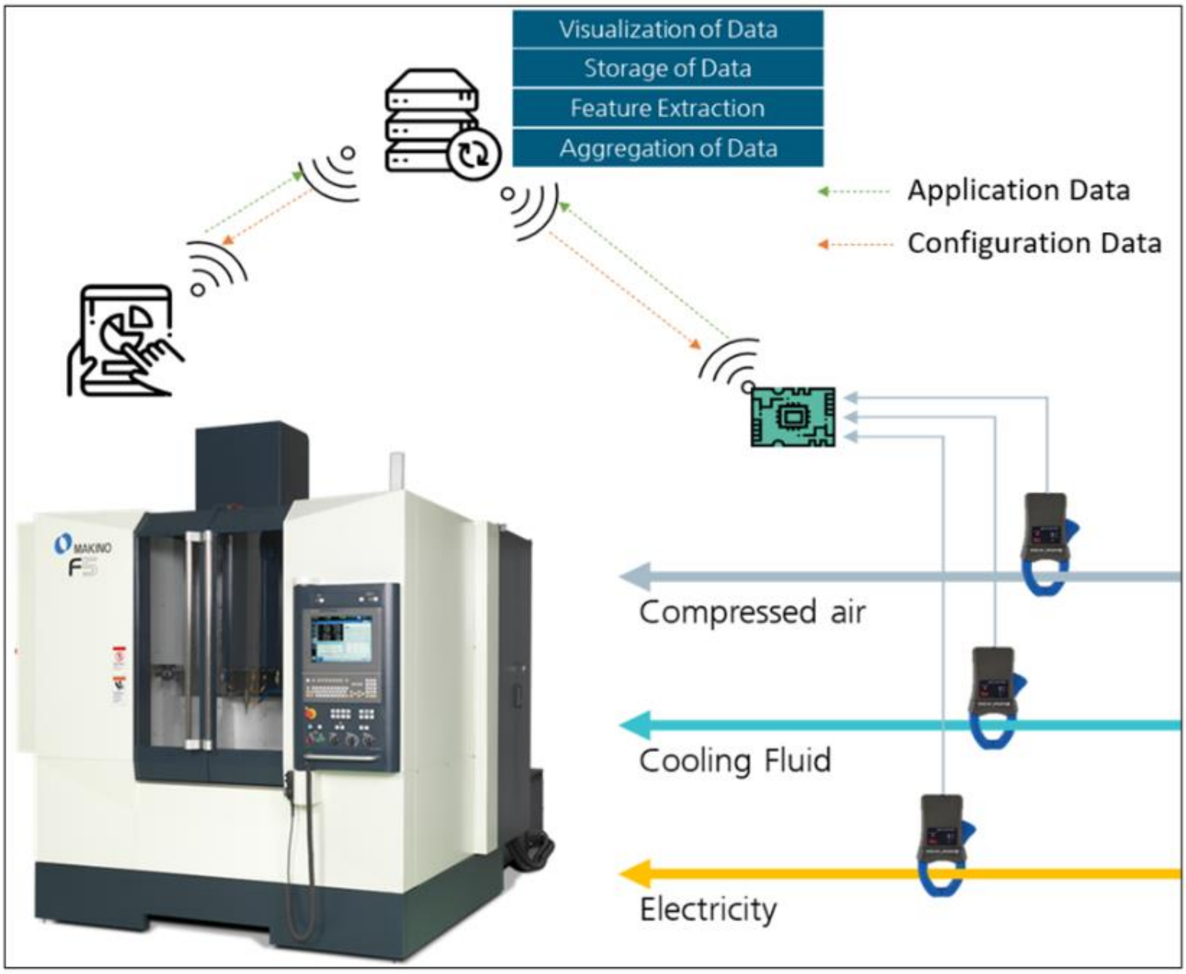

Figure 2-2: Systematic Architecture Diagram of the Environmental Condition Monitoring Use Case [1]

The above architecture shows the various environmental conditions that needs to be monitored using sensor platform using 5G. For the machine, the parameters such as compressed air flow, cooling fluid rate and consumed electricity are important and needs to be monitored along with the condition of the machine, in this case, the vibration observer and temperature in the operation area.

All these information is collected by the wireless sensor platform and sent to the cloud, where the information is aggregated, analyzed, and stored for applications such as condition monitoring, digital twin, etc.

2.1.2.2 Benefits of the Use Case

From a technical and economical perspective, monitoring of environmental impacts is beneficial as it provides additional insights into the milling process and helps to identify optimization potential to make the process more resource efficient. The additional insights can be used to enrich the digital twin of the milling machine with additional information and thus learn more about influencing factors that have an impact on the process outcomes. In this way, the overall process and product quality can be increased significantly.

From a societal perspective, the focus is primarily on sustainability aspects. Monitoring of environmental impacts is the first step for reduction of these impacts. The insights into the distribution of environmental impacts provide a basis for decision making on how to reduce the environmental impacts while at the same time maintaining the desired process and product quality. In this way, monitoring of the environmental impacts of the milling process provides the foundation for the reduction of the ecological footprint of the milling process.

2.1.2.3 Technical Requirements

For the implementation of the use case, two functional requirements must be met. First, an end-to-end QoS support is needed to guarantee the fulfillment of the performance and complimentary requirements defined in Table 4 and Table 5. Second, energy efficiency support is required since the sensor platform is powered by an integrated battery with a limited capacity. For this reason, the available energy from the battery needs to be consumed optimally which indicates the necessity for all communication through the 5G network to be conducted as energy efficient as possible. The technical network requirements for implementation of the Environmental Condition Monitoring use case are described in the following tables.

Table 4: Performance Requirements of the Environmental Condition Monitoring Use Case

DATA FLOW	AVERAGE DATA RATES	LATENCY	AVAILABILITY
MEASUREMENT DATA	< 500 Kbit/s	10 - 20 ms	99.999 %
CONFIGURATION DATA	< 1Kbit/s	N/A	99.999 %

Table 5 shows the complimentary requirements of the described use case.

Table 5: Complimentary Requirements of the Environmental Condition Monitoring Use Case

DATA FLOW	MESSAGE SIZE	TRANSFER INTERVAL	UE VELOCITY	#UE	SERVICE AREA	COMMUNICATION ATTRIBUTES
MEASUREMENT DATA	512 B	100 ms - 1 s	Static	1	1 m^2	Periodic
CONFIGURATION DATA	512 B	Aperiodic	Static	1	1 m^2	Asymmetrical

2.1.3 Use Case 3: Trace and Tracking of Workpieces

2.1.3.1 Description

The thematic focuses of this use case are on monitoring, and analytics. The objective of the use case is to integrate a multi-sensor platform into a milling machine enabling the tracking and tracing of a workpiece over the entire manufacturing process. In this way, the condition of the workpiece can be tracked and analyzed continuously enriching a digital twin of the workpiece with additional information from the process it was manufactured with. Information which are gathered here include vibration of the workpiece during milling, processing temperature, environmental conditions like humidity and pressure, as well as the motion the workpiece was exposed to. This approach allows to analyze the conditions of the workpiece over the entire manufacturing process, providing valuable information for later stages of the product lifecycle.

For implementation of the use case, the following steps need to be taken. At first, the parameters affecting the workpiece condition significantly need to be identified. Based on this, the necessary sensors that are needed for measurement of these parameters can be determined. Second, an energy efficient multi-sensor platform is developed and integrated into the process. The multi-sensor platform is also equipped with a 5G modem for connection to a 5G network. The multi-sensor platform contains sensors that enable both, inline condition monitoring of the workpiece as well as tracking and tracing of the workpiece. In this way, tracking of both the workpiece's current location during manufacturing as well as of the chronological sequence of the individual manufacturing steps can be carried out. In a third step, a connection between the multi-sensor platform and a cloud service is established- to log the measured data into a database and analyze it subsequently to gather more insight into the milling process and particularly the current as well as past conditions of the milled workpiece. Figure 2-3 shows the systematic architecture of the described use case.

Figure 2-3: Systematic Architecture Diagram of the Track and Tracing of Workpieces Use Case [1]

2.1.3.2 Benefits of the Use Case

From a technical and economical perspective, the use case provides valuable insights into the manufacturing process and helps to create a database containing information on a large amount of machined workpieces. This creates reference points for a multitude of optimization possibilities as the path a workpiece took through manufacturing as well as the conditions it was exposed to combined with the final product quality help to identify unknown relations between process parameters and process results. Furthermore, the use case also enables traceability of a large number of machined workpieces, which plays an important role in the event of complaints or subsequently discovered product defects. The created traceability makes it possible to determine which workpiece was processed at which location on which machine and at what time. This is a decisive advantage, particularly in the case of product recalls enabling both time and financial benefits.

From a societal perspective, the use case allows for more precise and at the same time less costly calculations of the ecological footprint of a milled workpiece. The gathered information can be used as input for the calculation of the workpiece's ecological footprint using the life cycle assessment (LCA) method. As a lack of data from production processes is one of the bottlenecks that stand in the way of precise ecological footprint calculations, the use case will provide a solution approach to enhance the database for ecological footprint calculations over the entire product lifecycle. Additionally, the gathered insights can also be used to optimize the milling process further by identifying emission hotspots and reducing the amount of rework required to achieve the desired product quality in high quantities.

2.1.3.3 Technical Requirements

Regarding end-to-end QoS support and energy efficiency support, the functional requirements for implementation of the use case match with those of the Environmental Condition Monitoring use case described in chapter 2.1.2. In addition to that, the applicability of localization services is another functional requirement for implementation of the Track and Tracing of Workpieces use case as the estimation of the location of the workpiece is required for both the tracking as well as the tracing of the workpiece. The technical network requirements for the implementation and application of the use case are described in Table 6 and Table 7.

