FORWARD LOOKING USE CASES, THEIR REQUIREMENTS AND KPIS/KVIS

Deliverable D1.2

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SHORT ABSTRACT	This Deliverable represents an update of Deliverable 1.1 outlining the developed Methodological Assessment Framework and its associated User-KPI and User-KVI that can be employed to capture the value proposition of industrial 5G use cases. The document contains a detailed description of the developed framework and describes how the individual User-KPI and User-KVI can be calculated for each use case.
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Executive Summary

The deliverable at hand describes the developments that took place in the second project year of the EU-funded research project TARGET-X regarding the evaluation of the use cases that are being developed in the individual work packages of the project. One key objective of the project is the transfer of innovative 5G technology and solutions that are built on this technology into the four verticals manufacturing, energy, automotive, and constructions. For this purpose, innovative use cases are being developed to showcase the technological capabilities of wireless communication. Since knowledge of the value proposition of a technology makes a decisive contribution to the adoption of said technology, the first work package of TARGET-X is dedicated to the development of a Methodological Assessment Framework (MAF) which utilizes User-KPI and User-KVI to capture the value proposition achieved through the implementation of the use cases in the individual vertical of TARGET-X. This deliverable is based on Deliverable 1.1 which was published after the first project year and provides an update on the works conducted for use case development and assessment. The document first describes the MAF and its underlying core principles in detail which is then followed by the description of each individual use case as well as the User-KPI and User-KVI which have been selected for the assessment of each use case.

The findings gathered in the first year of the project can be summarized as follows. The concretization of the evaluation methodology indicated the need to make a distinction between explicit and implicit value propositions. While explicit value propositions describe the potential for immediate realization of a use case's benefits through the implementation of a use case, implicit value propositions describe the mid- and long-term realization of the added value achieved through use case implementation.

The adaption of User-KPI and User-KVI to the individual use cases showed that certain common features exist. Individual User-KPI and User-KVI with associated, individual equations have been defined for all twelve TARGET-X use cases. For a majority of these use cases, new insights are gathered through the potential to employ 5G to enhance sensor integration and networking so that completeness and timeliness of data from the processes are increased, providing the opportunity to learn more about the use cases itself as well as the underlying cause-effect relationships within the use cases. Another common feature among the use cases is the benefit that the capability of the considered processes is expected to be increased by 5G usage, so that the process outcome is more stable and reproducible, thus creating an important prerequisite for the application of the use cases in industry.

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List of Acronyms and Abbreviations

Abbreviation/Acronym	Term
5G-ACIA	5G-Alliance for Connected Industries and Automation
AR	Augmented Reality
C-ITS	Cooperative Intelligent Transport System
GWP	Global Warming Potential
HO	Human Operator
IOC	Internet of Construction
KPI	Key Performance Indicator
KVI	Key Value Indicator
LCA	Life Cycle Assessment
MAF	Methodological Assessment Framework
MR	Mixed Reality
NPV	Net Present Value
OEM	Original Equipment Manufacturer
PC	Personal Computer
PLC	Programmable Logic Controller
RDF	Resource Description Framework
ROCOF	Rate of Change of Frequency
ROI	Return on Invest
TOV	Tele-operated Vehicle
UE	User Equipment

1 Introduction

The deliverable at hand is based on Deliverable 1.1 of TARGET-X [TAR23-D11] and represents an updated version of D1.1. Over the course of the second year of the project, significant development of all TARGET-X use cases has taken place. As a result, the Methodological Assessment Framework (MAF) of TARGET-X as well as the according Key Performance Indicators (KPI) and Key Value Indicators (KVI) have been further developed and adapted to the increasing technical maturity of the use cases. These updates and adaptions are described in the deliverable at hand. In Deliverable 1.1 of TARGET X, the network requirements have been defined for each individual use case. These requirements have not been adapted in the first project and are not within the focus of the use case evaluation. For this reason, the network requirements are not directly re-addressed in Deliverable 1.2.

The deliverable is structured in the following way. First, the introduction of the deliverable is concluded with a description of the objective of the document as well as a description of the relations of the activities in Work Package 1 of TARGET-X to other verticals, work packages and external parties. In the second part, the updated MAF and the underlying core principles that have been refined over the course of the second project year are elaborated together with the principles of KPI and KVI calculations. In the third part of the deliverable, each use case is taken into consideration describing the defined evaluation scenario as well as the selected User-KPI and User-KVI. In addition, the business potential of each use case outlining a potential transfer of the use case to industry is described. For this purpose, the guiding question "*What steps are necessary to transfer the solution to industry and how can industry users realize the value proposition of the use case?*" was answered for each use case individually.

The deliverable is concluded with a summary of the User-KPI and User-KVI descriptions and the key findings of the second project year of TARGET-X as well as an outlook on the next steps in the final phase of the project.

1.1 Objective of the document

The overall objective of Work Package 1 of TARGET-X is to develop a methodology that enables capturing the value proposition of the individual TARGET-X use cases in each vertical. The activities aim at contributing to the widespread use of 5G and 6G technology in the European industry by showcasing the techno-economic and societal benefits that can be achieved through the successful implementation and execution of use cases that are based on the ones developed within TARGET-X. Since companies frequently state a lack of clarity regarding the achievable benefits through the adoption of innovative technology like 5G [BIT19], developing a methodology to capture the technology's value proposition will contribute to the increased use of the technology in different industries and verticals. For this purpose, the first version of the MAF was drafted in the first project year of TARGET-X based on KPIs and KVIs that have been derived to fit each TARGET-X use case. Over the course of the second project year, the overall MAF as well as the associated KPI and KVI have been updated according to the further development of the TARGET-X use cases.

The objective of the document is to provide an overview of the updated MAF, KPI and KVI to disseminate the project finding within the research community. The presented versions of the MAF, KPI and KVI present the current development state and might be subject to change as the technical maturity of the use cases progresses further until the end of the project.

1.2 Relation to other activities

As TARGET-X contains four different verticals (manufacturing, energy, automotive, and construction) the project follows a cross-vertical approach combining a variety of different application scenarios, disciplines, and domains with each other. Figure 1-1 illustrates the interaction of the individual work packages of TARGET-X. As shown in the figure, WP1 has an overarching character covering all different verticals of the project. Therefore, the joint development of the MAF with all involved use cases also targets the continuous exchange of ideas across the different verticals, preventing the research activities to be carried out in silos. All activities in WP 1 are therefore carried out in close collaboration with the other WPs of TARGET-X.

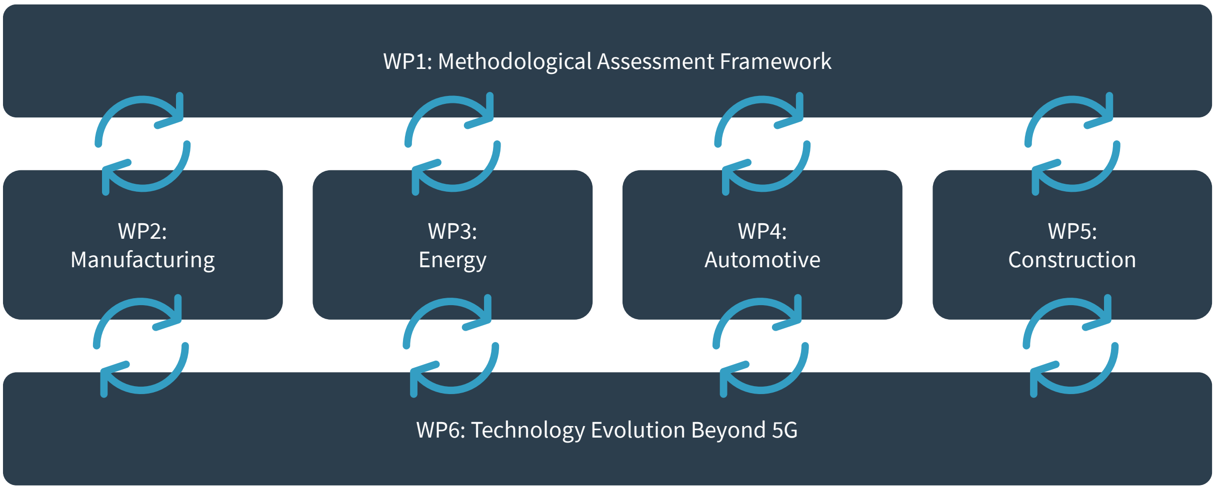

Figure 1-1: Cross-vertical interaction of work packages in TARGET-X

Next to the activities within the project consortium, WP 1 is also actively working on a Work Item in 5G-ACIA, the 5G Alliance for Connected Industries and Automation, focusing on the joint development of a (simplified) version of the assessment methodology together with industrial partners outside of the project consortium. These activities have so far resulted in an internal report that has been created with the members of 5G-ACIA. In addition, a 5G-ACIA Whitepaper will be created in cooperation with a Japanese automotive OEM that will be published in 2025.

Another aspect that WP 1 works on is cyber security. With increasing technical maturity of the TARGET-X use cases, the points of contact with the aspect of cyber security become more relevant. Work on cyber security will be intensified in the final phase of the project by focusing on a risk assessment of cyber security threats for each use case and by two FSTP projects that will address specific tasks related to the prevention and detection of cyber-attacks in wireless communication systems. Work on these aspects will be completed at the end of the project. A summarizing overview of cyber security is given in Deliverable 9.3 [TAR24-D93].

2 KPI/KVI-based Methodological Assessment Framework (Update)

2.1 Core Principles of the MAF

This chapter contains a detailed description of the updated TARGET-X MAF as well as an overview of the developed KPI and KVI set as part of the MAF. The first concept of the MAF is pictured in Figure 2-1. The concept was further developed and refined in the second project year. The core principles of the MAF have been retained with the benefits of the use cases from the individual verticals being collected and allocated to a techno-economic or a societal goal. The degree to which the respective goal is achieved is measured with either KPI (for the techno-economic goals) or KVI (for the societal goals).

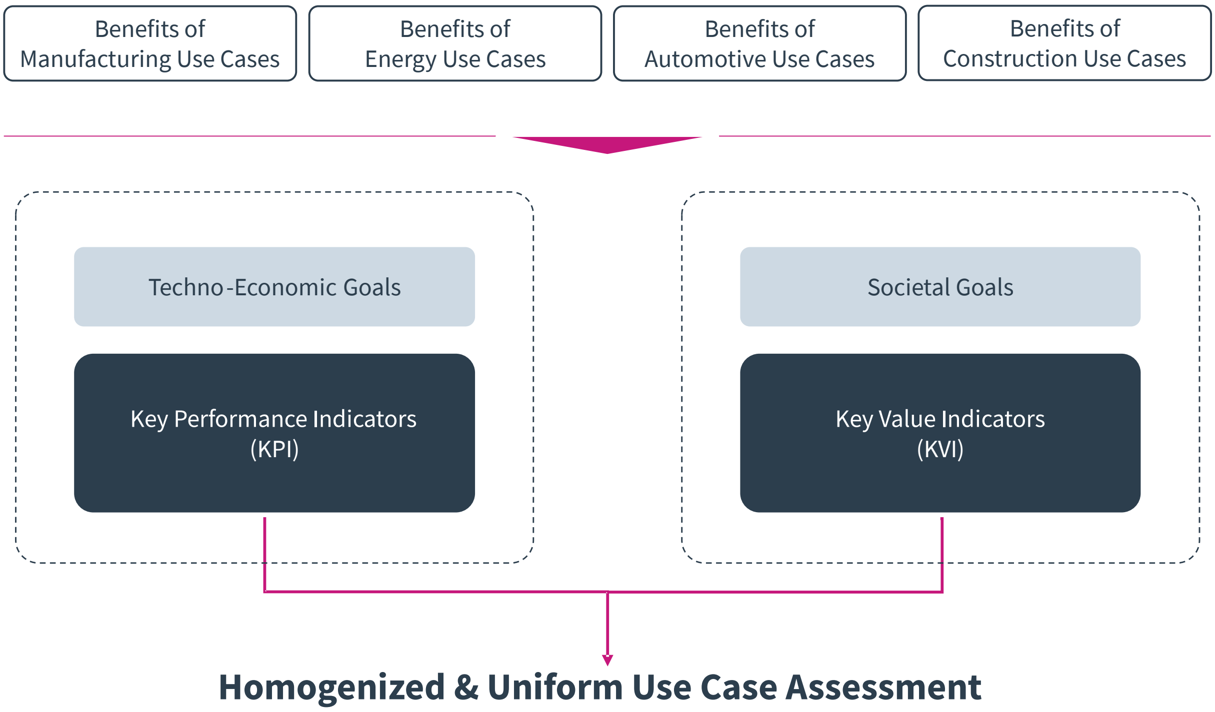

Figure 2-1: First Version of the Concept of the Methodological Assessment Framework for Use Case Assessment [TAR23-D11]

After completion of the first project year and review of the conducted works, it became apparent that the end user's perspective needs to be more emphasized for the further development of the MAF for both, techno-economic as well as societal goals. Research in the area of value propositions and perceived value illustrates, that different stakeholder groups understand the value proposition of a use case or a product differently, based on their evaluation or decision perspective [ROD20]. Therefore, for the evaluation of the TARGET-X use case it was decided that the evaluation should focus on the perceived value from the end user's perspective, since one of the core objectives of TARGET-X is to contribute to the wide use of 5G in different verticals. For this purpose, a quantification-based assessment of the value proposition of the TARGET-X use cases is an important prerequisite. This was achieved by adopting a new perspective for the assessment of the use cases: To evaluate the value proposition of the use case, the perspective of a potential end user of the use case should always be taken instead of the perspective of a person developing the solution. In the manufacturing sector, for instance, this means looking through the eyes of a production manager contemplating the integration of a 5G solution into their operations. This production manager likely lacks detailed knowledge about communication networks and is therefore not particularly concerned with technical aspects like latency or data rates. Instead, their focus is on key metrics that reflect the performance of their production system and the influence of the 5G solution, such as potential improvements in throughput, which is a central KPI in TARGET-X. Although this evaluation approach was already embedded in the design of the MAF and its associated KPI/KVI, it was further emphasized in the ongoing development process. Therefore, the guiding principle for the evaluation of each TARGET-X use case was derived in the following way: "*Take the perspective of the end user of the use case and describe what advantages/benefits the implementation and execution of the use case promises compared to the current state of the art*". In this way, the concrete value proposition of the use case is established as the key element for both development and evaluation of the use case. This principle led the activities for further development and refinement of the MAF of TARGET-X. Figure 2-2 shows the refined version of the MAF after the second project year.