Table 6: Performance Requirements of the Track and Tracing of Workpieces Use Case

DATA FLOW	AVERAGE DATA RATES	LATENCY	AVAILABILITY
MEASUREMENT DATA	> 1 - 2 Mbit/s	< 5 ms	99.9999 %
CONFIGURATION DATA	< 500 Kbit/s	N/A	99.9999 %

Table 7 shows the complimentary requirements of the described use case.

Table 7: Complimentary Requirements of the Track and Tracing of Workpieces Use Case

DATA FLOW	MESSAGE SIZE	TRANSFER INTERVAL	UE VELOCITY	#UE	SERVICE AREA	COMMUNICATION ATTRIBUTES
MEASUREMENT DATA	1500 B	5 ms	> 0.5 m/s	1	1 m^2	Periodic
CONFIGURATION DATA	1024 B	Aperiodic	> 0.5 m/s	1	1 m^2	Asymmetrical

2.2 Robotics

The edge robotics use case showcases the combination of 5G, mobile manipulators, transfer learning, and machine vision for automated tasks such as bin-picking. Real-time decision-making, motion planning and control, and effective communication are key points considered in the use case. The use case is described in more detail in [2].

2.2.1 Use Case 1: Edge-Controlled Automation with Mobile Manipulation

2.2.1.1 Description

The use case automates industrial tasks such as bin-picking by utilizing cutting-edge technologies like 5G communication, mobile manipulators, transfer learning, and machine vision. The use case emphasizes effective communication with beyond 5G technologies, enhanced motion control, and real-time decision-making. It addresses the use case class of closed loop- control. To ensure the best system efficiency for bin-picking, middleware setups and communication layer performance will be evaluated. In this use case, a mobile manipulator localizes itself, approaches assembly stations, scans, detects, and picks objects, transports them safely, and navigates between assembly stations as part of the automated tasks. A graphic depiction of the procedure can be found in Figure 2-4. The use case is described in further detail in [2]. The term "factory cloud" refers to a local server system located near the assembly stations with cloud capabilities.

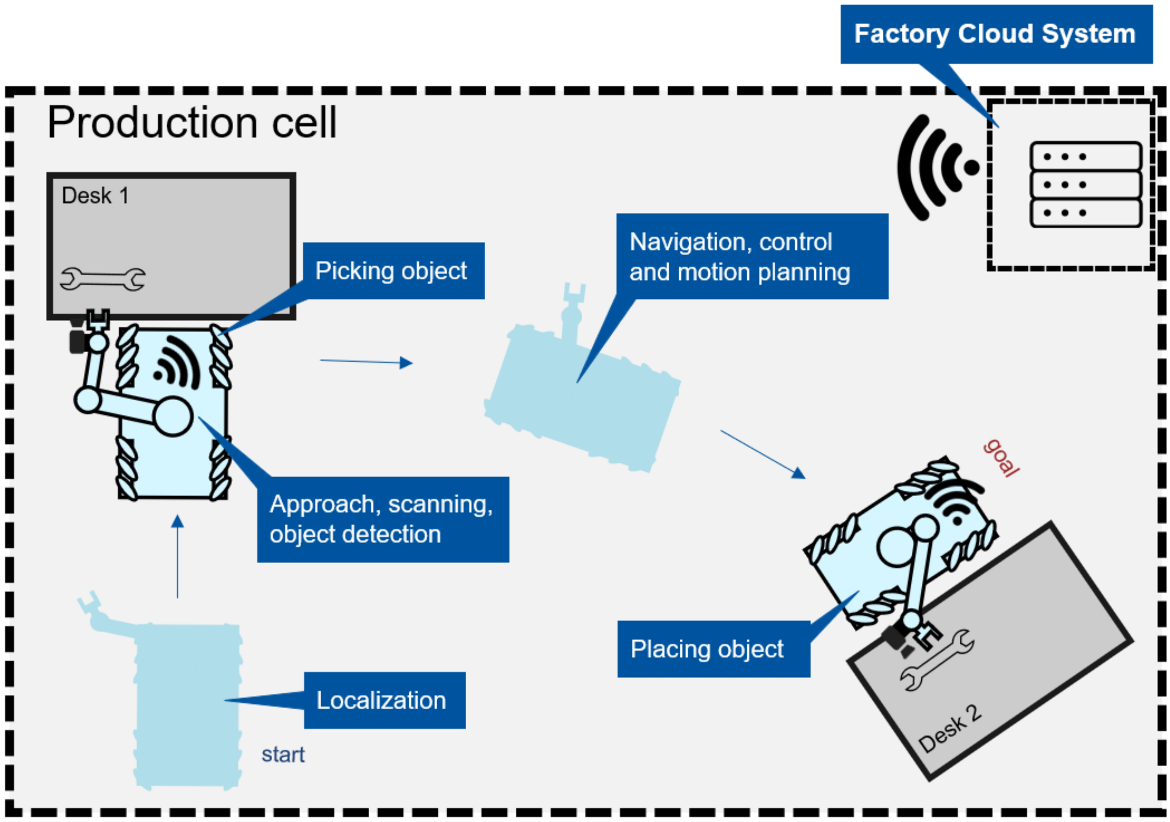

Figure 2-4: Use case description. Adapted from [2].

As shown in Figure 2-5, in this use case, the sensor and camera data are transmitted from the robot to the factory cloud system (uplink), while the control functions of the robot are transferred from the factory cloud system to the robot's onboard system (downlink). The robot controller in the factory cloud determines the path the robot should take and decides how to navigate its environment while taking obstacles into account. The data sent by the mobile robot's sensors via wireless communication (uplink) to the factory cloud system powers intelligence and decision-making in the cloud.

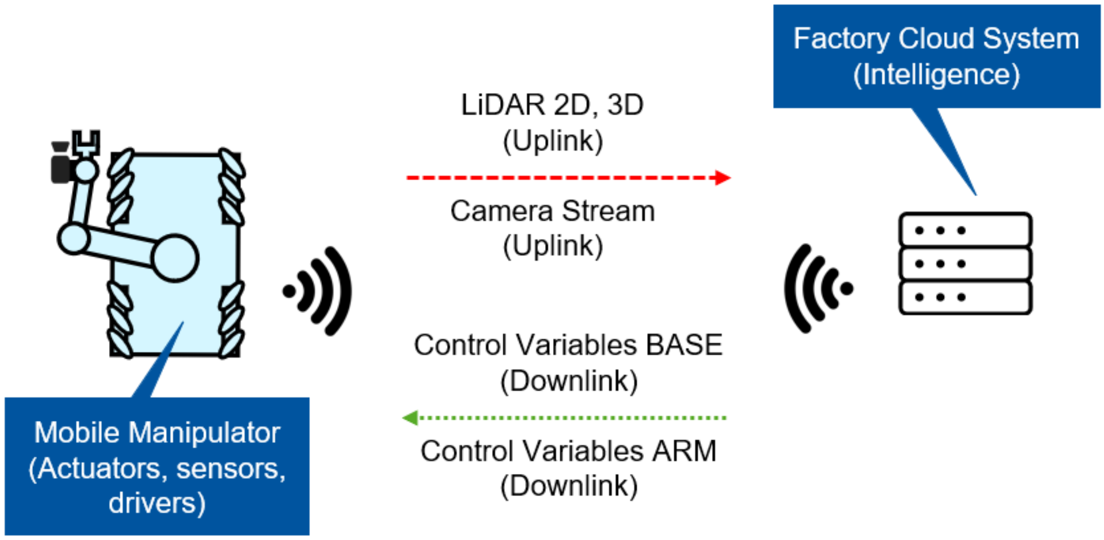

Figure 2-5: Communication Streams (Data Flow) involved in the Use Case [2]

2.2.1.2 Benefits of the Use Case

Benefits from both technical and economic perspectives encompass various aspects. Firstly, there is the advantage of execution time reduction and increased efficiency, where quicker execution not only enhances efficiency but also leads to cost reduction. In this way, competitiveness in the industrial setting is boosted. This is quantifiable through key metrics such as task time, production rates, and energy savings. Additionally, real-time decision-making and communication play a crucial role in improving system performance, facilitating seamless collaboration between robots and the factory cloud through advanced AI/ML techniques. Beyond 5G Technologies contribute to enhanced communication for mobile manipulators, ensuring reliable and rapid data transmission, thereby improving the speed and responsiveness of the robotic system for increased operational efficiency. Lastly, middleware evaluation focuses on optimizing communication, which enhances reliability, reduces data delays, and improves security, with KPIs including transfer speed, uptime, and security measures.

Next to technical and economic benefits, societal benefits can also be achieved through implementation and application of the use case. Firstly, job impact and safety are enhanced as automation not only transforms existing roles but also generates new positions in maintenance, control, and supervision. Robotics, particularly in tasks like bin-picking, contributes to improved safety by handling repetitive and hazardous activities. Secondly, the deployment of cutting-edge technology fosters skills development among workers, cultivating a proficient labor force capable of managing advanced robotic systems. This not only ensures immediate productivity gains but also establishes a foundation for long-term societal benefits. Thirdly, the environmental impact of production processes is positively influenced as efficient robotics reduce energy consumption and optimize resource consumption, aligning with sustainability goals and addressing environmental concerns. Lastly, manufacturing advancements resulting from the implementation of advanced technologies in processes such as bin-picking and pick & place lead to improved capabilities. This includes higher product quality, increased customization options, and enhanced industry competitiveness, ultimately benefiting society by providing superior products and driving economic growth.

2.2.1.3 Technical Requirements

For the implementation and application of the use case, three functional requirements have been defined (see Table 1). Network configuration management is required for monitoring and management of the entire system. Mobility management support is needed to manage the mobile entities such as the mobile manipulator. End-to-end (E2E) QoS support to guarantee the required latencies, throughputs, and network availability. In this way, the fulfilment of the technical network requirements for the Edge Controlled Automation of Industrial Tasks Using Mobile Manipulators use case that are described in the following section shall be enabled. The performance as well as the complimentary requirements of the use case are shown in Table 8 and Table 9.

Table 8: Performance Requirements of the Edge-Controlled Automation of Industrial Tasks Using Mobile Manipulators Use Case

DATA FLOW	AVERAGE DATA RATES	LATENCY	AVAILABILITY
CAMERA	> 17 Mbit/sec	< L_{ARM} (msec)	≥ 99.9 %
LIDAR 2D	> 3 Mbit/sec	< 40 msec	≥ 99.99 %
LIDAR 3D	> 52 Mbit/sec	< 40 msec	≥ 99.99 %
CONTROL VARIABLE: MM BASE	> 3 Mbit/sec	< 40 msec	≥ 99.99 %
CONTROL VARIABLE: MM ARM	> 6 Mbit/sec	L_{ARM} < 11 msec	≥ 99.99 %

Table 9 shows the complimentary requirements of the described use case.

Table 9: Complimentary Requirements of the Edge-Controlled Automation of Industrial Tasks Using Mobile Manipulators Use Case

DATA FLOW	MESSAGE SIZE	TRANSFER INTERVAL	UE VELOCITY	#UE	SERVICE AREA	COMMUNICATION ATTRIBUTES
CAMERA	70 KB	40 ms	< 0.45 m/s	1	20 m^2	Periodic
LIDAR 2D	35 KB	120 ms	< 0.25 m/s	1	20 m^2	Periodic
LIDAR 3D	640 KB	100 ms	< 0.25 m/s	1	20 m^2	Periodic
CONTROL VARIABLE: MM BASE	50 B	50 ms	< 0.25 m/s	1	20 m^2	Periodic
CONTROL VARIABLE: MM ARM	100 B	10 ms	< 0.45 m/s	1	20 m^2	Periodic

2.3 Energy

The main goal of the energy vertical is to enhance energy awareness and monitoring through the utilization of a private 5G network. For the implementation of the use case called "Energy Monitoring and Energy Consumption Awareness", the Institute for Automation of Complex Power Systems (ACS) will deploy devices for voltage and current measurement at the E. ON Energy Research Center (ERC). The communication infrastructure will utilize the local 5G network, test its capabilities, and provide a novel use case for 5G-driven measurement devices. This will increase energy awareness among the partner verticals and provide new insights into the local power grid.

2.3.1 Use Case 1: Energy Monitoring and Energy Consumption Awareness

2.3.1.1 Description

The use case is assigned to the use case classes of monitoring and analytics. The focus of the use case is on deploying voltage, current, phase, and energy measurement devices within the RWTH-ACS buildings. The goal is to increase energy awareness by creating energy transparency and to carry out measurements that enable the assessment of the state of the local grid. For implementation of the use case, three consecutive steps are carried out. In the first step, the measurement device is deployed at selected measurement points. For this purpose, an edge cloud Phasor Measurement Unit (edgePMU) is used. The device was developed in the EU -funded research project edgeFLEX and is employed to execute the measurement campaign in the second step of implementation [9]. In the measurement campaign, measurement data is acquired which is then analysed in the third and final step. The described procedure will enable the creation of a database that provides a foundation for analysis aiming towards energy transparency. Figure 2-6 illustrates the underlying architecture of the Energy Monitoring and Energy Consumption Awareness use case. Additional information regarding the architecture underlying the use case can be found in [13]

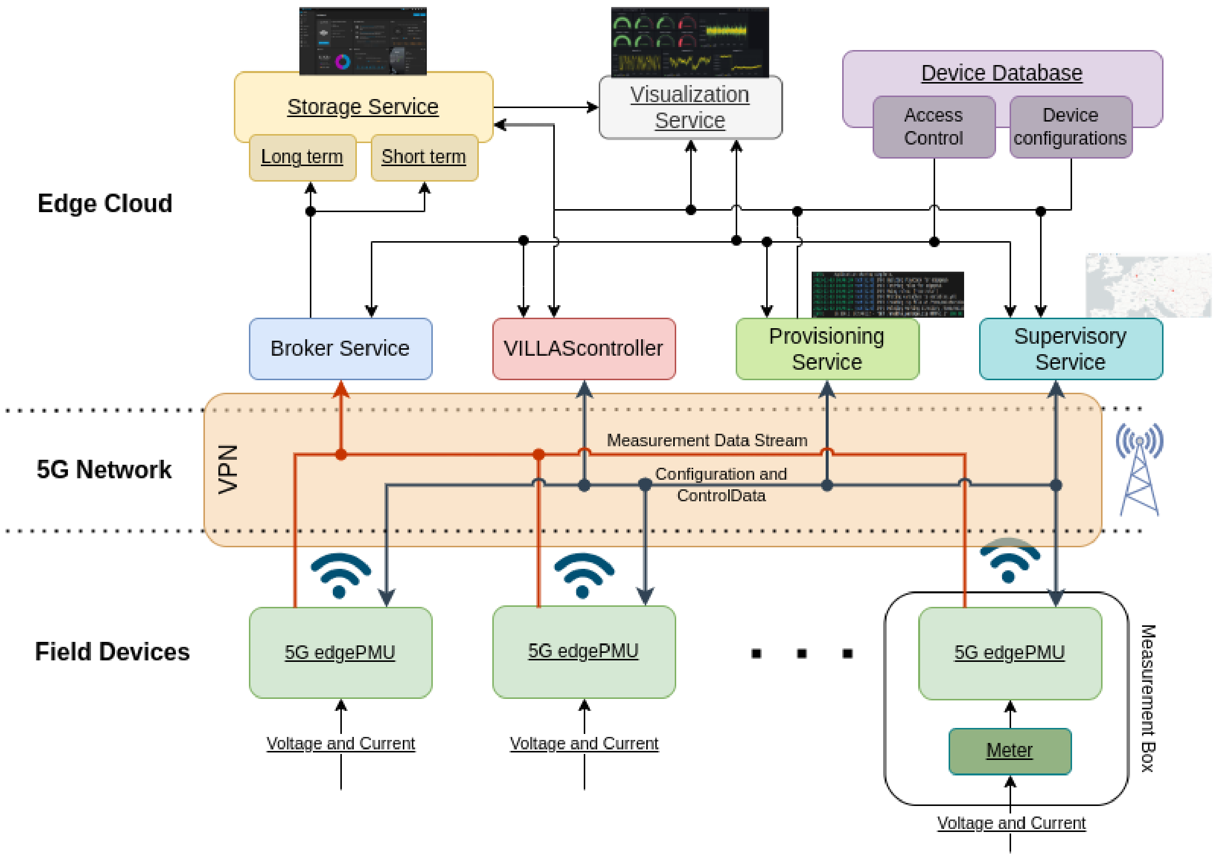

Figure 2-6: System Architecture Diagram Highlighting the Different Data Streams [13]

2.3.1.2 Benefits of the Use Case

The Energy Monitoring and Energy Consumption Awareness use case offers a variety of benefits from both a technical as well as an economical perspective. The ability to monitor energy consumption at different load levels enables a better understanding of the local grid conditions since with a more fine-grained view, a more local energy management is possible, which can reduce stress on higher grid levels and enable optimal use of energy on a local level. This can result in less losses for transmission as well as higher utilization of volatile energy sources by not having to shut them down in case of higher-level congestion. In addition, the more precise insights into the energy consumption also allow the identification and characterization of different energy consumers. In this way, novel insights can be gathered into the specific energy consumption of e.g., server clusters and real time simulators. The results gathered from this can be used to learn more about individual consumers and help identify energy inefficiencies and wastage. Based on this, optimization strategies aiming at the reduction of energy consumption can be derived. In this way, the potential for cost savings focusing on the decrease in operating costs is determined. In addition to the reduction of operating costs, cost reductions can be achieved when purchasing energy if energy consumption is planned more accurately, as this makes it possible to purchase energy at the standard prices.

From a societal perspective, the implementation of the Energy Monitoring and Energy Consumption Awareness will contribute to an increased energy awareness for individuals as transparency created by measuring energy consumption is the first step towards increasing awareness of actual energy consumption in comparison to the theoretical one.

2.3.1.3 Technical Requirements

The functional requirement for the implementation and application of the Energy Monitoring and Energy Consumption use case is the end-to-end QoS support which is supposed to enable the fulfillment of the performance as well as the complimentary requirements of the use case. The performance as well as the complimentary requirements are described in Table 10 and Table 11.

Table 10: Performance Requirements of the Energy Monitoring and Energy Consumption Awareness Use Case

DATA FLOW	AVERAGE DATA RATES	LATENCY	AVAILABILITY
MEASUREMENT DATA	< 80 Mbit/s	< 10 ms	≥ 99.999 %
CONFIGURATION DATA	Low	Not relevant	99.9999 %

Table 11 shows the complimentary requirements of the described use case.

Table 11: Complimentary Requirements of the Energy Monitoring and Energy Consumption Awareness Use Case

DATA FLOW	MESSAGE SIZE	TRANSFER INTERVAL	UE VELOCITY	#UE	SERVICE AREA	COMMUNICATION ATTRIBUTES
MEASUREMENT DATA	> 1 Byte	10 ms	Static	10	<3500 m^2	Periodic
CONFIGURATION DATA	> 1 Byte	On demand	N/A	10	<3500 m^2	Aperiodic

2.4 Automotive

Within the automotive vertical, three use cases will be implemented focusing on the exploitation of the potential offered by 5G to improve dedicated aspects of autonomous driving. These use cases are described in detail in the following section. For the description of the performance and the complimentary requirements, a column labeled 'reliability' is important to ensure acceptable availability of the automotive services that requires high reliability and should be able to detect any network failure. In addition, the label 'availability' was removed as it is implicitly included in the columns for reliability and latency. Additional information regarding the automotive use cases can be found in [4].