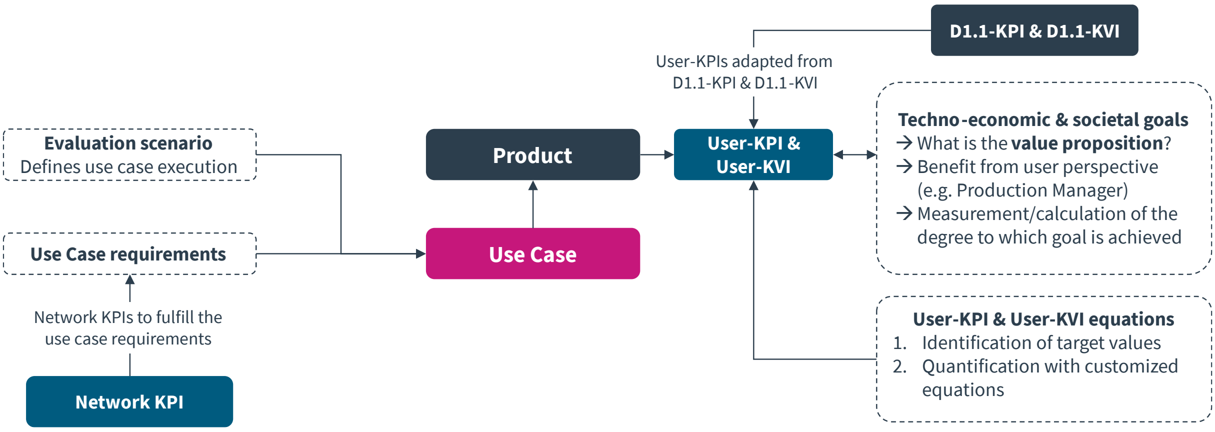

Figure 2-2: Refined TARGET-X MAF

The outcome of the execution of each use case is defined as a *product*, which, together with the use case itself, is located at the center of the MAF. The product does not necessarily have to be a physical object, it can for instance also be the successful transport of a passenger with an autonomously controlled vehicle in the automotive vertical or a successfully conducted mobile robotics operation in the manufacturing vertical. Placing the product at the center of the MAF follows the principle of prioritizing end user's needs and wants, as they mostly care about the product generating a value proposition for them as the result of a successfully executed use case. This approach also aligns with one of the core objectives of TARGET-X which is to accelerate the adoption of 5G (and 6G) in different industries as the concrete and tangible description of a use cases' value proposition is a crucial prerequisite for this objective. For each use case, a dedicated use case owner as a project member from the respective vertical has been defined in order to have one central person that is responsible for the collaboration with work package 1. This person is also responsible for the further development and finalization of their use case.

The next important component of the MAF that have been adapted are the individual *evaluation scenarios* for each use case. As a use case can be executed in a variety of different ways with different parameterization in each case, the evaluation scenarios describe test cases for the exemplary and sequential execution of the use cases which will then be subject to the evaluation. The evaluation scenarios for each use case are described in chapter 3.

Together with the *use case requirements*, the evaluation scenarios set the stage for the execution and evaluation of each use case. The use case requirements establish the link between the technical properties of the network, expressed with *Network-KPI*, and the actual product of the use case. For the successful execution of the use case, the use case requirements must be fulfilled by the network so that the targeted value proposition of the use case can be achieved. This can, for example, be certain requirements regarding latency, throughput, or localization accuracy. In this way, a concrete link is established between Network-KPI and User-KPI/-KVI as the Network-KPI propagate through the use case requirements to the use case and its product to the actual User-KPI/-KVI.

The wording differentiation between Network- and User-KPI addresses an important issue that can arise at the interface of two different domains which is the different interpretation of a commonly used term. Over the course of the second project year, a different understanding of the term KPI was frequently noticed within the project consortium. While network experts tend to interpret KPI to a description of network characteristics, domain experts (e.g. experts from the manufacturing domain) tend to interpret KPI as a term describing the performance of a production or construction system.

Therefore, the KPI and KVI used for the evaluation of a use cases we renamed to User-KPI and User-KVI. The illustration of both, Network-KPI and User-KPI/-KVI in the MAF addresses the issue of different understandings among experts from different domains and can act as a tool to build a bridge between different domains. User-KPI and User-KVI are both utilized to quantify the degree to which a techno-economic or a societal goal is achieved.

For each use case, an adaptation of the generic KPI and KVI from Deliverable 1.1 has been conducted together with the respective use case owner to tailor the evaluation to each use case specifically. For this purpose, equations have been defined for the estimation-based calculation of each User-KPI and each User-KVI. The goals are also formulated from an end user’s perspective. For instance, a production manager might want to increase the capability of a particular process in the production environment through the implementation of a 5G based use case. However, they will not have the intention to achieve certain latencies in the network which is employed for this purpose. Of course, latency requirements exist, but they are not the main focus of the evaluation; they merely form a prerequisite for the successful implementation of the use case. The techno-economic goals as well as the societal goals have been defined in Deliverable 1.1 [TAR23-D11] and have not been adapted in the second project year as only the User-KPI and User-KVI have been developed further.

The described core principles have been developed in continuous exchange with the other work packages of the project that focus on the development of their individual use cases. Additional input for the development of the MAF has been gathered through the WP 1 activities in 5G-ACIA. Furthermore, Work Package 1 took part in meetings with other SNS JU Stream D projects [6GS23] and was in exchange with the 6G IA sub-group “Societal Needs and Value Creation, SNVC” [6GIA23] to validate the created assessment frameworks with third parties outside the project consortium. Moreover, the MAF was discussed with the External Industrial Advisory Board of TARGET-X. In this way, the involvement of external perspectives was enhanced in the second project year. During the development of the MAF, results from other research activities were taken into consideration. For instance, the framework presented by Wikström et al. was considered and the synergy potential was examined. It was found that the two frameworks basically follow similar principles, but differ in detail, particularly regarding the application horizon and specific user focus. With its industrial background, the TARGET-X MAF focuses in particular on the value from the user's perspective and poses the question of how a value proposition can be quantified for the user [WIK24].

2.2 Principles for Estimation-based Calculation of KPIs and KVIs

One of the most significant challenges of building an assessment methodology is the identification of the right balance between accuracy of the methodology on the one hand and generalizability on the other hand. If a method has a high degree of accuracy, it enables the calculation of reliable results, but at the same time limits the generalizability, so that the method can only be applied to a small number of problems. This results in the need to determine a sweet spot between accuracy and generalizability of the methodological assessment framework, which enables the calculation of sufficiently accurate results and at the same time allows the application to different use cases. This question was at the center of the activities of WP1 in 5G-ACIA. Together with the industrial partners from 5G-ACIA, simplifications were made to the existing method. Figure 2-3 illustrates the principle of how estimation-based calculations will be conducted to calculate results for the User-KPI and User-KVI exemplarily.

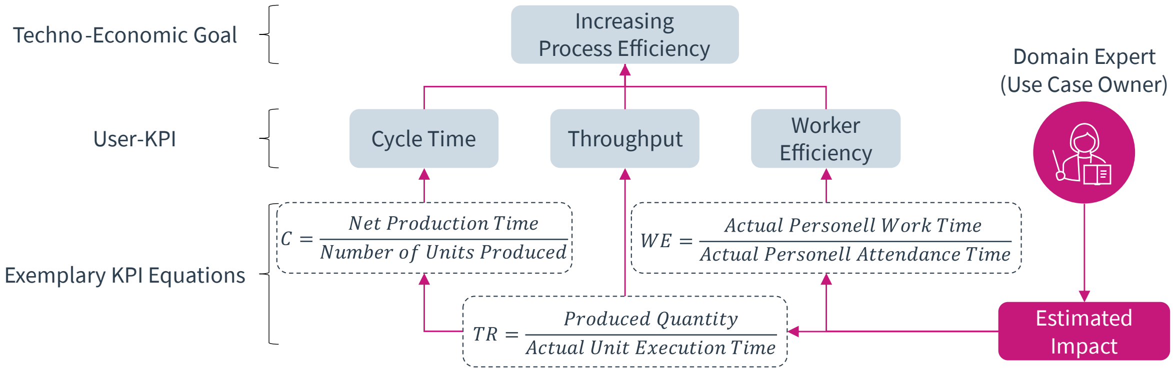

Figure 2-3: Estimation based User-KPI Calculation

In the figure, the selected techno-economic goal that is to be achieved through successful implementation and execution of a specific use case is *Increasing Process Efficiency*. The motivation behind this goal can be diverse. For instance, a production manager might want to tackle existing efficiency issues with a 5G-based automation use case, or a construction manager might want to install a robotics use case on a construction site to work more efficiently. As stated before, the degree to which a goal (Increasing Process Efficiency) is achieved, is measured with selected User-KPI (or User-KVI). These User-KPI are calculated with underlying KPI equations which use a variety of input parameters. Figure 2-3 also shows the generic equations for the User-KPI *Cycle Time, Throughput, and Worker Efficiency* that take different parameters from the associated use case as input values. For the analysis of a specific use case, these generic equations form the starting point as they are adapted to the respective evaluation scenario of the considered use case. For the User-KVI and the associated societal goals, the same procedure is applied.

2.3 TARGET-X User-KPI

Table 2-1 shows the technical and economic User-KPI that have been introduced in D1.1 and adapted to each individual TARGET-X use case. The adaptions are described in chapter 3.

Table 2-1: Technical User-KPI

TECHNICAL GOALS	USER-KPI
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
ECONOMIC GOALS	**USER-KPI**
INCREASE PROFITABILITY	Net Present Value (NPV)
	Return on Investment (ROI)

The economic goals are summarized with the objective to increase profitability through technical or societal improvements achieved by the implementation of the respective use case. During the analysis of the use cases, an estimation of the NPV and ROI will be given for each use case. For this purpose, the standard equations for the calculation of the NPV and ROI will be used, if they can be applied. Since no adaptations of the equations are necessary, the equations will not be listed in chapter 3 individually for each use case.

2.4 TARGET-X User-KVI

Table 2-2 shows the TARGET-X User-KVI that are adapted to each use case individually.

Table 2-2: Societal User-KVI

SOCIETAL GOALS	USER-KVI
IMPROVEMENT OF SAFETY-RELATED ASPECTS	Work accident rate manufacturing
	Work accident rate construction
	Absolute number of prevented traffic accidents
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

2.5 Implicit and Explicit Value Proposition

The adaptation of the listed User-KPI and User-KVI to capture the value proposition of the use cases indicates the necessity to differentiate between different types of value propositions: implicit and explicit value propositions. While some value propositions are immediately tangible and offer immediate added value, other value propositions are not immediately obvious and only offer added value in the mid or long term, which can be used based on further developments.

Therefore, two terms were defined for the evaluation of the TARGET-X use cases inspired by research on the quantification of value propositions in technology [PAY17]. The term *implicit value proposition* is used if the value proposition of a use case can be inferred based on the successful use case execution. For instance, the findings from the development of an automotive 5G-based use case might be an important contribution to the development of an innovative safety feature that uses the findings from said use case as an enabler. In this case, the value proposition of the use case is not immediately tangible but can become tangible in the future when certain future developments have been realized.

On the other hand, the term *explicit value proposition* is introduced to describe the clear and direct added value that can be achieved instantaneously by successful execution of the use case. E.g., a 5G-based use case that enables the implementation of an ad-hoc safety feature on a construction site immediately adds value to the people working on the considered construction site so that the value proposition in this case is explicit.

The investigation of value propositions and the possibilities to quantify them according to the differentiation between implicit and explicit has also shown that different value propositions are also aimed at different target groups. For instance, explicit value propositions are interesting for external stakeholder like customers, while implicit value propositions are interesting for internal stakeholder like technology developers who might follow a longer-term approach to make use of a certain value proposition.

3 Use Cases of the TARGET-X Verticals

In this chapter, each TARGET-X use case is considered in detail for the evaluations according to the principles described in chapter 2. First, the individual evaluation scenario for each use case is stated in a table. The evaluation scenarios are based on the use case descriptions from D1.1 and contain the further development that has been done in the second project year. The evaluation scenarios are followed by a listing of the selected User-KPI and User-KVI from the generic sets in Table 2-1, and Table 2-2 for each use case. The economic User-KPI are not adapted to each use case individually, as the standard equations will be used for the assessment of the use cases.

3.1 Manufacturing Vertical

3.1.1 Use Case 1: Inline Quality Assurance for Machining

3.1.1.1 Short Description of the Use Case

The Inline Quality Assurance for Machining use case focuses on building a solution for inline quality assurance of production processes utilizing 5G-TSN (time sensitive networking). For this purpose, a demo workpiece that is to be milled is equipped with a vibration sensor. The measurement data, created by the sensor during milling is transmitted via 5G-TSN to an edge server to enable real-time analysis of the transmitted data. Therefore, the use case product is defined as follows: the outcome of the successful use case execution is a continuous data stream that is established via a real-time wireless communication system utilizing 5G-TSN to analyze vibration measurement directly from a milling operation. In this way, this development sets an important prerequisite to create a closed-loop control of critical process parameters in future works. An in-depth description of this use case can be found in Deliverable 2.4 [TAR24-D24].

3.1.1.2 Evaluation Scenario

The following table describes the evaluation scenario for the Inline Quality Assurance for Machining use case. The depicted evaluation scenario has been developed in collaboration with the responsible use case owner from work package 2 of TARGET-X.

Table 3-1: Evaluation Scenario for the Inline Quality Assurance for Machining Use Case

STEP ID	STEP NAME	STEP DESCRIPTION	RESULT AFTER STEP EXECUTION	RELEVANT PROCESS PARAMETERS
1	Initialization	Vibration sensor is mounted on demo workpiece (Mini-BLISK from IPT showroom). Peripheral devices (PLC and PC) are connected and initialized for measurements.	Physical and virtual demo setup initialized for test runs and measurements.	
2	Excitation and Measurements	Excitation system acts on workpiece to simulate milling operations.	Workpiece is excited with a certain vibration	- Measurement data from

		Vibration sensor measures vibration signal during the milling operations.	value emitting a signal which is captured by the sensor.	vibration sensor - Timestamps from IO device (Mitsubishi remote station) for measurements
3	Data Transmission	Measurement data is sent to connected PLC via 5G-TSN.	Measurement data from vibration sensor available on the connected PLC.	- Measurement data from vibration sensor - Timestamps from IO device (Mitsubishi remote station) for measurements
4	Visualization	Transmitted data is visualized on a dashboard with a PC that is connected to the PLC.	Basis for analysis and insights for OT and IT partners.	Consistency, reliability, and timeliness of process data

3.1.1.3 Selected User-KPI

The following table describes the selected User-KPI for the evaluation of the Inline Quality Assurance for Machining use case from a techno-economic perspective. The listed User-KPI have been developed in collaboration with the responsible use case owner from work package 2 of TARGET-X.