2.4.1 Use Case 1: Cooperative Perception

2.4.1.1 Description

This use case can be assigned to the use case classes of closed loop control and monitoring. The overall principle of the use case is the utilization of shared data from a variety of different sensors which are integrated into different vehicles as well as the environment of the road. The use case aims at exploiting the potential that results from merging data from different sources and using it for an enhanced perception of the surroundings of each connected vehicle. Dynamic data is provided by other connected vehicles while static data is provided by sensors that are integrated into the infrastructure providing e.g., data regarding the road layout. In this way, an information sharing and merging mechanism is developed that is called "cooperative perception". The distribution of the information via dedicated messages to the involved parties is realized by a Collison Warning System (CWS).

For the detailed sequential description of the use case, two different scenarios have been defined that are described in a stepwise manner in the following. The first scenario – zero visibility intersection – starts with two vehicles approaching an intersection from different directions without any visibility of each other. One vehicle is a Connected and Autonomous Vehicle (CAV) and the other is an instrumented vehicle (i.e., equipped with 5G router, GNSS antenna, and HMI). In the second step, the CWS detects a possible accident by receiving cooperative awareness messages (CAM) and collective perception messages (CPM) from each vehicle. In the third step, an alarm is sent by the CWS via a decentralized environmental notification message (DENM) from the infrastructure to the CAV. In the fourth step, the CAV receives the DENM (Decentralized Environmental Notification Message) and the message is displayed in the HMI so that preventive measures can be taken by the vehicle driver to avoid a collision of the two vehicles.

In the second scenario – called road damaged vehicle – weather-related restrictions of visibility prevail. In this scenario, a damaged instrumented vehicle has broken down on the side of the road and blocks the path of an incoming CAV. As both vehicles, the one that is broken down as well as the incoming one are connected to the infrastructure, CAM and CPM are exchanged between both vehicles through the CWS sending dedicated DENM. In this way, a possible collision between the broken-down vehicle and the incoming one can be predicted so that the incoming CAV can adjust its trajectory and prevent the collision.

2.4.1.2 Benefits of the Use Case

The use case's basic principle relies on cooperative perception which is achieved by consolidating and distributing data in a targeted manner, so that a situation and context-specific data transmission is enabled. From a technical and economical perspective, this will lead to an improvement of vehicular communication contributing to a more efficient and safe way to operate CAVs.

From a societal perspective, cooperative perception will contribute to the increase of road safety resulting in a reduction of accidents.

2.4.1.3 Technical Requirements

For the implementation and application of the Cooperative Perception use case, five functional requirements have been defined (see Table 1). Fault management is required to enable monitoring of the network and display as well as track alarms, so that network problems and errors can be solved quickly and efficiently. End-to-end (E2E) QoS support to guarantee the required latencies, throughputs, and network availability. Mobility management support is needed to manage the mobile entities such as the connected vehicles. Furthermore, security management and localization services are required to enable the handling of confidential localization data within the use case. The performance requirements of the Cooperative Perception use case are shown in Table 12.

Table 12: Performance Requirements of the Cooperative Perception Use Case

DATA FLOW	AVERAGE DATA RATES	LATENCY	RELIABILITY
MEASUREMENT DATA	10 - 50 Mbit/s	40 - 50 ms	≥ 99.8 %
CONFIGURATION AND NOTIFICATION DATA	0.5 Mbit/s	40 - 50 ms	≥ 99.8 %

Table 13 shows the complimentary requirements of the described use case.

Table 13: Complimentary Requirements of the Cooperative Perception Use Case

DATA FLOW	MESSAGE SIZE	TRANSFER INTERVAL	UE VELOCITY	#UE	SERVICE AREA	COMMUNICATION ATTRIBUTES
MEASUREMENT DATA	< 1KB	40-50 ms	< 40Km/h	2	3.7 km^2	Periodic
CONFIGURATION AND NOTIFICATION DATA	< 1KB	On demand	< 40Km/h	2	3.7 km^2	Aperiodic

2.4.2 Use Case 2: Digital Twin

2.4.2.1 Description

The thematic focuses of this use case are on monitoring and closed-loop control. The objective of the use case is to create digital twins of the environment of neuralgic points of road sections that are also described in use case 2 cooperative reception. The two scenarios described in the cooperative perception use case are used for the digital twin use case as well. The digital twins are created by data acquisition from both scenarios. The first digital twin is a digital representation of the environment of the intersection from the first scenario of the cooperative perception use case. The second digital twin is a digital representation of the section of the road with the broken-down vehicle at the site of the road. Both digital twins can be used as a basis for scenario simulations. In this way, simulations of different scenarios can be carried out for optimization purposes.

2.4.2.2 Benefits of the Use Case

From a technical and economical perspective, the digital twin use case will support the development or refinement of control algorithms used for the determination of driving strategies of automated and connected vehicles. Simulations can be carried out to test and benchmark different parameter sets and simulate their impact on the outcome of the individual scenarios. In this way, the digital twin use case is beneficial for the increase of the level of technical maturity of control algorithms used for automated and connected vehicles.

From a societal perspective, the possibility to carry out scenario simulations will contribute to increased road safety. Learnings from the simulations will have an immediate impact on personal safety in road traffic. In the mid and long term, the digital twin use case will make a significant contribution to increasing general road safety.

2.4.2.3 Technical Requirements

For the Digital Twin use case, the same functional requirements have been defined as for the Cooperative Perception use case (see chapter 2.4.1.3). The network requirements for the Digital Twin use case are described in the following section. The performance requirements of the use case are shown in Table 14.

Table 14: Performance Requirements of the Digital Twin Use Case

DATA FLOW	AVERAGE DATA RATES	LATENCY	RELIABILITY
MEASUREMENT DATA	10 - 50 Mbit/s	Not critical	≥ 99.8 %
CONFIGURATION AND NOTIFICATION DATA	0.5 Mbit/s	Not critical	≥ 99.8 %

Table 15 shows the complimentary requirements of the described use case.

Table 15: Complimentary Requirements of the Digital Twin Use Case

DATA FLOW	MESSAGE SIZE	TRANSFER INTERVAL	UE VELOCITY	#UE	SERVICE AREA	COMMUNICATION ATTRIBUTES
MEASUREMENT DATA	< 1KB	40-50 ms	< 40Km/h	2	3.7 km^2	Periodic
CONFIGURATION DATA	< 1KB	On demand	< 40Km/h	2	3.7 km^2	Aperiodic

2.4.3 Use Case 3: Predictive Quality of Service for Tele-operated Vehicles.

2.4.3.1 Description

The Predictive Quality of Service for Tele-operated Vehicles use case can be assigned to the use case classes of closed-loop control and monitoring. The basic principle of the use case is that the Quality of Service (QoS) of the connection between the tele-operated vehicle (ToV) and the tele-operation center as well as other connected vehicles (CV) is continuously monitored while future potential degradations in QoS are predicted. In this way, alarms can be triggered in case a degradation is predicted so that preventive measures can be taken proactively.

The execution of the use case can be described sequentially in the following way: First, the tele-operated vehicle is driven with acceptable and sufficient Quality of Service on the intended test track. The 5G-based communication of the ToV and another connected vehicle is continuously collected and monitored. Possible degradations in the QoS and resulting deviations from the target corridor for QoS are detected by a predictive QoS module (pQoS). Potential causes for the QoS degradations include cell switches resulting in poorer network coverage. In case a deviation is detected, an alarm is sent by the pQoS to a tele-operation center which then triggers a remote driver to move the ToV to the right lane of the test track and stop it subsequently. The communication streams of this use case are depicted in Figure 2-7.

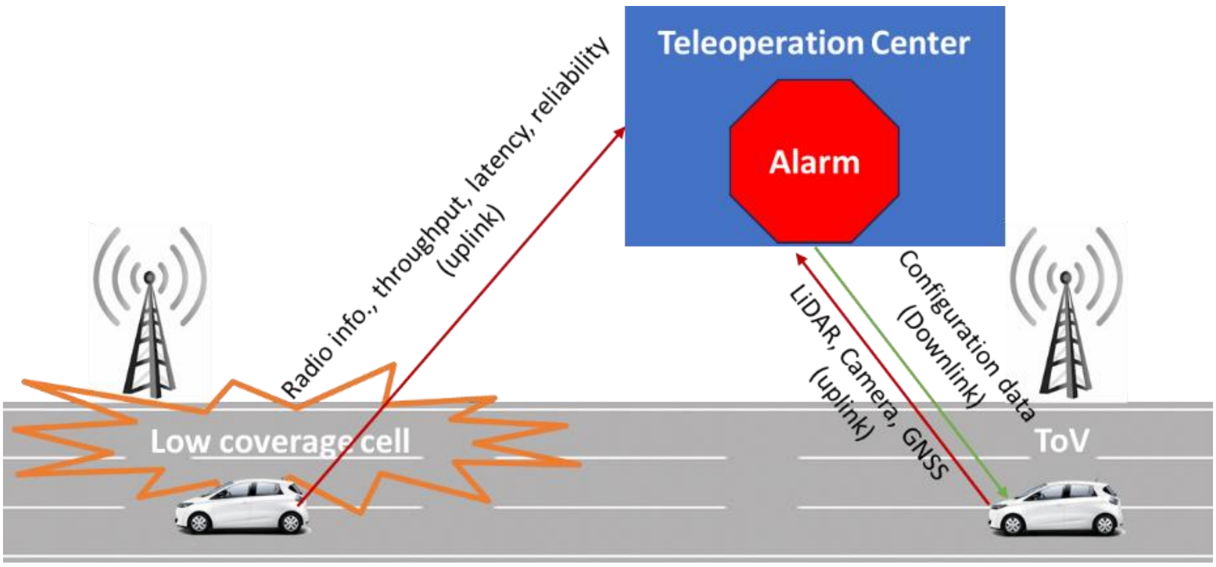

Figure 2-7: Communication Streams (Data Flow) involved in the predictive quality of service for tele-operated vehicles use case [4].