Table 3-2: Selected User-KPI for the Inline Quality Assurance for Machining Use Case

TECHNICAL GOAL	USER-KPI
Expanding Process Insights	Completeness of process and product data
	Timeliness of process and product data
Increasing Operational Capability	Process capability (c_p & c_{pk})
Increasing Process Efficiency	Flexibility*

The relevant User-KPI selected for the Quality Assurance for Machining use case are described in the following passage.

3.1.1.3.1 Completeness of Process and Product Data

The User-KPI "completeness of process and product data" is relevant for this use case because it will enable a decrease of packet loss enabled by deterministic communication (5G-TSN). The User-KPI is therefore determined in the following way: As completeness refers to whether a dataset includes all necessary records, without missing values or gaps, the packet loss can be measured for the considered data transmission. Equation 1 defines the average packet loss of for a variety of *n* measurements according to [KIE22]:

Equation 1:

$$L_{total} = \frac{\sum_1^n L_n}{n}$$

The packet loss can then be used to calculate the completeness of the transmitted data set with Equation 2:

Equation 2:

$$Completeness\ (\%) = 100 - L_{total}$$

For the considered use case, a positive impact and therefore an explicit value proposition is expected regarding the completeness of product and process data. These expectations will be verified in the final project phase of TARGET-X.

3.1.1.3.2 Timeliness of Process and Product Data:

The User-KPI "timeliness of process and product data" describes the speed with which the measured data can be transmitted from the milling process to the edge server where it can then be analyzed. Therefore, the timeliness is closely related to the latency of the network. For the calculation of the timeliness, the following equation has been defined:

Equation 3:

$$Timeliness\ (\%) = \frac{Number\ of\ packets\ received\ on\ time}{Total\ number\ of\ packets\ sent}$$

For the considered use case, a positive impact and therefore an explicit value proposition is expected regarding the timeliness of product and process data. These expectations will be verified in the final project phase of TARGET-X.

3.1.1.3.3 Process Capability:

The User-KPI "process capability" describes the ability of the process to produce output within certain specification limits. This User-KPI is stated as potential future benefit here since a closing of the control-loop is a necessary requirement for it to be realized. Therefore, the impact of the process capability on the goal to increase operational capability is formulated as an implicit value proposition for this use case. The values for c_p and c_{pk} can be calculated using the upper tolerance limit *UT* and *LT* the lower tolerance limit for the process output with the following equations [SCH15]:

Equation 4:

$$c_p = \frac{UT + LT}{6\sigma}$$

Equation 5:

$$c_{pk} = \frac{\min\,(UT - \bar{x};\ \bar{x} - LT)}{3\sigma}$$

UT describes the upper tolerance limit and LT the lower tolerance limit so that they both together define the specifications limits for the process output. The parameter σ describes the standard deviation of the considered (and measured) process parameter and $\bar{x}$ describes the mean of the considered value. For the use case at hand the measured process parameter can be the vibration signal measured by the vibration sensor mounted on the demo workpiece which needs to be within a certain range to achieve a capable process.

3.1.1.3.4 Flexibility

The User-KPI "flexibility" is not part of the original D1.1 KPI set and has been added for the Inline Quality Assurance for Machining use case to illustrate the value gained through the positive impact on the reconfigurability of production systems. It can be quantified by the analyzing the time needed to reconfigure a production system:

Equation 6:

$$Flexibility = \frac{Standard\ reconfiguration\ time}{Improved\ reconfiguration\ time}$$

The standard reconfiguration time describes the (estimated) reconfiguration time needed for reconfiguration tasks while the improved reconfiguration time describes the reconfiguration time needed when the 5G-TSN vibration sensor is employed. As the process capability User-KPI, the flexibility User-KPI also describes a future potential benefit if further development of the solution takes place (implicit value proposition).

3.1.1.4 Selected User-KVI

The following table lists the selected User-KVI for the evaluation of the Inline Quality Assurance for Machining use case from a societal perspective. The listed User-KVI have been developed in collaboration with the responsible use case owner from work package 2.

Table 3-3: Selected User-KVI for the Inline Quality Assurance for Machining Use Case

SOCIETAL GOAL	USER-KVI
Improvement of Safety-related aspects	Work accident rate manufacturing

The relevant User-KVI selected for the Quality Assurance for Machining use case is described in the following passage. As the use case focuses mostly on process monitoring for optimization purposes, only one User-KVI has been selected.

3.1.1.4.1 Work Accident Rate Manufacturing

If the solution developed in the Inline Quality Assurance for Machining use case is further developed and deployed in real production systems, a positive impact on the User-KPI "work accident rate in manufacturing" can be expected as the real-time communication enabled by 5G-TSN can contribute to the development of safety features implemented in production processes, like a real-time emergency stop, so that accidents might be prevented. Equation 7 stated a potential equation that can be utilized for the calculation of the work accident rate manufacturing:

Equation 7:

$$Work\ accident\ rate\ manufacturing = \frac{Total\ number\ of\ accidents}{Operation\ time}$$

For the calculation of the work accident rate manufacturing parameter, the total number of accidents occurred is divided by the total operation time. This User-KVI also addresses a implicit value proposition, as it can only provide added value if future development is successfully carried out.

3.1.1.5 Description of the Business Potential

For the assessment of the business potential of the developed use cases, a two-fold guiding question has been developed:

"What steps are necessary to transfer the solution to industry and how can industry users realize the value proposition of the use case?"

The Inline Quality Assurance for Machining Use Case focuses on the development of a solution to utilize 5G-TSN for industrial applications. Using 5G-TSN can therefore be considered as an enabler for a variety of real-time applications in manufacturing. However, the solution developed within TARGET-X only provides the technological basis for further development. The necessary steps for transferring the solution to industry therefore include achieving a high TRL for data exchange based on 5G TSN, in particular meeting industrial requirements for reliability and latency. This enables a closing of the control-loop, paving the way to implement a real-time process monitoring and control of manufacturing processes so that processes can be more stable, safe, and reproducible increasing the overall productivity of manufacturing systems.

3.1.2 Use Case 2: Environmental Condition Monitoring

3.1.2.1 Short Description of the Use Case

The Environmental Condition Monitoring use case focuses on the development of a sensor platform that can be integrated into milling processes. The sensor platform enables the acquisition of a variety of sustainability-related data sets through measurement of consumption values like electrical power, compressed air, coolant rate, etc. Therefore, one objective of the use case is to gather more insights enabling the calculation of the environmental footprint of the production process. For this use case, the aspect of 5G that is taken into consideration is the advantage that the technology offers regarding scalability, so that the number of communication participants can be increased in comparison to the implementation of the solution with legacy technology. Furthermore, the possibility to integrate the technology in existing manufacturing environments (brownfield approach) and enable the additional acquisition of data is another advantage of the technology. An in-depth description of this use case can be found in Deliverable 2.4 [TAR24-D24].

Description of the use case product: The outcome of the successful use case execution is enhanced sustainability related data acquisition and transfer through 5G for a reference milling process. Furthermore, valuable insights are gathered on how a 5G-integrated sensor platform must be designed so that the large-scale acquisition of sustainability related data can be implemented.

3.1.2.2 Evaluation Scenario

The following table describes the evaluation scenario for the Environmental Condition Monitoring use case. The depicted evaluation scenario has been developed in collaboration with the responsible use case owner from work package 2 of TARGET-X.

Table 3-4: Evaluation Scenario for the Environmental Condition Monitoring Use Case

STEP ID	STEP NAME	STEP DESCRIPTION	RESULT AFTER STEP EXECUTION	RELEVANT PROCESS PARAMETERS
1	Machine Setup	Installation of energy meters (submeters) for consumption monitoring of e.g. electrical power, compressed air, coolant rate, etc.	Machine is set up for measurement of sustainability related data during milling operations.	Setup time
2	Process initiation	Initiate milling process on a test workpiece.	Initiated milling process, whose consumption values can now be measured during test runs.	- Process data: Coolant rate and vibration data - Timestamp of use case execution start
3	Resource consumption measurement	Execution of exemplary test run removing 10 % of mass from the test workpiece through milling operations. Measurement of resource consumption via submetering for the energy	Recorded resource consumption of milling process to exemplary test run.	- Sub-meter data (compressed air in bar) on component level of machine - Sampling rate for transfer of data from energy meters: 10 ms (vibration, temperature,

		management system within the machine. (E.g., for compressed air: leakage detection)		coolant flow rate, airflow rate, power consumption)
4	Data transfer	Send data (every 10 ms) from energy meter and submeters to the edge server.	Resource consumption data is accessible on the edge server.	Data exchange rate: 10 ms
5	Digital energy twin	Generation of an energy twin on component level of the machine	Data is combined in holistic energy metrics represented in the digital energy twin	

3.1.2.3 Selected User-KPI

The following table describes the selected User-KPI for the evaluation of the Environmental Condition Monitoring use case from a techno-economic perspective. The listed User-KPI have been developed in collaboration with the responsible use case owner from work package 2 of TARGET-X.

Table 3-5: Selected User-KPI for the Environmental Condition Monitoring Use Case

TECHNICAL GOAL	USER-KPI
Expanding Process Insights	Completeness of process and product data
	Timeliness of process and product data

The relevant User-KPI selected for the Environmental Condition Monitoring use case are described in the following passage.

3.1.2.3.1 Completeness of Process and Product Data

As the 5G-integrated sensor platform enables the fast transmission of data from the submeters to the associated edge server, a positive impact of the solution on the User-KPI of "completeness of process and product data" is expected. Therefore, Equation 1 and Equation 2 defining the average packet loss for a variety of *n* measurements according to [KIE22] can also be employed here to calculate the completeness of data:

Equation 8:

$$L_{total} = \frac{\sum_1^n L_n}{n}$$

The packet loss can then be used to calculate the completeness of the transmitted data set with Equation 2:

Equation 9:

$$Completeness\ (\%) = 100 - \ L_{total}$$

The expected increase of completeness of data also leads to a more reliable analysis based on the data transmitted to the edge server: The 5G-integrated sensor platform enables the creation of higher resolution data sets (granularity and size of transferred data sets) containing measurement values for vibration, temperature, coolant flow rate, airflow rate, and power consumption. This will positively contribute to the expansion of process insights. These insights create an explicit value proposition as they can immediately be used for reporting and documentation purposes regarding the environmental footprint of the process.

3.1.2.3.2 Timeliness of process and product data

As for the Inline Quality Assurance for Machining use case, the use of 5G has a positive impact on the User-KPI “timeliness of process and product data”. A reduction in packet loss will enable more packets to be delivered on time, so that a real-time insight into the environmental footprint of the process can be created. For the calculation of the timeliness, the following equation will be used:

Equation 10:

$$Timeliness\ (\%) = \frac{Number\ of\ packets\ received\ on\ time}{Total\ number\ of\ packet\ sent}$$

Like the completeness of data, the timeliness will provide an explicit value proposition for the Environmental Condition Monitoring use case.

3.1.2.4 Selected User-KVI

The following table lists the selected User-KVI for the evaluation of the Environmental Condition Monitoring use case from a societal perspective. The listed User-KVI have been developed in collaboration with the responsible use case owner from work package 2. The value proposition of the listed User-KVI is that the achieved transparency will allow the calculation of the environmental footprint of the physical product which is being produced by the monitored milling operation. The expected increase in completeness and timeliness of the data will enable a more direct and accurate calculation of the environmental footprint.

Table 3-6: Selected User-KVI for the Environmental Condition Monitoring Use Case

SOCIETAL GOAL	USER-KVI
Transparency about Ecological Impacts	Global Warming Potential, GWP
	Water consumption, WCon
	Ozone depletion, ODep.
	Photochemical ozone formation, PhOz.
	Depletion of abiotic resources (fossil fuels), DepFF

The relevant User-KVI selected for the Environmental Condition Monitoring use case are described in the following passage. As the use case strongly focuses on the creation of transparency of the ecological footprint of the use case, a variety of sustainability-related indicators have been selected for the use case. The calculations of emissions for this use case are exclusively based on the consumption of electricity and do not consider the consumption of materials in the use case itself. [EUR24] and [NAU24] have been used as sources for the KVI description. For the assessment of these User-KVI the Life Cycle Assessment (LCA) methodology will be followed.

3.1.2.4.1 Global Warming Potential

The User-KVI “global warming potential, GWP” is calculated with the following equation:

Equation 11:

$$GWP = Consumed\ Electricity * Emission\ Factor\ Electricity$$

Equation 11 calculates the GWP for the measured consumed electricity for the use case execution. The consumed electricity is measured in kWh and the emission factor electricity is given in kg CO_2-equivalents/kWh and is determined based on the German energy mix from databases.

3.1.2.4.2 Water Consumption

The User-KVI “water consumption, WCon” is calculated based on the water consumed to generate electricity. The following equation have been defined for this purpose:

Equation 12:

$$WCon = Consumed\ Electricity * \ Emission\ Factor\ Water$$

The consumed electricity is measured in kWh and the emission factor water is given in m^3/kWh and is determined based on the German energy mix from databases.

3.1.2.4.3 Ozone Depletion

The User-KVI "ozone depletion, ODep." is calculated based on the emission of substances depleting the stratospheric ozone layer. All these emissions are converted to their equivalent of kilograms of trichlorofluoromethane (CFC-11). The User-KVI is calculated according to:

Equation 13:

$$ODep = Consumed\ Electricity * Emission\ Factor\ CFC11$$

The consumed electricity is measured in kWh and the emission factor CFC-11 is given in kg CFC11-eq./kWh and is determined based on the German energy mix from databases.

3.1.2.4.4 Photochemical Ozone Formation

The User-KVI "photochemical ozone formation, PhOz" describes the formation of ozone on the ground causing photochemical smog in the atmosphere on the ground. As a variety of different substances contribute to the photochemical ozone formation, the contributions are collected by calculation of the equivalent of kilograms of Non-Methane Volatile Organic Compounds (kg NMVOC eq.)

Equation 14:

$$PhOz = Consumed\ Electricity * Emission\ Factor\ NMVOC$$

The consumed electricity is measured in kWh and the emission factor NMVOC is given in kg NMVOC-eq./kWh and is determined based on the German energy mix from databases.

3.1.2.4.5 Depletion of Abiotic Resources (fossil fuels)

The User-KVI "depletion of abiotic resources (fossil fuels), DepFF" describes the consumption of fossil fuels for the generation of electricity. It is calculated in the following way:

Equation 15:

$$DepFF = Consumed\ Electricity * Emission\ Factor\ Fossil\ Fuels$$

The consumed electricity is measured in kWh and the emission factor fossil fuels is given in MJ/kWh and is determined based on the German energy mix from databases.

3.1.2.5 Description of the Business Potential

For the assessment of the business potential of the developed use cases, a two-fold guiding question has been developed:

> *"What steps are necessary to transfer the solution to industry and how can industry users realize the value proposition of the use case?"*

The Environmental Monitoring use case provides a foundation for the calculation of the environmental footprint of a manufacturing process. As the 5G-integrated sensor platform will already have a relatively high TRL at the end of the project, the solution can be deployed in manufacturing processes without further development soon. Industry users can realize the value proposition of the use case by employing the measured data for the calculation of the environmental footprint of a manufacturing process and employ it for reporting, documentation, and optimization purposes. In this way, manufacturing companies employing the solution cannot only fulfill reporting requirements but also gain competitive advantage by lowering the environmental footprints of their processes and products. The potential competitive advantages represent another implicit value of the use case that might be realizable based on further developments in the future.

3.1.3 Use Case 3: Trace and Tracking of Workpieces

3.1.3.1 Short Description of the Use Case

The Trace and Tracking of Workpieces use case of TARGET-X focuses on the development of a solution for the end-to-end to record of the various positions of a workpiece travelling through a variety of different process stations in a production environment to gather new insights into the process chain that is used for manufacturing. For the use case, the usage of 5G is relevant due the technology's capability to transmit data reliably between a UE on the shopfloor close to the process and an edge server.

Description of the use case product: The outcome of the successful use case execution is end-to-end data on positions and conditions of the tracked workpiece during operation as well as transport between different machines. An in-depth description of this use case can be found in Deliverable 2.4 [TAR24-D24].

3.1.3.2 Evaluation Scenario

The following table describes the evaluation scenario for the Trace and Tracking of Workpieces use case. The depicted evaluation scenario has been developed in collaboration with the responsible use case owner from work package 2 of TARGET-X.

Table 3-7: Evaluation Scenario for the Trace and Tracking of Workpieces Use Case

STEP ID	STEP NAME	STEP DESCRIPTION	RESULT AFTER STEP EXECUTION	RELEVANT PROCESS PARAMETERS
1	Workpiece mounting	Workpiece is mounted with a wireless sensor (accelerometer and gyroscope)	Sensor successfully mounted on workpiece to be monitored	Initial workpiece location expressed through predefined coordinates
2	Workpiece transport	The workpiece is transported between three different stations and processed (milling) at each station	Workpiece location is changed	Transfer time (in seconds) for each transfer
3	Workpiece localization	In parallel to the workpiece transport, the	Registration of different workpiece	Timestamps of individual locations

		localization of the workpiece via Bluetooth triangulation is carried out	locations (localization)	
4	Workpiece tracing	Tracing: Conditions of workpiece are monitored during the different milling processes	Measurement of current conditions of workpiece (vibration based on accelerometer data; orientation based on gyroscope)	- Timestamps of individual locations - Vibration of workpiece during processing (milling) - Acceleration of workpiece during processing (milling)
5	Data transmission	Transmission of tracing information via 5G to an edge server	Current conditions of workpiece are registered in the edge server	- Localization data - Timestamps - Sensor data from accelerometer and gyroscope
6	Data aggregation	Combination of tracking and tracing regarding conditions and localization of the workpiece alongside the recorded timestamps	Generation of track and trace data set for considered workpiece	- Localization data - Timestamps Sensor data from accelerometer and gyroscope
7	Data visualization	Visualization of track and trace data set on a dashboard for monitoring purposes	Track and trace data set visible as timeseries on the shopfloor	Visualization of: - Localization data - Timestamps - Sensor data from

				accelerometer and gyroscope

3.1.3.3 Selected User-KPI

The following table describes the selected User-KPI for the evaluation of the Trace and Tracking of Workpieces use case from a techno-economic perspective. The listed User-KPI have been developed in collaboration with the responsible use case owner from work package 2 of TARGET-X.

Table 3-8: Selected User-KPI for the Trace and Tracking of Workpieces Use Case

TECHNICAL GOAL	USER-KPI
Expanding process insights	Completeness of process and product data
Increasing Process Efficiency	Cycle time
	Throughput

The relevant User-KPI selected for the Trace and Tracking of Workpieces use case are described in the following passage.

3.1.3.3.1 Completeness of Process and Product Data

The described use case will enable the compilation of an end-to-end data set describing the considered product (conditions and locations), forming the base for broader and more in-depth analysis of correlations and impact of each individual process step. Therefore, the explicit value proposition of the use case can be quantified with the User-KPI "completeness of process and product data". Equation 1 and Equation 2 defining the average packet loss for a variety of *n* measurements according to [KIE22] can also be employed here to calculate the completeness of data:

Equation 16

$$L_{total} = \frac{\sum_1^n L_n}{n}$$

The packet loss can then be used to calculate the completeness of the transmitted data set with Equation 2:

Equation 17

$$Completeness\ (\%) = 100 - \ L_{total}$$

3.1.3.3.2 Cycle Time and Throughput

The User-KPI "cycle time" as well as "throughput" have been identified as contributors to an implicit value proposition that can be achieved if further development of the use case is conducted. The gained insights enabled by the increased completeness of the data sets will enable the improvement of performance related parameters like cycle time and throughput since buffer times and overall waste in the process can be identified. As these User-KPI cannot be addressed directly by the use case, equations for their calculation are not provided here.

3.1.3.4 Selected User-KVI

For the Trace and Tracking of Workpieces use case, no User-KVI were defined. As the use case is closely related to the Environmental Condition Monitoring use case (chapter 3.1.2), the societal benefits are addressed by the Environmental Condition Monitoring use case while the Trace and Tracking use cases focuses on the performance improvement and the aspect of learning more about interlinking different manufacturing processes.

3.1.3.5 Description of the Business Potential

For the assessment of the business potential of the developed use cases, a two-fold guiding question has been developed:

"What steps are necessary to transfer the solution to industry and how can industry users realize the value proposition of the use case?"

The data sets that can be compiled based on the implementation of the Trace and Tracking of Workpieces use case can enable a variety of optimization approaches as they enrich the insight into the cause-and-effect relationships within process chains. However, in order to realize the full potential of the use case, the localization functionality of 5G technology needs to be rolled out broadly, so that 5G can be used instead of Bluetooth for the localization of workpieces. If Bluetooth usage can be substituted by 5G for localization purposes, the barriers for use case implementation is decreased as only one technological solution is required for implementation.

3.2 Robotics Vertical

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

3.2.1.1 Short Description of the Use Case

For the Edge-Controlled Automation with Mobile Manipulation use case, a solution focusing on leveraging the technology's potential to enable mobile robotics for (dis)assembly operations is developed. For this purpose, a pick-and-place solution moving a module of a battery pack from location A to location B is implemented utilizing the potential of 5G to enable localization as well as fast communication for data exchange.

Description of the use case product: The outcome of the successful use case execution results in a reduced execution time of the use case enabled by a more reliable wireless communication with 5G. An in-depth description of this use case can be found in Deliverable 2.3 [TAR24-D23].

3.2.1.2 Evaluation Scenario

The following table describes the evaluation scenario for the Edge-Controlled Automation with Mobile Manipulation use case. The depicted evaluation scenario has been developed in collaboration with the responsible use case owner from work package 2 of TARGET-X.

Table 3-9: Evaluation Scenario for the Edge-Controlled Automation with Mobile Manipulation Use Case

STEP ID	STEP NAME	STEP DESCRIPTION	RESULT AFTER STEP EXECUTION	RELEVANT PROCESS PARAMETERS
1	Initial self-localization	Self-localization of mobile manipulator (MM) utilizing sensor fusion of 2D and 3D LiDAR data and transmitting the fused data to an edge server (uplink)	Precise localization of current MM position	- 2D and 3D LiDAR data - Accuracy of localization: Percentage deviation between digital position and real-world position - Timestamp
2	Path planning I	The transmitted data is used on the edge server to plan the path which the MM will travel. The defined path and the according control functions are	MM received the planned path and starts moving to first workstation.	Planned path for MM.

		sent back from the edge server to the MM onboard system (downlink). MM start to execute the planned movements and moves to first workstation (first desk).		
3	Object scanning	MM moves its arm into a scanning pose to the scan the object which is to be picked up on the first workstation (module of a battery pack).	MM ready to pick up targeted module of a battery pack.	Camera data for object scanning.
4	Object picking	MM moves its end-effector to the targeted module of a battery pack and closes the gripper to pick up the battery pack. Afterwards, the MM moves its arm with the end-effector into a transport pose for safe handling of the module of the battery pack to be transported.	Module of the battery pack picked up from desk and ready for transport.	Number of required picking attempts to successfully grab the module of the battery pack with the end-effector.
5	Path planning II	On the edge server, the path	MM received the planned path	Planned path for MM.

		from the first workstation to the second one is planned. The planned path and the according control functions are sent back to the MM. MM start to move to the second workstation upon reception of the message from the edge server.	and starts moving to second workstation.	
6	Scanning of placing space	Upon arrival at the second workstation, the MM scans the placing space at the second workstation.	Scanned placing space at second workstation for placement of the transported module of the battery pack.	Camera data with scanning data.
7	Module of the battery pack placements	MM moves its end-effector to the placing space with the orientation for object placing, opens the gripper, releases the module of the battery pack and retracts the arm.	Object successfully placed on second workstation.	
8	Return to initial position	After successfully placing the module of the battery pack, the	MM back at initial position	Timestamp

		robot navigates back to the initial position.		

3.2.1.3 Selected User-KPI

The following table describes the selected User-KPI for the evaluation of the Edge-Controlled Automation with Mobile Manipulation use case from a techno-economic perspective. The listed User-KPI have been developed in collaboration with the responsible use case owner from work package 2 of TARGET-X.

Table 3-10: Selected User-KPI for the Edge-Controlled Automation with Mobile Manipulation Use Case

TECHNICAL GOAL	USER-KPI
Increasing operational capability	Process capability (c_p & c_{pk})
Increasing process efficiency	Cycle time
	Throughput
	First-pass yield
	Overall Equipment Efficiency, OEE

The relevant User-KPI selected for the Edge-Controlled Automation with Mobile Manipulation use case are described in the following passage. All described User-KPI are expected to have an explicit value proposition, so that the added value can immediately have an impact on a production system.

3.2.1.3.1 Process Capability (c_p & c_{pk})

The User-KPI "process capability" describes the ability of the process to produce output within certain specification limits. This User-KPI is stated as an explicit and direct value proposition for the Edge-Controlled Automation with Mobile Manipulation use case as a direct analysis of the impact of 5G on the process capability can be tested. The values for c_p and c_{pk} can be calculated with the following equations [SCH15]:

Equation 18:

$$c_p = \frac{UT + LT}{6\sigma}$$

Equation 19:

$$c_{pk} = \frac{\min\,(UT - \ \bar{x};\ \bar{x} - LT)}{3\sigma}$$

UT describes the upper tolerance limit and *LT* the lower tolerance limit so that they both together define the specifications limits for the process output. The parameter σ describes the standard deviation of the considered process parameter and $\bar{x}$ describes the mean of the considered value.

For the use case at hand this can be overall execution time that can be derived from the timestamps recorded during the execution of the evaluation scenario.

3.2.1.3.2 Cycle Time

The cycle time describes the time needed for production of one unit in the production system. For the use case at hand, the cycle time describes the time needed for the successful transportation of the battery pack from the initial self-localization to the return of the mobile manipulator to the initial position. Thus, the following equation is used for calculation of the cycle time:

Equation 20:

$$Cycle\ time\ = \frac{Total\ Execution\ Time}{Number\ of\ Conducted\ Operations}$$

If only one operation is conducted, the cycle time is equal to the total execution time. By calculation of the cycle time, the immediate impact of 5G communication on the execution time can be demonstrated. The expected improvement of the cycle time can be justified with a more stable wireless communication enabled by 5G.

3.2.1.3.3 Throughput

The User-KPI “throughput” quantifies the productivity of a production system by dividing the total produced quantity by the uptime of the production system. With this User-KPI, the impact of 5G on the availability of the mobile manipulator can be calculate using the following equation:

Equation 21:

$$Throughput = \frac{Produced\ Quantity}{Uptime\ of\ Mobile\ Manipulator}$$

The expected improvement of the throughput can be justified with a more stable wireless communication enabled by 5G.

3.2.1.3.4 First Pass Yield

The User-KPI “first-pass yield” describes how well the process can be executed after an adaptation has been conducted (e.g. a new product is supposed to be transported or new workstations have been added). For the calculation of the User-KPI the following equation has been defined:

$$First\ pass\ yield = \frac{First\ time\ good\ quantity}{Inspected\ quantity}$$

3.2.1.3.5 Overall Equipment Efficiency

The User-KPI “Overall Equipment Efficiency, OEE” has been defined to evaluate efficiency of the use case when it is executed according to the defined evaluation scenario. It is determined by the calculation of the three metrics availability, performance, and quality.

Equation 22:

$$OEE = Availability * Performance * Quality$$

Equation 23:

$$Availability = \frac{Operating\ Time}{Planned\ Production\ Time}$$

Equation 24:

$$Performance = \frac{Ideal\ Cycle\ Time * Total\ Units\ Produced}{Operating\ Time}$$

Equation 25:

$$Quality = \frac{Good\ Units}{Total\ Units\ Produced}$$

Together with the User-KPI cycle time, throughput, and first pass yield, the OEE completes the metrics to evaluate the improvement of process efficiency if the use case is implemented with 5G technology.

3.2.1.4 Selected User-KVI

The following table lists the selected User-KVI for the evaluation of the Edge-Controlled Automation with Mobile Manipulation use case from a societal perspective. The listed User-KVI have been developed in collaboration with the responsible use case owner from work package 2.

Table 3-11: Selected User-KVI for the Edge Controlled Automation with Mobile Manipulation Use Case

SOCIETAL GOAL	USER-KVI
Improvement of Safety-related Aspects	Work accident rate manufacturing

The relevant User-KVI selected for the Edge-Controlled Automation with Mobile Manipulation use case is described in the following passage. Similar to the User-KVI described in section 3.2.1.3, the User-KVI also offers an explicit value proposition that has immediate impact on the production system.

3.2.1.4.1 Work Accident Rate Manufacturing

As the 5G-based communication is more reliable (less packet loss), it also enables a safer operation of the mobile manipulator as interfering obstacles can be detected more reliably so that the total amount of work accidents (i.e., the robot can react better to obstacles and avoid collisions) can be reduced. The following equation has been defined for the User-KVI "work accident rate manufacturing":

Equation 26:

$$Work\ accident\ rate\ manufacturing = \frac{Total\ number\ of\ accidents}{Operation\ time}$$

3.2.1.5 Description of the Business Potential

For the assessment of the business potential of the developed use cases, a two-fold guiding question has been developed:

"What steps are necessary to transfer the solution to industry and how can industry users realize the value proposition of the use case?"

As the solutions developed for the Edge-Controlled Automation with Mobile Manipulation use case is in a prototypical state, a higher TRL of the solution is required for the transfer to industry. For this purpose, further development of different aspects like environment and object detection, 5G-based localization, and the use of Machine Learning techniques for gripping operations needs to be carried out. Based on these developments, the automation of processes can be implemented, offering manufacturing companies the potential to increase productivity by achieving more stable, efficient, and overall more cost-effective processes that are also not affected by labor shortages.