2.4.3.2 Benefits of the Use Case

From a technical and economical perspective, tele-operated driving offers the benefit, that the need for physical presence of human drivers inside the ToV is eliminated. Thus, remote drivers can operate vehicles remotely and switch from one vehicle to another quasi-instantaneously. As a result, taxis can be sent to rural zones where normal taxis cannot go for economic reasons. Tele-operated driving is also beneficial for tele-operated parking, which will make valet parking more efficient, economical, and sustainable specially in dense urban zones. Adding QoS prediction will make tele-operating driving technically feasible in highway with high speed and will reduce fuel consumption as decisions can be taken more efficiently.

From a societal perspective, tele-operated driving with predictive QoS will be beneficial for safety aspects since teleoperation with predictive QoS will increase the overall safety of traffic due to a higher involvement of monitoring and control mechanisms. In addition, by providing tele-operating driving people who used to drive for long distances as part of their job (e.g., truck drivers, touristic bus drivers) or for vacations or business will allow them have time to rest, sleep, finish some work, or even have fun. This will - especially for those who drive as part of their job - reduce health and psychological impacts of long-distance driving.

Furthermore, replacing remote human drivers with AI-based machines will reduce car accidents, increase traffic efficiency by choosing the best paths and practices. This will also reduce the cost of the journeys and carbon emission by optimizing the use of vehicle power and brakes.

2.4.3.3 Technical Requirements

For the Predictive Quality of Service for Tele-Operated Vehicles use case, the same functional requirements have as for the Cooperative Perception use case have been defined (see chapter 2.4.1.3). The network requirements for the Predictive Quality of Service for Tele-Operated Vehicles use case are described in the following section. The performance requirements of the use case are shown in Table 16.

Table 16: Performance Requirements of the Predictive Quality of Service for Tele-Operated Vehicles Use Case

DATA FLOW	AVERAGE DATA RATES	LATENCY	RELIABILITY
MEASUREMENT DATA	10 - 50 Mbit/s	< 100 ms	95 - 99 %
CONFIGURATION DATA	0.5 Mbit/s	20 - 50 ms	99 – 99.9%

Table 17 shows the complimentary requirements of the described use case.

Table 17: Complimentary Requirements of the Track and Tracing of Workpieces Use Case

DATA FLOW	MESSAGE SIZE	TRANSFER INTERVAL	UE VELOCITY	#UE	SERVICE AREA	COMMUNICATION ATTRIBUTES
MEASUREMENT DATA	<10KB	100 ms	80-130 km/h	1	3.7 km^2	Periodic
CONFIGURATION DATA	N/A	on demand	80-130km/h	1	3.7 km^2	Aperiodic

2.5 Construction

Within the construction vertical, two different use cases will be implemented. The first one – 5G for automation of deconstruction processes – focuses on the conversion of a traditional demolition robot into a machine for controlled deconstruction. The second use case – 5G for energy analytics of construction processes – focuses on the monitoring of energy consumption of construction processes. Additional information regarding the construction related use cases can be found in [5].

2.5.1 Use Case 1: 5G for Automation of Deconstruction Processes

2.5.1.1 Use Case Description

The thematic focuses of this use case are closed-loop control and monitoring. The use case objective is to utilize 5Gbased communication to convert a demolition robot into a machine for controlled deconstruction. For this purpose, sequences of a deconstruction process are controlled remotely and partially automated. A 5G-based communication between the robot and a remote operator enables real-time communication and data exchange between the remote operator and the place of operation. Figure 2-8 illustrates the system architecture for the use cases including the individual data streams. The use case can be described sequentially in the following way: Firstly, pathways for the deconstruction robot are derived from a dedicated deconstruction planning which guides the entire deconstruction process. Secondly, the coordinates from these pathways are sent to a processing unit. These coordinates are then employed to define control messages for the robot in the processing unit. Thirdly, the control messages are sent to the robot via the 5G network so that the robot executes the movements accordingly. The robot movements are continuously recorded with a depth camera and a mobile sensor platform. The video signal is then streamed to a remote operator who is monitoring the execution of the deconstruction process from a distance.

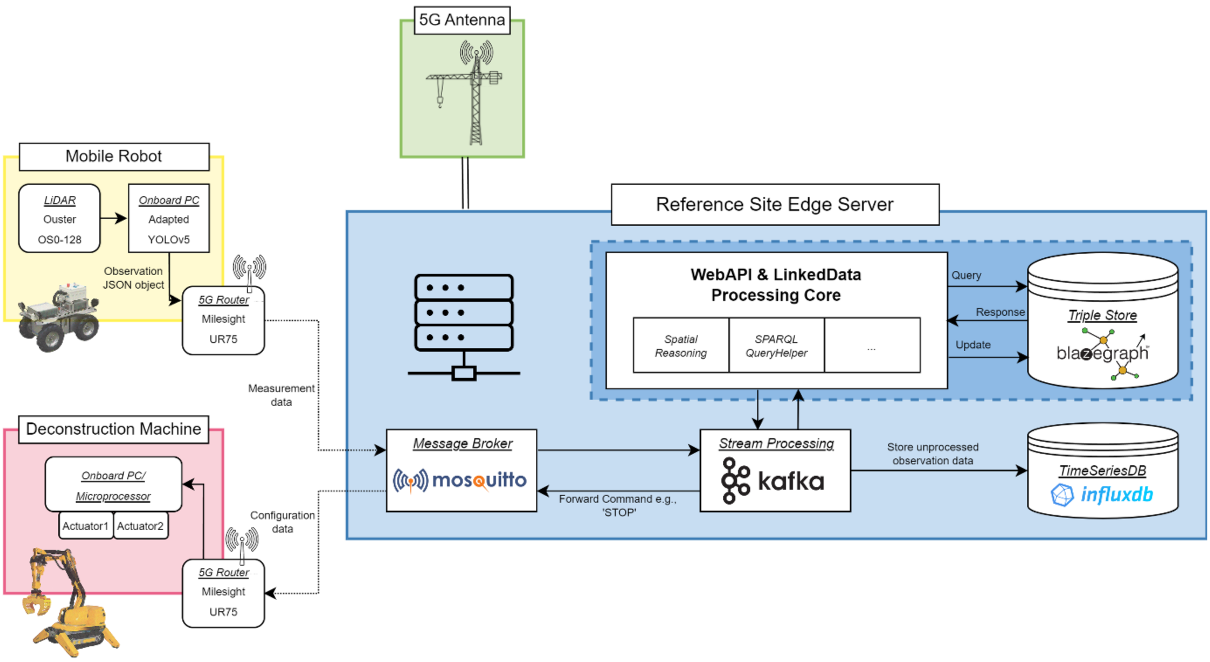

Figure 2-8: System Architecture Diagram Highlighting the Different Data Streams

2.5.1.2 Benefits of the Use Case

From a technical and economical perspective, the implementation of the use case offers two main benefits. Firstly, the deconstruction process becomes safer, as spatial separation of the operator and the potentially dangerous workspace of the deconstruction machine can be achieved since the operator of the deconstruction machine is not working in the direct working space of the machine and operates from a safe distance. Secondly, due to the pre-planning and visual support for the process, deconstruction becomes coordinated and controlled. Remote control offers the elimination of inefficiencies in the process execution as it enables the precise execution of the planned deconstruction tasks, e.g., by reducing the required efforts for dissemble and deconstructing the construction spontaneously. Moreover, the remote control and partially automated deconstruction offer the possibility of operating different machines at the same time which also increases the productivity on site.

From a societal perspective, the implementation of the use case can contribute to a reduction of work accidents caused by close local cooperation with construction machinery. Enabling the removal of site workers from critical and potentially dangerous points of deconstruction operations will have a positive impact on worker safety. In this way, 5G-enabled remote control can potentially increase the overall safety on construction sites. In addition, the physical strain on construction workers can also be reduced.

2.5.1.3 Technical Requirements

For the implementation of the use case, three functional requirements must be met (see Table 1). First, an end-to-end QoS support is needed to guarantee the fulfillment of the performance and complimentary requirements defined in Table 18 and Table 19. Second, deterministic latency is required to enable the reaction on critical events in the process flow. Third, security management is required due to the need of confidentiality and data integrity. The performance requirements of the use case are shown in Table 18. In both tables, Table 18 and Table 19, the measurement data stream refers to the camera stream from the robot camera, while the configuration data stream refers to ROS messages.

Table 18: Performance Requirements of the 5G for the Automation of Deconstruction Processes Use Case

DATA FLOW	AVERAGE DATA RATES	LATENCY	AVAILABILITY
MEASUREMENT DATA	25 Mbit/s	< 10 ms	≥ 99.9999 %
CONFIGURATION DATA	0.2 Mbit/s	< 10 ms	≥ 99.9999 %

Table 19 shows the complimentary requirements of the described use case.

Table 19: Complimentary Requirements of the 5G for the Automation of Deconstruction Processes Use Case

DATA FLOW	MESSAGE SIZE	TRANSFER INTERVAL	UE VELOCITY	#UE	SERVICE AREA	COMMUNICATION ATTRIBUTES
MEASUREMENT DATA	Constant stream	100 ms	< 36 deg/s	1	4000 m^2	Periodic
CONFIGURATION DATA	< 1 MB	Message is sent only once	N/A	1	4000 m^2	Aperiodic

The UE velocity in Table 19 describes the angular velocity of the robot base.

2.5.2 Use Case 2: 5G for Energy Analytics of Construction Processes

2.5.2.1 Use Case Description

The focus point of this use case is analytics. The objective of the use case is to enable a better understanding of the energy consumption of individual construction and deconstruction processes in general and individual consumers on construction sites in detail. Integration of sensors for energy measurements and connection to the 5G-network enables the creation of transparency about the consumption of energy during construction and deconstruction operations. The insights gained from this can be used for an energy-optimized task planning. This use case is closely related to the use case from the energy vertical described in chapter 2.3.

For the implementation of the use case, the following steps need to be taken. In the first step, an edgePMU (see chapter 2.3.1.1 for detailed description), is deployed in the construction machine. The edgePMU is a newly developed phasor measurement unit which is connected to a 5G network enabling seamless measurements of energy consumption [8]. In the next step, data on the energy consumptions of typical construction and deconstruction processes is acquired by measurement with the edgePMU. Afterwards, this data is aggregated to a complete data set which is subsequently analyzed. The analysis results are then used to create energy profiles of the construction and deconstruction processes leading to transparency on the energy consumption of different processes. The compiled energy profiles can then be utilized for optimizations of process orchestrations e.g., by avoiding peak loads which will result in a reduction of costs.

2.5.2.2 Benefits of the Use Case

From a technical and economical perspective, the use case will lead to an optimized energy consumption of machinery involved in construction and deconstruction processes. This will lead to a reduction of costs and thereby make the construction and deconstruction processes more economical.

From a societal perspective, the ecological footprint of the processes is reduced. Less consumption of energy will directly result in a better ecological footprint of the processes. Therefore, the overall CO_2 emissions of construction sites are improved due to a better use of resources.

2.5.2.3 Technical Requirements

For the implementation of the 5G for Energy Analytics of Construction Process use case, two functional requirements must be met (see Table 1). First, an end-to-end QoS support is needed to guarantee the fulfillment of the performance and complimentary requirements defined in Table 20 and Table 21. Second, security management is required due to the need of confidentiality and data integrity. The performance requirements of the use case are shown in Table 20.

Table 20: Performance Requirements of the 5G for Energy Analysis of Construction Processes

DATA FLOW	AVERAGE DATA RATES	LATENCY	AVAILABILITY
MEASUREMENT DATA	< 20 Mbit/s	N/A	N/A
CONFIGURATION DATA	< 1 Mbit/s	Not relevant	Not relevant

Table 21 shows the complimentary requirements of the described use case.

Table 21: Complimentary Requirements of the 5G for Energy Analysis of Construction Processes Use Case

DATA FLOW	MESSAGE SIZE	TRANSFER INTERVAL	UE VELOCITY	#UE	SERVICE AREA	COMMUNICATION ATTRIBUTES
MEASUREMENT DATA	N.A.	100 ms	< 1.5 m/s	1	4000 m^2	Periodic
CONFIGURATION DATA	N.A.	N.A.	< 1.5 m/s	1	4000 m^2	Aperiodic

2.6 Interim Conclusion and Challenges for Implementation

The use case descriptions in chapters 2.1 to 2.5 show the variance and range among the different use cases of the TARGETX project, emphasizing on the interdisciplinarity and the broad spectrum of different technical aspects covered within the project. A total of ten use cases have been described and characterized. The use cases share the common features that on the one hand the executability and controllability of the underlying processes shall be improved. On the other hand, additional data and information from inside the processes shall be gathered in order utilize this information, e.g., for the calculation of the economical footprint of the process or use case. These common features will be used in chapter 3 to determine overarching technical, economic, and societal goals shared by all use cases in order to quantify the value proposition enabled by implementation and application of the use cases.

The combination of the interdisciplinarity of the use cases and the fact that they are still in an early state of research and development, each use case has very individual requirements which at certain point surpass the current state of the art regarding achievable data rates, required latencies, fully deterministic communication, and utilization of the localization feature of 5G. In this regard, achieving the required data rates will pose one of the most difficult technical challenges. The stated average data ranges in the tables for the performance requirements vary significantly between the individual use cases with the range going from < 1 Gbit/s to < 500 Kbit/s. The high data rate use cases pose a challenge for existing 5G networks with real data rates often lying below the required values. Research in this area will lead to valuable insights for the evolution of 5G to 6G and the changing requirement profile of industrial communication.

One common feature shared by all use cases is the relatively early stage of technological maturity resulting in low technology readiness levels (TRL). Most use cases can be assigned to somewhere between TRL 4 and TRL 5, which indicates that unforeseen development issues or barriers can cause potential challenges for implementation and application of the use cases. For instance, the sensor platform of the environmental condition monitoring use case (chapter 2.1.2) is still under development or the technologies for realization of the connection from the shopfloor to the remote station for condition monitoring for the inline quality assurance for machining use case (chapter 2.1.1) still need to be determined. As this was planned to be researched within the project, these challenges were clear from the outset and are being solved by innovative approaches within the scope of this project so that also regarding this aspect new insights can be gained for the evolution from 5G to 6G.

Another challenge faced by the use cases is the aspect of IT security. As data is exchanged by a multitude of involved communication participants in the network, principles for secure, reliable, and trustful data exchange and sharing need to be defined and adhered to. For example, the energy monitoring use case (chapter 2.3.1) touches the topic of critical infrastructure when dealing with the power grid, so that IT security must be highly prioritized. The challenge of secure 5Gbased communication will therefore be addressed in task 1.5 of the first work package in the further course of the project.

3 KPI/KVI-based Methodological Assessment Framework

The use cases described in chapter 2 represent opportunities to develop new approaches to solving existing problems in the different verticals. However, as in many cases where new technologies are used, the assessment of the added value gained using technology is not always obvious at first glance. To counteract this, the following chapter presents a description of a KPI/KVI-based methodological assessment framework (MAF). This framework is supposed to enable the quantification of the value proposition of the implementation and application of the use cases within the TARGET-X project and focuses on both, technical and economic as well as societal benefits. While existing approaches mostly focus on the quantification of technical and economic benefits, the scope of the TARGET-X MAF is enhanced to also include the societal perspective. In this way, the assessment of novel technologies from a multitude of perspectives is enabled. This also enables a value driven approach for technology design, as the positive impacts can be quantified using the respective KVIs.

The main challenge for building a KPI/KVI-based MAF for all use cases from the different verticals of TARGET-X is the interdisciplinarity of the different domains involved. The interdisciplinarity indicates the need for an assessment framework that is application and industry neutral through an appropriate level abstraction while still consideration the right amount of detail to enable a precise analysis of the value of the implemented and applied use cases. For a first version of the KPI/KVI-based methodological assessment framework, an adaption of the approaches developed by Kiesel et al. [10] as well as by 6G-IA [7] is chosen. Kiesel et al. developed an approach in which, as a first step, a goal or objective is defined which is to be achieved through implementation of a use case. In the next step, KPIs are defined to measure the fulfillment rate of this goal. The defined KPIs are then operationalized by specific KPI-formula that use data from different sources (process and product data) as input values to calculate the KPI [10]. For the use cases of TARGET-X, technical and economic as well as societal goals are defined based on the collected benefits that are to be achieved through implementation and application of the use cases. The benefits of the use cases described in chapters 2.1 to 0 are collected and evaluated regarding existing similarities so that overarching goals from a technical and economic as well as societal perspective can be derived. The basic concept for the methodological assessment framework for TARGET-X is illustrated in Figure 3-1.

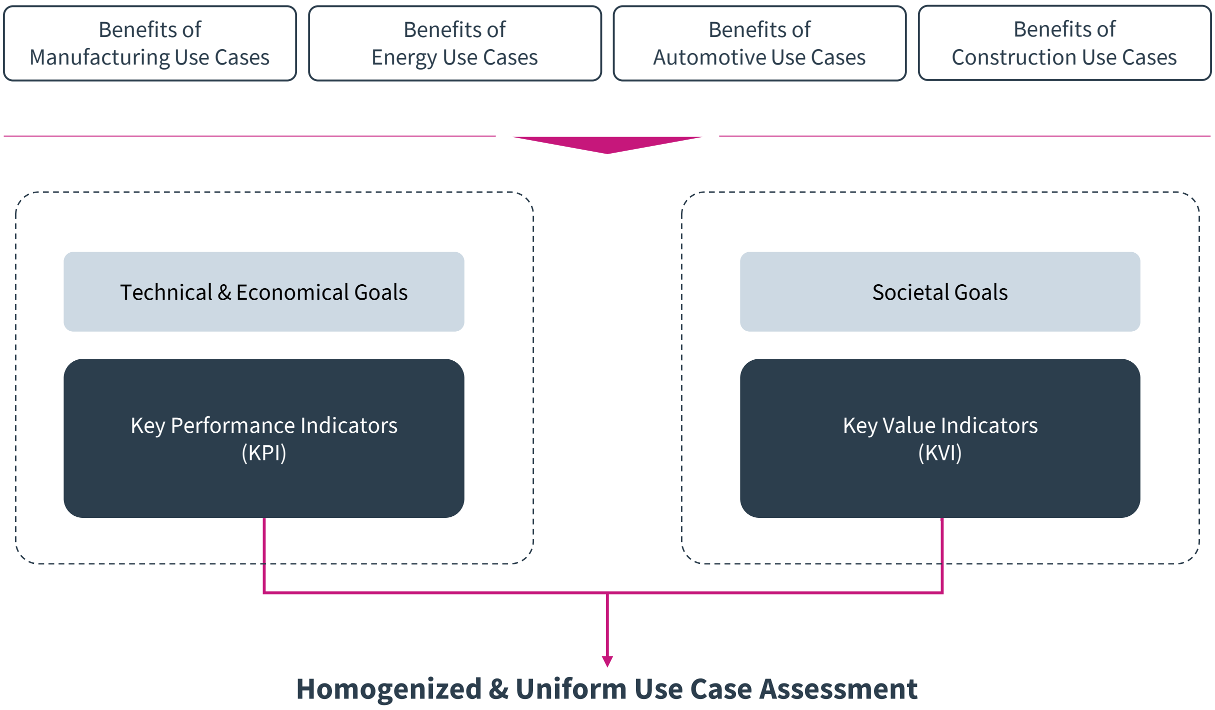

Figure 3-1: Concept of the Methodological Assessment Framework for Use Case Assessment

3.1 Definition of Technical and Economic Goals

Table 22 contains the collection of the benefits from a technical and economic point of view. This table was compiled by aggregating the benefits described in chapters 2.1 to 0.