3.3 Energy Vertical

3.3.1 Use Case 1: Energy Monitoring and Energy Consumption Awareness

3.3.1.1 Short Description of the Use Case

The objective of the Energy Monitoring and Energy Consumption Awareness of Work Package 3 of TARGET-X is developing and deploying a tool, the edgePMU, that enables high-resolution measurements of current and voltage for different energy consumers. The measurement results can be utilized to gather new insights into local grid conditions and energy consumers. In this way, the use case sets a foundation for the analysis of grid characteristics (e.g., voltage levels over time and voltage quality) to detect potential malfunctions in the local grid.

Description of the use case product: The outcome of the successful use case execution is a comprehensive data set describing current, voltage and phasors over the measurement period. This data set also serves as a foundation for analysis of grid characteristics (e.g. voltage levels over time and voltage quality) to detect potential malfunction within the grid. Additional information regarding this use case can be found in Deliverables 3.1, 3.2, and 3.4 [TAR23-D31], [TAR23-D32], [TAR24-D34].

3.3.1.2 Evaluation Scenario

The following table describes the evaluation scenario for the Energy Monitoring and Energy Consumption Awareness use case. The depicted evaluation scenario has been developed in collaboration with the responsible use case owner from work package 3 of TARGET-X.

Table 3-12: Evaluation Scenario for the Energy Monitoring and Energy Consumption Awareness Use Case

STEP ID	STEP NAME	STEP DESCRIPTION	RESULT AFTER STEP EXECUTION	RELEVANT PROCESS PARAMETERS
1	Installation	The edgePMU is installed at a test site (laboratory with different energy consumers: server, machining equipment from mechanical workshop, measurement equipment. The edgePMU is also connected to a 5G network for data transmission to the edge cloud for computation offloading (data storage and analysis)	Successful installation of edgePMU so that measurements can be conducted.	
2	Measurements	Long term measurements (up to approx. 6 months)	Compiled data set of current	Availability and uptime

		of current and voltage during daily operation of the monitored energy consumers in the laboratory. Measured data is transferred to the edge cloud via 5G.	and voltage of the measurement period.	describing the completeness of measurements over the measurement period.
3	Post processing	Calculation of phasors with current and voltage (phase, amplitude, frequency, rate of change of frequency [rocof]). Calculations are conducted on the edge cloud (computation offloading).	Data set enhanced with calculated phasors (data augmentation)	
4	Long term data storage	Acquired and enhanced data sets are stored to enable deepening of research in potential follow up projects.		

3.3.1.3 Selected User-KPI

The following table describes the selected User-KPI for the evaluation of the Energy Monitoring and Energy Consumption Awareness use case from a techno-economic perspective. The listed User-KPI have been developed in collaboration with the responsible use case owner from work package 3 of TARGET-X.

Table 3-13: Selected User-KPI for the Energy Monitoring and Energy Consumption Awareness Use Case

TECHNICAL GOAL	USER-KPI
Expanding Process Insights	Completeness ratio of process data
Increasing operational capability	Increased observability of critical events

The relevant User-KPI selected for the Energy Monitoring and Energy Consumption Awareness use case are described in the following passage.

3.3.1.3.1 Completeness of Process Data

The measurement with the edgePMU combined with the use of 5G enables higher resolutions for measurements by an increase of sampling rates. Furthermore, computation offloading to the edge cloud which is also enabled using 5G increases the quality of the calculations and thereby the detectability of events (voltage drops). As a result, the completeness of measurement data is increased through the impact of 5G when compared to the use of WiFi.

The equation to calculate the difference regarding the completeness ratio of data is defined as follows:

Equation 27:

$$Completeness\ ratio = \frac{Data\ set\ size_{5G}}{Data\ set\ size_{WiFi}}$$

If the completeness ratio is greater than 1, the 5G data set is more complete than the WiFi one. Additional comparisons like the number of entries as well as a comparison of missing entries over the same time frame for both data sets can be added to refine the analysis of the completeness ratio. The User-KPI completeness is expected to provide an explicit value proposition, so that the added value can immediately have an impact on the monitoring of local grids.

3.3.1.3.2 Increased Observability of Critical Events

The edgePMU that is being developed in WP 3 of TARGET-X offers a solution for grid monitoring that can be implemented in large number, predominantly due to low costs. As a results, the observability of critical events (variance in the rate of change of frequency and amplitude of voltage) in local grids increases, since a large number of devices can be implemented for moderate overall costs. The prospect of these benefits being realized in the future is addressed here with the User-KPI “increased observability of critical events”. Since this User-KVI only has an implicit value proposition, no concrete equation is stated here.

3.3.1.4 Selected User-KVI

For the Energy Monitoring and Energy Consumption Awareness use case no User-KVI were defined. The sustainability related KVI that are enabled by energy monitoring with solutions developed in WP 3 are addressed with the 5G for Energy Analytics of Construction Processes use case of WP 5 (see 3.5.3.4)

3.3.1.5 Assessment of the business potential

For the assessment of the business potential of the developed use cases, a two-fold guiding question has been developed:

“What steps are necessary to transfer the solution to industry and how can industry users realize the value proposition of the use case?”

As described in the User-KPI section the value proposition of the Energy Monitoring and Energy Consumption Awareness use case is an increase in observability of events in the local grid. To realize this in industry, a large-scale deployment of edgePMUs is necessary so that a broad data basis is built. As the TRL of the developed solution is already relatively high, deployments could start within a short time horizon. Industry users can realize the use case’s value proposition by analyzing the data gathered by a large-scale deployment to learn more about cause-and-effect relationships within the grid, so that further optimization approaches can be derived based on the findings.

3.4 Automotive Vertical

3.4.1 Use Case 1: Cooperative Perception

3.4.1.1 Short Description of the Use Case

The cooperative perception use case can be realized in two slightly different scenarios. In the first scenario, two vehicles (Vehicle A and Vehicle B) approach an intersection with no visibility of each other. This scenario is also used for the evaluation of the use case so that it is described in the evaluation scenario of the use case in section 3.4.1.2.

In the second scenario, a roadside damaged (Vehicle B) vehicle is in the same path as another vehicle in movement (Vehicle A) so that Vehicle B potentially blocks the way of Vehicle A. The complexity in this scenario is the lack of visibility due to weather conditions (e.g., heavy rain, fog, or snowfall). Thanks to the CAMs and CPMs messages sent by the vehicles (both from the damaged vehicle as well as the moving vehicle), the C-ITS (Cooperative Intelligent Transport System) will be able to warn both vehicles regarding a collision risk. For both scenarios, a cooperative perception of the environment of both vehicles is implemented using 5G for fast data exchange.

Description of the use case product: The outcome of the successful use case execution is the implementation of a safety feature to increase passenger safety by warning drivers ahead of potential collisions through forecasting based on cooperative perception. Additional information regarding this use case can be found in Deliverable 4.2 [TAR24-D42].

3.4.1.2 Evaluation Scenario

The following table describes the evaluation scenario for the Cooperative Perception use case. The evaluation of this use case will only be carried out for the situation in which the two vehicles approach the intersection. The depicted evaluation scenario has been developed in collaboration with the responsible use case owner from work package 4 of TARGET-X.

Table 3-14: Evaluation Scenario for the Cooperative Perception Use Case

STEP ID	STEP NAME	STEP DESCRIPTION	RESULT AFTER STEP EXECUTION	RELEVANT PROCESS PARAMETERS
1	Setup	Two vehicles (vehicle A and vehicle B) approach an intersection without any visibility of each other.		
2	Data transmission	Measurement data is transmitted via 5G between the two vehicles to	Measurement data from both vehicles is available on the	- Measurement data from vehicles (speed,

		the C-ITS service.	C-ITS service (cloud).	distance, trajectory - Latency of data transfer from vehicle to C-ITS
3	Collision forecasting	On the C-ITS, an estimation of the trajectories of the vehicles is calculated based on the transmitted measurement data. Calculated trajectories are employed to make a forecast for potential collisions, so that these collisions can be avoided.	Forecast of time of collision and area of collision.	- Trajectory - Forecasted time to potential collision - Forecasted area of potential collision
4	Issuing of warning message	In case a collision is forecasted, a warning message is issued and sent to the vehicles where it is displayed on the vehicle HMI. Warning message contains warning icon with “Collision Risk!” statement.	Drivers of affected vehicle are warned about the potential collision.	- System reaction time (max. 150 ms)

5	Braking maneuvers	Braking maneuver is carried out by the driver (both vehicle A and vehicle B) upon reception of the collision warning message.	Collision of the vehicles is prevented by braking of both vehicles.	- Human reaction time (min. 200 ms)

3.4.1.3 Selected User-KPI

The following table shows the selected User-KPI for the Cooperative Perception use case from a techno-economic perspective. The User-KPI has been developed in collaboration with the responsible use case owner from work package 4.

Table 3-15: Selected User-KPI for the Cooperative Perception Use Case

TECHNICAL GOAL	USER-KPI
Increasing operational capability	Process capability (c_p & c_{pk})

The relevant User-KPI selected for the Cooperative Perception use case is described in the following passage. The User-KPI is expected to have an explicit value proposition, so that the added value can immediately have an impact on automotive solutions.

3.4.1.3.1 Process Capability (c_p & c_{pk})

The User-KPI "process capability" describes the ability of the process to produce output within certain specification limits. This User-KPI indicates how stable the use case is and how reproducible the outcomes of the use case are. The values for c_p and c_{pk} can be calculated with the following equations [SCH15]:

Equation 28:

$$c_p = \frac{UT + LT}{6\sigma}$$

Equation 29:

$$c_{pk} = \frac{\min\,(UT - \ \bar{x};\ \bar{x} - LT)}{3\sigma}$$

UT describes the upper tolerance limit and *LT* the lower tolerance limit so that they both together define the specifications limits for the process output. The parameter σ describes the standard deviation of the considered process parameter and $\bar{x}$ describes the mean of the considered value. For the use case at hand this is the system reaction time which always needs to be around 150 ms for the use case to be operated safely. The user KPI process capability can be used to determine whether the system is working properly, as it makes it possible to check whether the system response time requirement of a maximum of 150 ms is met.

3.4.1.4 Selected User-KVI

The following table lists the selected User-KVI for the evaluation of the Cooperative Perception use case from a societal perspective. The listed User-KVI have been developed in collaboration with the responsible use case owner from work package 4.

Table 3-16: Selected User-KVI for the Cooperative Perception Use Case

SOCIETAL GOAL	USER-KVI
Improvement of Safety-related Aspects	Absolute number of prevented traffic accidents

The relevant User-KVI selected for the Cooperative Perception use case is described in the following passage.

3.4.1.4.1 Absolute Number of Prevented Traffic Accidents

For the calculation of this User-KVI, the difference in the number accidents occurring is determined for the assessment scenario described. Simulations are used to compare how many accidents occur once with C-ITS and once without C-ITS at the intersection under consideration. Based on the simulations, the absolute number of prevented traffic accidents using 5G communication and the C-ITS is calculated according to Equation 30.

Equation 30:

$$Absolute\ Number\ of\ Prevented\ Accidents = n_{no\_CITS} - n_{CITS}$$

$n_{no\_C\text{-}ITS}$: Simulated number of accidents without C-ITS

$n_{C\text{-}ITS}$: Simulated number of accidents with C-ITS

3.4.1.5 Description of the Business Potential

For the assessment of the business potential of the developed use cases, a two-fold guiding question has been developed:

> *"What steps are necessary to transfer the solution to industry and how can industry users realize the value proposition of the use case?"*

The necessary steps to transfer the developed solution if the Cooperative Perception use case to industry include achieving a high TRL so that the solution fulfills industrial requirements regarding safety, reliability, and transparency. After this has been achieved, industry users can implement the developed solution into their solutions to add a safety component making use of the increased awareness of a vehicle's surroundings. The surrounding awareness is an important factor in the domain of autonomous and tele-operated driving, so that the use case can contribute to the overall technical maturity from applications of this domain.

3.4.2 Use Case 2: Digital Twin

3.4.2.1 Short Description of the Use Case

The second use case of the automotive vertical is the digital twin use case. This use case realizes the second scenario of the cooperative perception use case described in 3.4.1.1 with Vehicle A driving behind Vehicle B. The objective of the use case is to build a digital twin as a digital representation of the events occurring in the evaluation scenario described in 3.4.2.2.The created digital twin is then supposed to be used for the simulation of high-risk traffic situations and the development of safety-features based on the simulations of these high-risk situations.

Description of the use case product: The outcome of the successful use case execution is the confirmation of the system's reliability based on the reproducibility of the data. Additional information regarding this use case can be found in Deliverable 4.2 [TAR24-D42].

3.4.2.2 Evaluation Scenario

The following table describes the evaluation scenario for the Digital Twin use case. The depicted evaluation scenario has been developed in collaboration with the responsible use case owner from work package 4 of TARGET-X.

Table 3-17: Evaluation Scenario for the Digital Twin Use Case

STEP ID	STEP NAME	STEP DESCRIPTION	RESULT AFTER STEP EXECUTION	RELEVANT PROCESS PARAMETERS
1	Recording of reference scenario	Record data from a real scenario (Scenario 2 of the cooperative perception use case): Two vehicles are driving in the same lane, the vehicle driving ahead (Vehicle B) of the other vehicle (Vehicle A) brakes abruptly (due to low visibility caused by fog). Vehicle A receives a warning message to avoid the collision with	Recording of reference scenario available for creation of the digital twin.	- CAM - CPM - Both data types are sent from the vehicle to the C-ITS

		Vehicle B utilizing CAMs (Cooperative Awareness Messages) or CPMs (Collected Perception Messages) and conducts a braking maneuver. CAMs and CPMs are recorded to build the digital twin.		
2	Building of digital twin	Employ the recorded data to build the digital twin as a digital representation of the real scenario.	Digital twin is available in a database.	Timestamps from the real scenario based on the CAM & CPM messages (sampling rate: 100 ms for CAM and CPM)
3	Application of digital twin	Application of the digital twin use case to simulate scenario 2 of the Cooperative Perception use case. Comparison of the sequences of scenario 2 (simulated vs. recorded sequence).		- CAM - CPM - Timestamps of CAMs and CPMs
4	Deviation analysis	Analysis of differences/deviations between simulated and recorded sequence for scenario 2.	Validation of the created Digital Twin	- CAM - CPM - Timestamps of CAMs and CPMs

		Insights gives indications on how precise the digital twin models the real world Insights gives indications on how precise the digital twin models the real world.		