Table 22: Collection of Technical and Economic Benefits of all Described Use Cases

VERTICAL	USE CASE NAME	TECHNICAL AND ECONOMIC BENEFITS
MANUFACTURING	Inline Quality Assurance for Machining	▪ Process optimization through increased insights ▪ Reduced tool wear ▪ Reduced material consumption
	Environmental Condition Monitoring	▪ Process optimization through increased insights
	Tracking and Tracing of Workpieces	▪ Process optimization through increased insights ▪ Traceability of machined workpieces
	Edge-controlled Automation with Mobile Manipulation	▪ Reduction of Task Time ▪ Increased Process Efficiency and Stability

		▪ Reduced Process Costs
ENERGY	Energy Monitoring and Energy Consumption Awareness	▪ Better understanding of local grid conditions ▪ Cost reduction through optimized energy usage
AUTOMOTIVE	Predictive Quality of Service for Tele-operated Vehicles	▪ Increased technical feasibility of tele-operated driving ▪ Increased economic feasibility of tele-operated driving
	Cooperative Perception	▪ Increased efficiency in the operation of Connected Autonomous Vehicles (CAVs)
	Digital Twin	▪ Improvement of development of control algorithms for automated and connected vehicles
CONSTRUCTION	5G for Automation of Deconstruction Processes	▪ Process optimization and reduction of inefficiencies through increased coordination and control ▪ Increased productivity
	5G for Energy Analytics of Construction Processes	▪ Cost reduction through optimized energy consumption

Based on the compilation and summary of the technical and economic benefits in Table 22, the following three overarching goals are derived. The first technical and economic goal is expanding data-based process insights to learn more about the processes behind the use cases in general and the mechanisms underlying the process. These gained insights can be used to characterize processes deeper and more comprehensive and they represent a starting point for a multitude of optimizations. The second overarching technical and economic goal is increasing the operational capability which describes the ability of operations to execute processes according to specified limits. This goal is closely related to the aspect of process capability and quality and derived from this principle which originates from quality management [11]. The third technical and economic goal is increasing the operational efficiency which describes the ability of operations to execute processes with an optimal use of resource while producing low waste and having an overall high productivity. Figure 3-2 illustrates how the collected benefits address these three overarching goals from a technical and economic perspective.

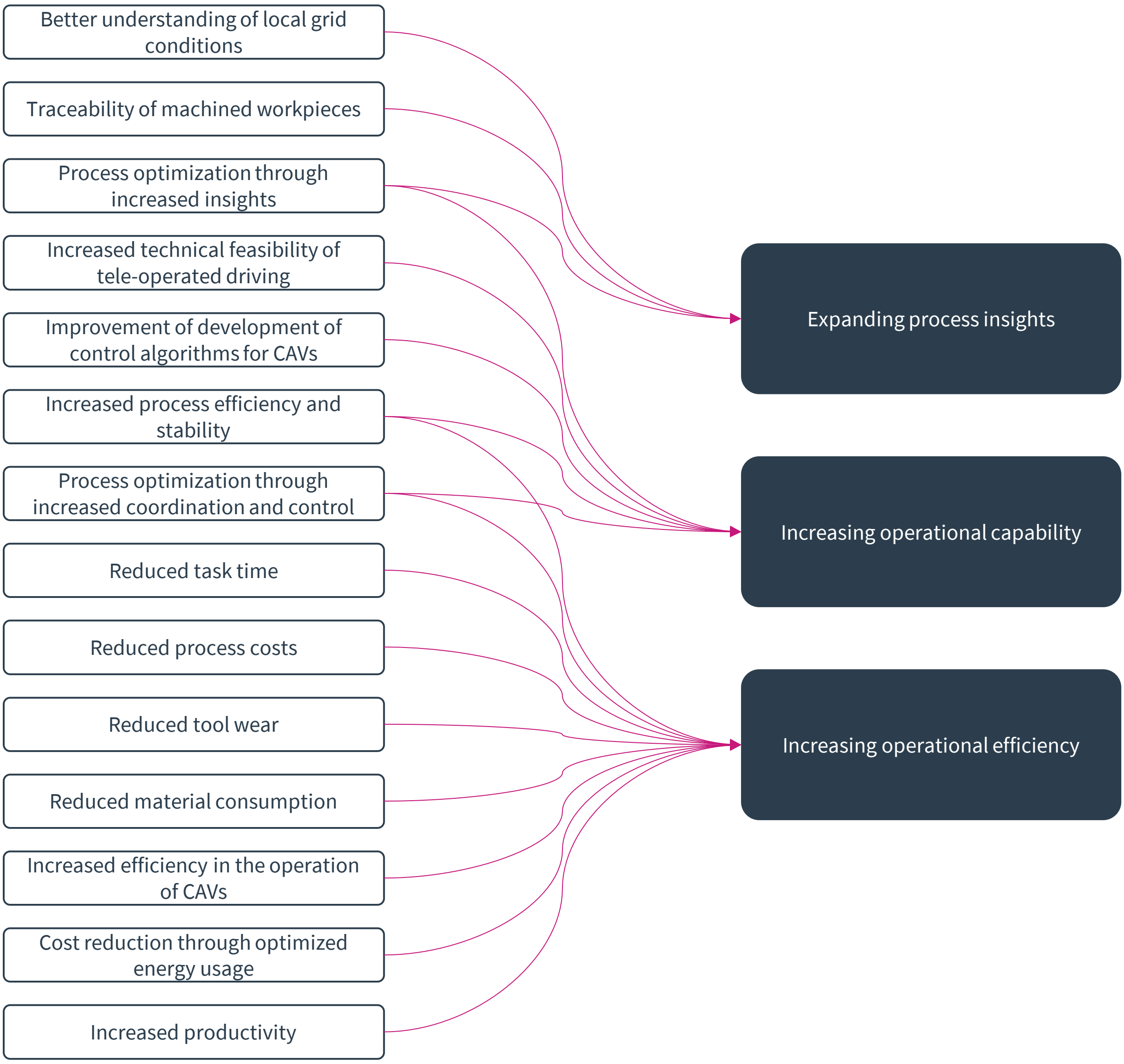

Figure 3-2: Illustration of How the Compiled Technical and Economic Benefits Address the Derived Goals

The goal of increasing the operational capability and the goal of increasing the operational efficiency are closely related to each other but address different aspects. While operational capability describes the ability of process to achieve results within predefined tolerance limits and specifications, operational efficiency describes the ability of operations to use inputs (resources) efficiently and to produce the desired results with as little waste as possible.

3.2 Definition of Key Performance Indicators

In the following section, a draft for the KPI set is presented, that will be utilized in the further course of the project to measure the fulfillment of the defined technical and economic goals. Table 23 provides an overview of the drafted KPI set.

Table 23: Draft of the KPI Set for Assessment of the Technical and Economic Goals of Use Case Implementation

TECHNICAL AND ECONOMIC GOAL	KEY PERFORMANCE INDICATORS
EXPANDING PROCESS INSIGHTS	Accuracy of process and product data
	Completeness of process and product data
	Consistency of process and product data
	Reliability of process and product data
	Timeliness of process and product data
	Uniqueness of process and product data
	Validity of process and product data
INCREASING OPERATIONAL CAPABILITY	Process performance index (P_{pk})
	Process capability (C_p & C_{pk})
	Process variability
INCREASING PROCESS EFFICIENCY	Cycle time
	Throughput
	First-pass yield
	Overall equipment efficiency (OEE)
	Error rate
	Quality rate
	Worker efficiency

It is important to point out that this KPI set is a first draft that could be subject to change as the project progresses. As of now, the applicability of the KPI set could not be verified due to the current maturity of the use cases that are to be implemented. If the need for adaptions becomes apparent during the application of the KPI set, adaptions will be made to enable a uniform assessment of all TARGET-X use cases.

3.3 Definition of Societal Goals

Table 24 contains the collection of the benefits from a societal point of view. The table was compiled by aggregation of the benefits of the use cases described in chapters 2.1 to 2.5.