3.4.2.3 Selected User-KPI

No technical User-KPI have been defined for this use case, as it is based on the cooperative perception of vehicles use cases and focuses exclusively on safety aspects as well. However, the aspect of cost cutting enabled by usage of digital twins for testing purposes shall be emphasized here. This represents an implicit value proposition, as further development of the solutions is required to realize the economic potential of the use case. Nevertheless, economic benefits can be predicted, as the required effort for physical testing of automotive solutions can be reduced by employing simulations based on the digital twin use case, particularly for early-stage testing. In this way, the overall development costs can be decreased, so that the foreseeable time to market of newly developed solutions can also be reduced. This economic benefit is addressed with the User-KPI NPV and RoI.

3.4.2.4 Selected User-KVI

The following table lists the selected User-KVI for the evaluation of the Digital Twin use case from a societal perspective. The listed User-KVI have been developed in collaboration with the responsible use case owner from work package 4.

Table 3-18: Selected User-KVI for the Digital Twin Use Case

SOCIETAL GOAL	USER-KVI
Improvement of Safety-related Aspects	Absolute number of prevented traffic accidents (simulated)

The relevant User-KVI selected for the Digital Twin use case is described in the following passage.

3.4.2.4.1 Absolute Number of Prevented Traffic Accidents

The creation of the digital twin enables the digital reproduction/creation of high-risk situations for testing purposes without the need to reproduce high risk situations on the real test track. Therefore, the same calculation rule is used as in 3.4.1.4.1:

Equation 31:

$$Absolute\ Number\ of\ Prevented\ Accidents = n_{no\_CITS} - n_{CITS}$$

$n_{no\_C\text{-}ITS}$: Simulated number of accidents without C-ITS

$n_{C\text{-}ITS}$: Simulated number of accidents with C-ITS

For both use cases, Cooperative Perception as well as Digital Twin, the value proposition is rather implicit as further development based on the results achieved in TARGET-X is required to provide quantifiable added value in real-world application. However, the development work makes an important contribution to the further development of safety features.

3.4.2.5 Description of the Business Potential

As the Digital Twin use case is based on the Cooperative Perception use case, no additional description of the business potential is added here. For a description of the business potential of the Cooperative Perception use case, see 3.4.1.5.

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

3.4.3.1 Short Description of the Use Case

For this use case a scenario is defined with two vehicles, Tele-operated Vehicle (ToV) A and Tele-operated (ToV) Vehicle B traveling a defined route with the tele-operation being realized by 5G communication. On this route, a degradation of the Quality of Service (QoS) occurs at some point, that would cause the ToVs to stop due to low network coverage. Here the prediction of the QoS comes into play, allowing ToV B to avoid the low coverage area by detouring.

Description of the use case product: The outcome of the successful use case execution is ToV B avoiding low coverage areas and reaching the targeted destination based on the prediction of the QoS along the route travelled. Additional information regarding this use case can be found in Deliverable 4.2 [TAR24-D42].

3.4.3.2 Evaluation Scenario

The following table describes the evaluation scenario for the Predictive Quality of Service for Tele-operated Vehicles use case. The depicted evaluation scenario has been developed in collaboration with the responsible use case owner from work package 4 of TARGET-X.

Table 3-19: Evaluation Scenario for the Predictive Quality of Service for Tele operated Vehicles Use Case

STEP ID	STEP NAME	STEP DESCRIPTION	RESULT AFTER STEP EXECUTION	RELEVANT PROCESS PARAMETERS
1	Initial routing	Two cars (ToV A and ToV B) are travelling a defined route. Dijkstra-Algorithm has been used to define the best route for both ToVs with ToV B being aware of bad radio cells along the route. ToV A travels on route type 1 without prediction function regarding QoS (only uses GPS). ToV B travels on route type 2 with prediction function of QoS (additional layer “network map” on Google Maps indicating areas on the map with low coverage).	Best route is chosen for each ToV from a variety of different routes. Routes are evaluated for both ToVs differently so that the best route for ToV A is different from the best route for ToV B.	- Initial location - Targeted destination - Starting timestamp - QoS (coverage) along route type 2 for ToV B
2	ToV A: Loss of connection	Loss of connection due to a problem of coverage in a certain network cell that is necessary for ToV A to successfully travel a defined route. The problem of the network is static. ToV A stops without rerouting.	ToV A stops and is stuck on the road.	- Location ToV A - Distance of travelled km - Timestamp of vehicle stop
3	ToV B: Rerouting	Degrading QoS along route type 2 is predicted so that a rerouting of ToV B is initiated to avoid the low coverage area.	New route chosen for ToV B.	- Location of ToV B - Load of radio cell (radio resource block, combination

				of time & bandwidth) - Network status (radio cell up or down) - Optimal chosen routes (key parameter: travel time to target)
4	ToV B: Arrival at destination	ToV B avoids low coverage area through rerouting and arrives at the targeted destination.	ToV B reaches destination through rerouting.	- Timestamp of arrival

3.4.3.3 Selected User-KPI

The following table describes the selected User-KPI for the evaluation of the Predictive Quality of Service for Tele operated Vehicles use case from a techno-economic perspective. The listed User-KPI have been developed in collaboration with the responsible use case owner from work package 4 of TARGET-X.

Table 3-20: Selected User-KPI for the Predictive Quality of Service for Tele operated Vehicles Use Case

TECHNICAL GOAL	USER-KPI
Increasing operational capability	Process capability (c_p & c_{pk})
Increasing process efficiency	Cycle time
	Worker efficiency

The relevant User-KPI selected for the Predictive Quality of Service for Tele-operated Vehicles use case are described in the following passage.

3.4.3.3.1 Process Capability (c_p & c_{pk})

The User-KPI "process capability" describes the ability of the process to produce output within certain specification limits. This User-KPI is stated as an explicit and direct value propositions for the Predictive Quality of Service for Tele-operated Vehicles use case as a direct analysis of the impact of 5G on the process capability can be tested. As for the other use cases for that process capability has been selected as a relevant User-KPI, the values for c_p and c_{pk} are calculated with the following equations [SCH15]:

Equation 32:

$$c_p = \frac{UT + LT}{6\sigma}$$

Equation 33:

$$c_{pk} = \frac{\min\,(UT - \bar{x};\ \bar{x} - LT)}{3\sigma}$$

UT describes the upper tolerance limit and *LT* the lower tolerance limit so that they both together define the specifications limits for the process output. The parameter σ describes the standard deviation of the considered process parameter and $\bar{x}$ describes the mean of the considered value. For the use case at hand this is the additional travel time which is needed after re-routing of the vehicle. This additional travel time should always be within pre-defined specification limits, as users of the service would not want to have a lot of scatter or variance in the travel times. Therefore, it can be stated that the use case only provides a real value proposition to the user when the result of re-routing is within specification limits so that a reproducibility of travel times is achieved.

3.4.3.3.2 Cycle Time

The cycle time describes the time needed for the execution of a certain number of operations divided by the total sum of conducted operations. For the use case at hand, the cycle time describes the time needed for the successful transportation of a passenger from the starting point to the targeted destination. As already described in 3.4.3.3.1 the travel time is calculated for the evaluation of the value proposition of the use case. Thus, the following equation is used for calculation of the cycle time:

Equation 34:

$$Cycle\ Time\ = \frac{Total\ Execution\ Time}{Number\ of\ Conducted\ Operations}$$

3.4.3.3.3 Worker Efficiency

The User-KPI “worker efficiency” is expected to be positively affected by the use case since it enables workers controlling tele-operated vehicles to work on more operations. If the cycle time is optimized (decreased) less time is spent on each individual tele-operated driving session. This results in the workers being able to work on more remote operations at the same time. Worker efficiency can be calculated with the following equation

Equation 35:

$$Worker\ Efficency = \frac{Total\ Number\ of\ Operations}{Personnel\ Work\ Time}$$

The parameter “Total Number of Operations” describes the sum of all tele-operations conducted by a specific worker and the parameter “Personnel Work Time” describes the attendance time of the considered worker at their workplace. The value proposition that is expected from the implementation of this use case is explicit as it will come into effect immediately when the use case is implemented.

3.4.3.4 Selected User-KVI

No dedicated User-KVI has been defined for the Predictive Quality of Service for tele-operated vehicles as the use case has a strong focus on the technical implementation. However, the use case can provide an important contribution to the adoption of tele-operated driving as it addresses the aspect of perceived quality (perceived by the end user). This aspect is briefly covered in the next section and will be taken into consideration for the evaluation of the use case.

3.4.3.5 Description of the Business Potential

For the assessment of the business potential of the developed use cases, a two-fold guiding question has been developed:

> *"What steps are necessary to transfer the solution to industry and how can industry users realize the value proposition of the use case?"*

The most important prerequisite for the transfer of the use case to industry is an increase of technical maturity so that the solution offers a reliable, safe, and transparent way to realize the tele-operation of vehicles on public roads. If the required technical maturity has been achieved, industry users can employ the technology to realize the value proposition of tele-operated driving which includes predominantly safety enhancements enabled by interventions of human operators as well as overall more efficient operations enabled by real-time monitoring and control of vehicles on a large scale. Besides this, the developed solution is estimated to have a positive impact on the perceived quality of tele-operated driving services offering a seamless adaption of routes in case a degradation of network coverage is predicted. In this way, the use case represents an important component of the aspect of technology adoption which then in turn will lead to a broader application of this digitally enabled service. The evaluation of this use case will also take this aspect into consideration.

3.5 Construction Vertical

3.5.1 5G for Automation of Deconstruction Processes

3.5.1.1 Short Description of the Use Case

The objective of the use case is to automate a deconstruction task on a construction site through the collaboration of a human on-site worker and a deconstruction robot. 5G is used to establish a real-time communication on the construction site between specific user equipment (UE) which in this case is a 5G-enabled tablet and the robot

Description of the use case product: The outcome of the successful use case execution is an automated deconstruction process on a construction site utilizing a robot and 5G communication. Additional information regarding this use case can be found in Deliverable 5.2 [TAR24-D52].

3.5.1.2 Evaluation Scenario

The following table describes the evaluation scenario for the 5G for Automation of Deconstruction Processes use case. The depicted evaluation scenario has been developed in collaboration with the responsible use case owner from work package 5 of TARGET-X and makes use of standardized process representations of construction processes defined by the Internet of Construction (IoC) ontology [KIR24], [BRE24].

Table 3-21: Evaluation Scenario for the 5G for Automation of Deconstruction Processes Use Case

STEP ID	STEP NAME	STEP DESCRIPTION	RESULT AFTER STEP EXECUTION	RELEVANT PROCESS PARAMETERS
1	Task Assignment	On-site worker receives a task to be carried out using a tablet.	Task assigned to the on-site worker.	- Information on to be deconstructed element (see XR Use Case)
2	Machine and Structure Identification	On-site worker goes to the deconstruction machine (mobile industrial robot) designated for the deconstruction task and scans the marker on the machine as well as the marker on the structure containing the to be	Markers are scanned so that more information is sent to the on-site worker.	- Process step - Process status - Timestamp when operation starts (starts with scanning of markers) - Three markers for object recognition: 1) Marker on the robot 2) Marker on the structure (ReStage)

		deconstructed building elements. Upon scanning of the markers, the on-site worker receives more information on the to be deconstructed building elements.		3) Marker on the building element (to be deconstructed)
3	Selection of Building Elements	On-site worker selects building elements that are to be deconstructed on the tablet	Building elements which are to be deconstructed have been selected by on-site worker.	- Process step - Process status - Timestamp
4	Trajectory Visualization	On the tablet, a simulation of the robot's trajectory is carried out from its current position to the building element that is to be deconstructed. Afterwards, the on-site worker confirms the suggested trajectory.	Trajectory of robot arm confirmed by on-site worker.	- Process step - Process status - Timestamp - Robot arm trajectory
5	Data Transmission and Setup	Robot receives target position data of the elements from XR application via 5G.	Robot has received the target position and is ready to start the task execution.	- Process step - Process status - Timestamp - Coordinates of the to be deconstructed elements and

		A static depth camera mounted in front of the robot monitors the operation to enable avoiding collisions happening during the deconstruction process.		end effector (mounted on robot) - Rotation (arm movement in degree) of each joint of the robot - Depth measurement, space awareness, human detection
6	Marker Recognition and Robot Arm Movement	The camera on the end effector recognizes the marker that is on the steel beam (building element), end effector then moves to the precise position for gripping of the building element. Visual feedback from the camera is sent to the tablet via 5G to provide further supervision by the on-site worker.	Robot arm has moved to targeted building element.	- Process step - Process status - Timestamp - RGB information - video stream from camera on robot arm to on-site worker
7	Gripping with Robot Arm	Once the precise position for gripping has been reached by the end effector, a command is sent automatically to activate the	Magnetic gripper of robot arm has gripped the targeted building element.	- Process step - Process status - Timestamp

		magnetic gripper.		
8	Fastener Loosening	The on-site worker then loosens the fasteners (screws), of the building element which the robot will lift.	Targeted building element no longer attached and removable from initial position	- Process step - Process status - Timestamp
9	Lift of Building Element	The robot lifts the building element and carries the deconstructed steel beam onto an AGV.	Building element removed from initial position by robot arm	- Process step - Process status - Timestamp
10	Transport	The AGV transports the element to a loading area	Building element transported to loading area	- Process step - Process status - Timestamp
11	Confirmation that the Task has Been Completed	After the successful execution of the deconstruction operation, the on-site worker confirms the results on the tablet.	Task assigned to the on-site worker completed successfully.	- Process status - Timestamp of confirmation of successful operation

3.5.1.3 Selected User-KPI

The following table describes the selected User-KPI for the evaluation of the 5G for Automation of Deconstruction Processes use case from a techno-economic perspective. The listed User-KPI have been developed in collaboration with the responsible use case owner from work package 5 of TARGET-X.

Table 3-22: Selected User-KPI for the 5G for Automation of Deconstruction Processes Use Case

TECHNICAL GOAL	USER-KPI

Expanding of Process Insights	Completeness of process data
	Reliability of process data
Increasing operational Capability	Process capability (c_p & c_{pk})
Increasing process efficiency	Throughput
	Worker efficiency

The User-KPI selected for the evaluation of this use case are described in the following passage.

3.5.1.3.1 Completeness of Process Data

The detailed tracking of process steps, statuses and time stamps makes it possible to gain extended process insights through the previously unestablished use of wireless communication technologies such as 5G. In this way, the deconstruction processes can be monitored in detail for the first time. In addition, the overall execution time can - for the first time for this process - be calculated based on the recorded times stamps, process steps and statuses. Unlike the manufacturing related use cases, the completeness of process data is not calculated with the packet loss in this use case.

Instead, the User-KPI completeness of process data is estimated by analysis of the recording logs for process step, process status, and the respective timestamps. No target value is defined for this User-KPI as the successful execution of each step must be acknowledged by the Human Operator in order to be able to start the next process step. In this way, the completeness of process data is increased immediately: a digital image of the executed process is available after its successful execution and creates a basis for further analyses and optimizations. As no digital image would be available without the use of 5G, no equation to quantify the impact of the use of 5G is stated at this point. However, the completeness of data will be illustrated by stating the amount of acquired data logs during use case execution so that an approximate order of magnitude for the impact of the use of 5G can be conveyed.

3.5.1.3.2 Reliability of Process Data

Due to the increased completeness of process data, the data describing the production process also leads to more reliable insights into the process. As the reliability of process data was zero before the use case was implemented with 5G, an equation-based description of a calculation rule for the reliability of the gathered insights cannot be stated.

3.5.1.3.3 Process Capability (c_p & c_{pk})

The overall execution time was selected as the input parameter for the calculation of the process capability. The User-KPI describes the ability of the process to produce output within certain specification limits. This User-KPI is stated as an explicit and direct value propositions for the 5G for Automation of Deconstruction Processes use case as a direct analysis of the impact of 5G on the process capability can be tested. As for the other use cases for that process capability has been selected as a relevant User-KPI, the values for c_p and c_{pk} are calculated with the following equations [SCH15]:

Equation 36:

$$c_p = \frac{UT + LT}{6\sigma}$$

Equation 37:

$$c_{pk} = \frac{\min\,(UT - \bar{x};\, \bar{x} - LT)}{3\sigma}$$

UT describes the upper tolerance limit and *LT* the lower tolerance limit so that they both together define the specifications limits for the process output. The parameter σ describes the standard deviation of the considered process parameter and $\bar{x}$ describes the mean of the considered value. For the 5G for Automation of Deconstruction Processes use case this is the overall execution time which is the sum of all timestamps record during execution of the defined evaluation scenario. From a user's perspective, the automation of the process offers a higher benefit if the process execution time is not subject to scatter or variance and always produces outputs within predefined specification limits.

3.5.1.3.4 Throughput

Labor shortage is a significant bottleneck on construction sites frequently delaying the finalization of construction projects. The 5G for Automation of Deconstruction Processes offers an explicit value proposition by increasing the throughput on a construction site:

Equation 38:

$$Throughput = \frac{Conducted\ Deconstruction\ Operations}{Time\ of\ Work\ Shift}$$

The automation of deconstruction process is expected to have a positive impact on the User-KPI "throughput" as more deconstruction processes can be conducted in the same period of one work shift on the construction site.

3.5.1.3.5 Worker Efficiency

Next to the impact of the 5G-enabled automation on the actual throughput, a positive impact is also expected on the efficiency of worker on the construction site, as more operations can be conducted at the same time due to the automation of certain tasks. The worker efficiency is calculated with the following equation:

Equation 39:

$$Worker\ Efficency = \frac{Total\ Number\ of\ Operations}{Personnel\ Work\ Time}$$

The expected value proposition is also explicit as the impact of the improvement will results in an immediately added value.

3.5.1.4 Selected User-KVI

The following table lists the selected User-KVI for the evaluation of the 5G for Automation of Deconstruction Processes use case from a societal perspective. The listed User-KVI have been developed in collaboration with the responsible use case owner from work package 5.

Table 3-23: Selected User-KVI for the 5G for Automation of Deconstruction Processes Use Case

SOCIETAL GOAL	USER-KVI
Improvement of Safety-related Aspects	Work accident rate construction

The User-KVI selected for this use case is described in the following passage.

3.5.1.4.1 Work Accident Rate Construction

A positive impact on the work accident rate on construction sites is expected since the physical separation of the worker from the physical process, accidents can be avoided in the first place. The work accident rate is calculated with the following equation:

Equation 40:

$$Work\ accident\ rate\ construction = \frac{Total\ number\ of\ accidents}{Time\ of\ Work\ Shift}$$

For the calculation of the work accident rate for the construction site, the total number of accidents occurred is divided by the total operation time that is based on the time of work shifts on the construction site. This User-KVI can only be calculated based on expert assumptions as the total number of accidents can only be simulated.

3.5.1.5 Description of the Business Potential

For the assessment of the business potential of the developed use cases, a two-fold guiding question has been developed:

"What steps are necessary to transfer the solution to industry and how can industry users realize the value proposition of the use case?"

As indicated by the User-KPI and User-KVI selected for this use case, the overall value proposition of this use case is the automation of a deconstruction process that used to be done manually before automation was enabled using 5G communication. To transfer the solution to industry, further development to increase the technical maturity of the developed solution is required. In addition, extensive testing is required to verify the safety of the automation. If the automation can be realized and deployed on a large scale on construction site, the use case has the potential to significantly increase the efficiency and productivity of construction sites, while at the same time contributing to an increase in safety during operations.

3.5.2 5G for Mixed Reality Supported Deconstruction Planning

3.5.2.1 Short Description of the Use Case

The objective of the considered use case is to enable the use of mixed reality (MR) applications to provide information specific to the situation and context which a human worker on the construction site is in. For this purpose, the use case employs a 5G-enabled tablet to conduct planning, documentation, and visualization tasks on the construction site.

Description of the use case product: The outcome of the successful use case execution is an improvement of planning, documentation, and visualization of deconstruction processes, enabled by the use of MR and 5G communication. Additional information regarding this use case can be found in Deliverable 5.2 [TAR24-D52].

3.5.2.2 Evaluation Scenario

The following table describes the evaluation scenario for the 5G for Mixed Reality Supported Deconstruction Processes use case. The depicted evaluation scenario has been developed in collaboration with the responsible use case owner from work package 5 of TARGET-X.

Table 3-24: Evaluation Scenario for the 5G for Mixed Reality Supported Deconstruction Planning Use Case

STEP ID	STEP NAME	STEP DESCRIPTION	RESULT AFTER STEP EXECUTION	RELEVANT PROCESS PARAMETERS
1	Data Reception	File (in the .ifc format) is received from different vendors (steel, timber, concrete) containing a building model that has been modeled according to BIM (Building Information Modeling). Received file is converted to ontology-based linked building data represented as RDF (Resource Description Framework).	Linked building data is received.	- Linked building data represented in the form of triples in the RDF format.
2	Upload of Linked Building Data to Edge Server	Linked building data is uploaded and hosted on the edge server. Scenario 1: Disassembly order is	BIM is available as linked building data in RDF format on the edge server and so that it can be queried from various	

		available, sent to the edge server and can be updated if needed via UE on construction site. Scenario 2: Disassembly order is not available beforehand and has to be created with UE on the construction site.	locations having access to the edge server.	
3	AR Deployment and Connection	AR application is deployed on UE (tablet with 5G connection) and connection to the edge server is established via 5G.	5G communication between UE and edge server is established.	
4	Anchoring	Marker in the physical world is scanned anchoring the 3D model from the BIM onto it. Background task in backend: Sparql query is created, data is sent to UE, and 3D mesh is rendered in real time onto the physical building element on the UE (superimposing	Digital model is anchored on the physical world and visualized as a 3D model visible on the 5G tablet.	- GUID (Global Unique Identifier) for each element of the BIM to match physical and digital world - All information contained in the BIM is made available from the edge server to the UE (5G tablet)

		of virtual model on top of the physical object)		
5	Interaction and Update	Scenario 1: User can interact with the 3D model to visualize the planned deconstruction task Scenario 2: User can interact with the 3D model to gather information from the respective building data and update disassembly order on UE.	Scenario 1: Deconstruction task available by the information enriched 3D model on the tablet for the user. Scenario 2: Deconstruction task created by user available on the tablet.	
6	Execution	Execution of a certain task (e.g., step 5 of the automation of deconstruction processes)	Execution of targeted task (depending on chosen use case).	
7	Validation	Worker confirms (successful) execution of the targeted task, e.g. for documentation of verification purposes by clicking a confirmation button in the app.	Validation and documentation of executed task uploaded to the edge server in the RDF format.	Parameter: Completeness of the documentation of the executed task

3.5.2.3 Selected User-KPI

The following table describes the selected User-KPI for the evaluation of the 5G for Mixed Reality Supported Deconstruction Processes use case from a techno-economic perspective. The listed User-KPI have been developed in collaboration with the responsible use case owner from work package 5 of TARGET-X.

Table 3-25: Selected User-KPI for the 5G for Mixed Reality Supported Deconstruction Planning Use Case

TECHNICAL GOAL	USER-KPI
Expanding Process Insights	Completeness of process data
	Reliability of process data
Increasing Process Efficiency	Error Rate
	Worker Efficiency

The User-KPI selected for the evaluation of this use case are described in the following section.

3.5.2.3.1 Completeness of Process Data

Regarding the User-KPI completeness of process data, the same principles apply for the 5G for Mixed Reality Supported Deconstruction Planning use case as for the automation use case described in section 3.5.1.3:

The detailed tracking of process steps, statuses and time stamps makes it possible to gain extended process insights through the previously unestablished use of wireless communication technologies such as 5G. In this way, the deconstruction processes can be monitored in detail for the first time. In addition, the overall execution time can - for the first time for this process - be calculated based on the recorded times stamps, process steps and statuses. Unlike the manufacturing related use cases, the completeness of process data is not calculated with the packet loss in this use case.

Instead, the User-KPI completeness of process data is estimated by analysis of the recording logs for process step, process status, and the respective timestamps. No target value is defined for this User-KPI as the successful execution of each step must be acknowledged by the Human Operator in order to be able to start the next process step. In this way, the completeness of process data is increased immediately: a digital image of the executed process is available after its successful execution and creates a basis for further analyses and optimizations. As no digital image would be available without the use of 5G, no equation to quantify the impact of the use of 5G is stated at this point. However, the completeness of data will be illustrated by stating the amount of acquired data logs during use case execution so that an approximate order of magnitude for the impact of the use of 5G can be conveyed.

3.5.2.3.2 Reliability of Process Data

Due to the increased completeness of process data, the data describing the production process also leads to more reliable insights into the process. As the reliability of process data was zero before the use case was implemented with 5G, an equation-based description of a calculation rule for the reliability of the gathered insights cannot be stated.

3.5.2.3.3 Error Rate

As the use case addresses planning, documentation, and information visualization, a positive impact on errors occurring during task execution on the construction site is expected. The error rate can be calculated with the following equation:

Equation 41:

$$Error\ Rate = \frac{n_{Errors}}{Time\ of\ Work\ Shift}$$

n_{Errors}: Total number of errors occurring during the considered work shift

Time of Work Shift: Considered time frame for the analysis of the error rate

For a more detailed analysis of the error rate, a dedicated consideration of certain error types (execution errors, documentation errors, etc.) can be conducted. In this way, more can be learned about the cause-and-effect relationships within the use case.

3.5.2.3.4 Worker Efficiency

The User-KPI "worker efficiency" is also expected to be influenced positively by the implementation of the considered use case. Providing information more precisely in a context and situation specific way on the construction site, will reduce the time needed for information search and cumbersome manual documentation of executed work steps. The time saved can be used for value-adding activities instead, so that the worker efficiency is increased. The worker efficiency is calculated with the following equation:

Equation 42:

$$Worker\ Efficency = \frac{Total\ Number\ of\ Operations}{Personnel\ Work\ Time}$$

The expected value proposition is also explicit as the impact of the improvement will results in an immediately added value.

3.5.2.4 Selected User-KVI

The following table lists the selected User-KVI for the evaluation of the 5G for Mixed Reality Supported Deconstruction Processes use case from a societal perspective. The listed User-KVI have been developed in collaboration with the responsible use case owner from work package 5.

Table 3-26: Selected User-KVI for the 5G for Mixed Reality Supported Deconstruction Planning Use Case

SOCIETAL GOAL	USER-KVI
Digital Inclusion	Digital literacy

The relevant User-KVI selected for the Mixed Reality Supported Deconstruction Processes use case is described in the following passage.

3.5.2.4.1 Digital Literacy

This Use-KVI addresses the digital inclusion of workers on construction sites while utilizing the benefits of digital technologies with the objective to support in the execution of activities on construction sites. While the other User-KPI for this use case can be determined quantitively, for this

User-KVI a qualitative analysis will be carried out to estimate the value proposition of the developed solution by considering usability and user-friendliness. This analysis will be conducted with a questionnaire.

3.5.2.5 Description of the Business Potential

For the assessment of the business potential of the developed use cases, a two-fold guiding question has been developed:

> *"What steps are necessary to transfer the solution to industry and how can industry users realize the value proposition of the use case?"*

As the 5G for Mixed Reality Supported Deconstruction Planning use case is closely interconnected with the 5G for Automation of Deconstruction Processes use case, the same assumptions regarding the business potential of the use case are valid as described in 3.5.1.5. In addition, the use case provides another value proposition which is the aspect of digital inclusion. Enabling the use of tablets on construction sites through 5G technology expands the user base of digital technologies, which can make a significant contribution to digitalization on construction sites. In this way, the situation and context specific provision of information on the construction site does not only make processes more efficient and productive but also allows more users to profit from the benefits of digital technologies.

3.5.3 5G for Energy Analytics

3.5.3.1 Short Description of the Use Case

This use case focuses on the creation of energy profiles for lift operations transporting test loads (like e.g. Ytong blocks or steel beams) to different levels of the ReStage demonstrator on the reference construction site in Aachen, Germany. The ReStage demonstrator is a physical building that was created within WP 5 of TARGET-X to validate the solutions developed in the construction vertical [TAR24-D52]. The overall objective of the 5G for Energy Analytics use case is to gather insights into the consumption of electrical energy caused by the lift operations, so that transparency regarding the environmental footprint can be created. In addition, the energy profiles provide reference or starting points for optimization approaches to decrease the consumption of electricity on construction sites. The use case is developed in collaboration by WP 3 and WP 5.

Description of the use case product: The outcome of the successful use case execution are energy profiles for the characterization of energy consumption of construction processes providing a basis for the derivation of optimization approaches. Additional information regarding this use case can be found in Deliverable 3.4 and Deliverable 5.2 [TAR24-D34], [TAR24-D52].

3.5.3.2 Evaluation Scenario

The following table describes the evaluation scenario for the 5G for Energy Analytics of Construction Processes use case. The depicted evaluation scenario has been developed in collaboration with the responsible use case owner from work package 5 of TARGET-X.