Table 24: Collection of Societal Benefits of all Described Use Cases

VERTICAL	USE CASE NAME	SOCIETAL BENEFITS
MANUFACTURING	Inline Quality Assurance for Machining	▪ Reduced material consumption ▪ Increased worker safety
	Environmental Condition Monitoring	▪ Transparency over environmental impacts ▪ Reduction of environmental impacts ▪ Provision of database for precise product/process LCA
	Tracking and Tracing of Workpieces	▪ Transparency over environmental impacts ▪ Reduction of environmental impacts ▪ Provision of database for precise product/process LCA
	Edge-controlled Automation with Mobile Manipulation	▪ Improved environmental impact of production processes through energy savings and optimized resource consumption ▪ Digital inclusion of workers ▪ Increased worker safety
ENERGY	Energy Monitoring and Energy Consumption Awareness	▪ Transparency over energy consumption ▪ Improved environmental footprint through reduction of energy consumption
AUTOMOTIVE	Predictive Quality of Service for Tele-operated Vehicles	▪ Increased safety in road traffic ▪ Reduced physical and psychological impact of long-distance driving
	Cooperative Perception	▪ Increased safety in road traffic

	Digital Twin	▪ Increased safety in road traffic
CONSTRUCTION	5G for Automation of Deconstruction Processes	▪ Increased safety on construction sites ▪ Reduction of physical strain on construction site workers
	5G for Energy Analytics of Construction Processes	▪ Transparency over environmental impacts of construction processes ▪ Improved ecological footprint of construction processes

Based on the collection of societal benefits that are to be achieved through implementation and application of the use cases, the following overarching goals from a societal perspective have been defined. The first goal is the improvement of safety related aspects. The added value in terms of safety increases has been named as a benefit in the manufacturing, automotive and construction vertical, emphasizing on 5G's ability to contribute to an optimization of this aspect through an optimization of situational awareness. The second overarching goal from a societal point of view has defined as transparency about ecological impacts of operations. This goal is two-fold as 5G use cases contribute to both, transparency over environmental impacts of 5G use cases as well as the possibility to improve the ecological footprint of these use cases based on the created transparency. Since transparency provides the basis for optimization, creation of transparency is defined as the actual goal which is to be achieved by implementation and application of the use cases. When considering this aspect, it is also important to mention that transparency about the ecological footprints is not directly achieved by using 5G. Instead, 5G-based communication enables the acquisition, preparation and analysis of data which can subsequently be used to create the desired transparency about the ecological impacts of the use cases. The third overarching goal is defined as digital inclusion. The integration of 5G-based communication directly addresses the aspect of digital literacy e.g., of factory or construction site workers, as it enables application-oriented learning of digital technologies in the work environment. Figure 3-3 illustrates how the collected benefits address these three overarching goals from a societal perspective.

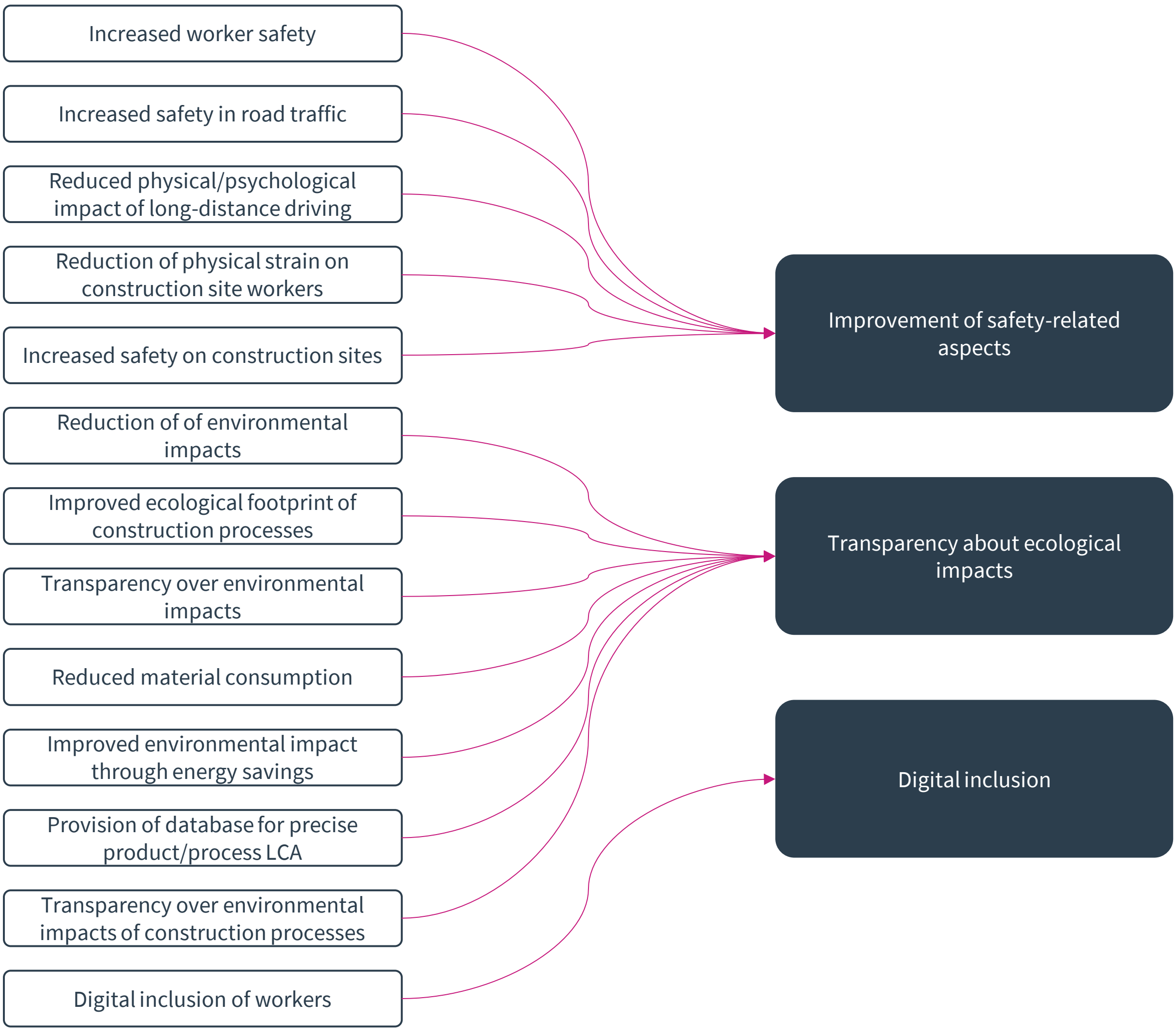

Figure 3-3: Illustration of How the Compiled Social Benefits Address the Derived Goals

The overarching societal goals might be expanded as the project progresses. Table 25 provides an overview of possible societal goals, the addressing of which will be examined in the further course of the project. Consideration of Table 25 also indicates, that the already determined societal goals of TARGET-X are aligned with this goal selection.

Table 25: Possible Societal Goals for the Use of 5G/6G [12]

DEMOCRACY	ECOSYSTEM	INNOVATION
Privacy	Sustainability	Safety
Fairness	Business value	Security
Digital inclusion	Economic growth	Regulation
Trust	Open collaboration	Responsibility
	New value chain	Energy Consumption

3.4 Definition of Key Value Indicators

In this section, a draft for the KVI set is presented which will be utilized in the further course of the project to measure the fulfillment of the defined societal goals that are to be achieved through implementation and application of the use cases of TARGET-X. Table 26 contains an overview of the drafted KVI set.

Table 26: Draft of the KVI set for the Assessment of the Societal Goals of Use Case Implementation

SOCIETAL GOAL	KEY VALUE INDICATORS
IMPROVEMENT OF SAFETY-RELATED ASPECTS	Work accident rate manufacturing
	Work accident rate construction
	Absolute number of prevented traffic accidents (simulated)
TRANSPARENCY ABOUT ECOLOGICAL IMPACTS	Global warming potential, GWP
	Water consumption
	Ozone depletion
	Photochemical ozone formation
	Depletion of abiotic resources (minerals and metals)
	Depletion of abiotic resources (fossil fuels)
DIGITAL INCLUSION	Digital literacy

It is important to point out that this KVI set is a first draft that could be subject to change as the project progresses. As of now, the applicability of the KVI set could not be verified due to the current maturity of the use cases that are to be implemented. If the need for adaptions becomes apparent during the application of the KPI set, adaptions will be made to enable a uniform assessment of all TARGET-X use cases.

4 Conclusion, Critical Reflection and Outlook on the Next Steps

The deliverable at hand described the 5G-based use cases of TARGET-X in the verticals manufacturing, robotics, energy, automotive, and construction. In total, ten different use cases, their underlying system architectures, their requirements, and their benefits have been described in a standardized format achieving a uniform description of all use cases of the project. Based on the described benefits, overarching goals have been defined from a technical and economic perspective as well as from a societal perspective. After the definition of the goals, specific KPI and KVI have been defined in order to enable the measurement of the degree to which the overarching goals have been fulfilled. In this way, a holistic approach for the assessment of the value proposition of the use cases in the different verticals employing the iteratively developed MAF will be achieved at the end of the project.

As mentioned in chapter 3, the described MAF is currently under development and represents a draft version. The current MAF also has a strong manufacturing influence due to the high amount of manufacturing related use cases. The following steps in the coming project year are intended to reduce the manufacturing influence and achieve a more heterogeneous weighting of the influences of the other verticals. Another aspect that is influencing the current version of the MAF is the maturity of the use case definitions. At the time of the finalization of this deliverable, not all use case definitions have been finalized and some points remain open. This specifically applies to the calculations of the KPI und KVI as it is still unclear which data will be available with which data quality and data quantity after the implementation of the use cases. Therefore, the MAF described in the deliverable at hand will be subject to change over the remaining course of TARGET-X. The defined goals as well as the preliminary KPI and KVI will be developed further and tested extensively so that adaptions can be made depending on the test results as well as expert feedback which will be collected from the domain experts of the different verticals. Furthermore, reference points for analyzing the benefits of using 5G/6G must be defined for each vertical. For instance, the economic impact of the use of 5G/6G in a use case needs to be compared to a scenario in which legacy technology like Ethernet or Wi-Fi is employed. This was also foreseen in the planning of the project, as the iterative trial and improvement of the MAF and its KPI and KVI will be the focus of the activities of work package 1 in the second project year.

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