Table 3-27: Evaluation Scenario for the 5G for Energy Analytics of Construction Processes Use Case

STEP ID	STEP NAME	STEP DESCRIPTION	RESULT AFTER STEP EXECUTION	RELEVANT PROCESS PARAMETERS
1	Lift setup	Deployment of Meter-X measurement system and weighing of test loads that are to be transported and loading of them onto the lift.	Setup finished.	- Weight of test load
2	Transport & Measurement	Transport is carried out from ground floor to the first floor and back (approx. 3 m of distance). Different test runs with different test loads of changing overall weight are carried out. During the lift operation, measurements with the Meter-X system are carried out.	Successful completion of the test runs and recording of the energy consumption data.	- Total weight of test loads - Measurement parameters (sampling rate = 1/s): - Electrical power (active and reactive) - Electrical energy (active and reactive) - Voltage and current
3	Data Upload	Upload of Meter-X measurement values onto the edge cloud via 5G.	Measurement data available for analysis in the edge cloud.	Upload capability which is defined by Network-KPI (latency, bandwidth, etc.)
4	Data Analysis & Visualization	Data analysis and derivation of energy profiles (plotting and analysis of measurement values) based on the Meter-X measurement values and the transported test loads.	New insights into the energy consumption of lift operation and creation of an energy consumption profile of the use case.	Identical to Step 2 (Transport & Measurement)

3.5.3.3 Selected User-KPI

The following table describes the selected User-KPI for the evaluation of the 5G for Energy Analytics of Construction Processes use case from a techno-economic perspective. The listed User-KPI have been developed in collaboration with the responsible use case owner from work package 5 of TARGET-X.

Table 3-28: Selected User-KPI for the 5G for Energy Analytics of Construction Processes Use Case

TECHNICAL GOAL	USER-KPI
Expanding Process Insights	Completeness of process data
	Timeliness of process data

The relevant User-KPI selected for the Energy Analytics of Construction Processes use case are described in the following passage.

3.5.3.3.1 Completeness of Process Data

As the employed Meter-X has a sampling rate of 1/s, a continuous data stream is built from the construction site to the edge cloud which is realized by 5G. The value proposition provided by this data can only be fully utilized, if the packet loss is small and the data stream is not interrupted frequently. Therefore, the completeness of data is calculated in the same way as for the manufacturing use cases (see section 3.1 and 3.2). The following equation has been defined for the completeness of data. Equation 1 defines the average packet loss of for a variety of *n* measurements according to [KIE22]:

Equation 43:

$$L_{total} = \frac{\sum_1^n L_n}{n}$$

The packet loss can then be used to calculate the completeness of the transmitted data set with Equation 2:

Equation 44:

$$Completeness\ (\%) = 100 - \ L_{total}$$

For the considered use case, a positive impact and therefore an explicit value proposition is expected regarding the completeness of process data.

3.5.3.3.2 Timelines of Process Data

Next to the completeness of process data, the use of 5G is expected to have a positive impact on the User-KPI “timeliness of process data”. A reduction in packet loss will enable more packets to be delivered on time, so that a real-time insight into the environmental footprint of the process can be created. For the calculation of the timeliness, the following equation will be used:

Equation 45:

$$Timeliness\ (\%) = \frac{Number\ of\ packets\ received\ on\ time}{Total\ number\ of\ packet\ sent}$$

Like the completeness of data, the timeliness will provide an explicit value proposition for the considered use case.

3.5.3.4 Selected User-KVI

The following table lists the selected User-KVI for the evaluation of the 5G for Energy Analytics of Construction Processes use case from a societal perspective. The listed User-KVI have been developed in collaboration with the responsible use case owner from work package 5.

Table 3-29: Selected User-KVI for the 5G for Energy Analytics of Construction Processes Use Case

SOCIETAL GOAL	USER-KVI
Transparency about Ecological Impacts	Global Warming potential, GWP
	Water consumption, WCon
	Ozone depletion, ODep
	Photochemical ozone formation, PhOz
	Depletion of abiotic resources (fossil fuels), DepFF
	Consumed electricity per kilogram of transported mass, E

The relevant User-KVI selected for the Energy Analytics of Construction Processes use case are described in the following passage. As the use case has some parallels to the Environmental Condition Monitoring use case from the manufacturing vertical (see 3.1.2) a similar approach was chosen for the definition of the sustainability-related User-KVI. The calculations of emissions for this use case are exclusively based on the consumption of electricity and do not consider the consumption of materials in the use case itself. [EUR24] and [NAU24] have been used as sources for the KVI description. For the assessment of these User KVI the Life Cycle Assessment (LCA) methodology will be followed.

3.5.3.4.1 Global Warming Potential

The User-KVI "global warming potential, GWP" is calculated with the following equation:

Equation 46:

$$GWP = Consumed\ Electricity * Emission\ Factor\ Electricity$$

Equation 11 calculates the GWP for the measured consumed electricity for the use case execution. The consumed electricity is measured in kWh and the emission factor electricity is given in kg CO_2-equivalents/kWh and is determined based on the German energy mix from databases.

3.5.3.4.2 Water Consumption

The User-KVI "water consumption, WCon" is calculated based on the water consumed to generate electricity. The following equation have been defined for this purpose:

Equation 47:

$$WCon = Consumed\ Electricity * \ Emission\ Factor\ Water$$

The consumed electricity is measured in kWh and the emission factor water is given in m^3/kWh and is determined based on the German energy mix from databases.

3.5.3.4.3 Ozone Depletion

The User-KVI "ozone depletion, ODep." is calculated based on the emission of substances depleting the stratospheric ozone layer. All of these emissions are converted to their equivalent of kilograms of trichlorofluoromethane (CFC-11). The User-KVI is calculated according to:

Equation 48:

$$ODep = Consumed\ Electricity * Emission\ Factor\ CFC11$$

The consumed electricity is measured in kWh and the emission factor CFC-11 is given in kg CFC11-eq./kWh and is determined based on the German energy mix from databases.

3.5.3.4.4 Photochemical Ozone Formation

The User-KVI "photochemical ozone formation, PhOz" describes the formation of ozone on the ground causing photochemical smog in the atmosphere on the ground. As a variety of different substances contribute to the photochemical ozone formation, the contributions are collected by calculation of the equivalent of kilograms of Non-Methane Volatile Organic Compounds (kg NMVOC eq.)

Equation 49:

$$PhOz = Consumed\ Electricity * Emission\ Factor\ NMVOC$$

The consumed electricity is measured in kWh and the emission factor NMVOC is given in kg NMVOC-eq./kWh and is determined based on the German energy mix from databases.

3.5.3.4.5 Depletion of Abiotic Resources (fossil fuels)

The User-KVI "depletion of abiotic resources (fossil fuels), DepFF" describes the consumption of fossil fuels for the generation of electricity. It is calculated in the following way:

Equation 50:

$$DepFF = Consumed\ Electricity * Emission\ Factor\ Fossil\ Fuels$$

The consumed electricity is measured in kWh and the emission factor fossil fuels is given in MJ/kWh and is determined based on the German energy mix from databases.

3.5.3.4.6 Consumed Energy per Kilogram of Transported Mass

Equation 51:

$$E = \frac{Consumed\ Electricity}{Transported\ Mass}$$

The User-KVI "consumed energy per kilogram of transported mass" is calculated by dividing the measured electricity consumption by the transported mass (total weight of test loads).

3.5.3.5 Description of the Business Potential

For the assessment of the business potential of the developed use cases, a two-fold guiding question has been developed:

> *"What steps are necessary to transfer the solution to industry and how can industry users realize the value proposition of the use case?"*

The 5G for Energy Analytics addresses similar goals as the Environmental Monitoring use case from the manufacturing vertical (see 3.1.2). Both use cases provide a foundation for the calculation of the environmental footprint of a process, with the 5G for Energy Analytics use case focusing on construction site utilizing the Meter-X measurement device which already has a high technical maturity so that it can be deployed in industrial applications in the short term. As a results, the considered use case enables the creation of energy profiles, deepening the knowledge of how electricity is consumed in construction processes and more importantly, how the electricity consumption can be decreased. Therefore, the main value proposition of the use case is the predictability of electricity consumption as well as transparency regarding the environmental footprint of construction processes.

3.5.4 5G for Safety Assistant System

3.5.4.1 Short Description of the Use Case

This use case focuses on the development of a safety feature for the observation of safety zones on the reference construction site. For this purpose, two different robots are employed, a mobile robot supervises the safety zones of a deconstruction task that is carried out by a deconstruction robot. The human operator (HO) of the deconstruction robot also observes the safety zones, but due to the conditions on the construction site, blind spots exist which are out of the sight of the HO. Therefore, the mobile robot supervises the safety zones and sends observation data to the HO.

Description of the use case product: The outcome of the successful use case execution is safely executed deconstruction operation including robots on a construction site. The safety is directly enabled by the possibility for the HO to exit the safety zone during the operation of the robot. Additional information regarding this use case can be found in Deliverable 5.2 [TAR24-D52].

3.5.4.2 Evaluation Scenario

The following table describes the evaluation scenario for the 5G for Safety Assistant System use case. The depicted evaluation scenario has been developed in collaboration with the responsible use case owner from work package 5 of TARGET-X.

Table 3-30: Evaluation Scenario for the 5G for Safety Assistant System Use Case

STEP ID	STEP NAME	STEP DESCRIPTION	RESULT AFTER STEP EXECUTION	RELEVANT PROCESS PARAMETERS
1	Decon-struction Task Distribution	Human operator (HO) receives the task to deconstruct a part of the building with defined safety zones and designated workspaces. The deconstruction task is planned to be executed with a deconstruction robot. Since some areas of the safety zones and the designated workspace cannot be observed,	Building which is to be dismantled is targeted. Safety zones and designated workspaces are defined and communicated to the HO	

		further environment supervision through enhanced perception is required.		
2	Environment Perception	Movement and observation of mobile robot: Smaller mobile robot receives target coordinates and drives autonomously to a location from where it can observe remaining blind spots.	Check of safety zones by mobile robot and clearance to start deconstruction process.	- Timestamps (from start until clearance) - Target coordinates for safety zone observation for mobile robot so that it can check the safety zones
3	Safety Zone Observation	Mobile robot observes safety zone. Scenario differentiation: 1) No human detected → Process is cleared. 2) Human detected but only close to safety zone, not inside safety zone → Process is cleared. 3) Human observed inside safety zone → Process aborted; HO is informed by the system	Confidence level of detection: "*How valid and reliable is the detection capability of the employed system?*"	

3.5.4.3 Selected User-KPI

The following table describes the selected User-KPI for the evaluation of the 5G for Safety Assistant System use case from a techno-economic perspective. The listed User-KPI have been developed in collaboration with the responsible use case owner from work package 5 of TARGET-X.

Table 3-31: Selected User-KPI for the 5G for Safety Assistant System Use Case

TECHNICAL GOAL	USER-KPI
Increasing operational capability	Process capability (c_p & c_{pk})
Increasing process efficiency	Cycle time
	Throughput
	Error Rate
	Worker Efficiency

The User-KPI selected for the considered use case are described in the following passage.

3.5.4.3.1 Process Capability:

The User-KPI "process capability" describes the ability of the process to produce output within certain specification limits. For the 5G for Safety Assistant System use case, the calculation of the process capability enables the evaluation alert delay which describes the time needed to communicate a detection within the safety zone to the HO. The values for c_p and c_{pk} can be calculated with the following equations [SCH15]:

Equation 52:

$$c_p = \frac{UT + LT}{6\sigma}$$

Equation 53:

$$c_{pk} = \frac{\min\,(UT - \bar{x};\ \bar{x} - LT)}{3\sigma}$$

UT describes the upper tolerance limit and LT the lower tolerance limit so that they both together define the specifications limits for the process output. The parameter σ describes the standard deviation of the considered process parameter and $\bar{x}$ describes the mean of the considered value. For the use case at hand this is the alert delay, which must be within specification limits so that the use case can implemented (prerequisite for use case implementation).

3.5.4.3.2 Cycle Time

The cycle time describes the time needed for the successful execution of one process run. For the use case at hand, the cycle time describes the time needed for the completion of the dismantling task by the HO. As the HO does not need to carry out observations in the blind spots anymore, he can exclusively focus on the operation of the deconstruction robot. As a result, a decrease in cycle time by the implementation of the use case is expected. The following equation is used for calculation of the cycle time:

Equation 54:

$$Cycle\ time = \frac{Total\ Execution\ Time}{Number\ of\ Conducted\ Operations}$$

If only one operation is conducted, the cycle time is equal to the total execution time. By calculation of the cycle time, the immediate impact of 5G communication on the execution time can be demonstrated.

3.5.4.3.3 Throughput

The User-KPI "throughput" quantifies the productivity of a system by dividing the process outcome by the uptime of the system. With this User-KPI, the increased focus of the HO on the dismantling task can be quantified similarly to the calculation of the cycle time. For the throughput calculation, the following equation has been defined:

Equation 55:

$$Throughput = \frac{Number\ of\ Successful\ Operation}{Uptime\ of\ Deconstruction\ Robot}$$

3.5.4.3.4 Error Rate

He increased focus of the HO on the dismantling task is also expected to have a positive impact on the error rate of the HO, as distractions from the main task will occur less frequently. The error rate can be calculated with the following equation:

Equation 56:

$$Error\ Rate = \frac{n_{Errors}}{Time\ of\ Work\ Shift}$$

n_{Errors}: Total number of errors occurring during the considered work shift

Time of Work Shift: Considered time frame for the analysis of the error rate

3.5.4.3.5 Worker Efficiency

The User-KPI "worker efficiency" is also expected to be influenced positively by the implementation of the safety assistant. Worker efficiency is expected to increase as the cycle time and error rate decrease while the throughput also increases. The following equation can be used for the calculation of the worker efficiency:

Equation 57:

$$Worker\ Efficency = \frac{Total\ Number\ of\ Operations}{Personnel\ Work\ Time}$$

All addressed User-KPI are expected to increase by shifting the responsibility for safety zone observation from the HO to the mobile robot. In this way, the impact of 5G becomes apparent: it enables the automation of a certain task with a reliability that enables human workers to focus on other more complicated and value-adding tasks.

3.5.4.4 Selected User-KVI

The following table lists the selected User-KVI for the evaluation of the 5G for Safety Assistant System use case from a societal perspective. The listed User-KVI have been developed in collaboration with the responsible use case owner from work package 5.

Table 3-32: Selected User-KVI for the 5G for Safety Assistant System Use Case

SOCIETAL GOAL	USER-KVI
Improvement of safety related aspects	Work accident rate construction

3.5.4.4.1 Work accident rate

A reduction of work accidents on construction sites is the expected main value proposition of the successful implementation of the 5G for Safety Assistant System use case. The reliable and automated supervision of safety zones is expected to contribute to the avoidance of work accidents. The work accident rate can be calculated with the following equation:

Equation 58:

$$Work\ accident\ rate\ construction = \frac{Total\ number\ of\ accidents}{Time\ of\ Work\ Shift}$$

For the calculation of the work accident rate for the construction site, the total number of accidents that occurred is divided by the total operation time that is based on the time of work shifts on the construction site. This User-KVI will be calculated based on expert assumptions as the total number of accidents can only be simulated. The existence of a safety concept utilizing the technical capabilities of 5G to enable real-time supervision and detection on construction sites is also an important prerequisite for the deployment of robotics applications on construction sites. Therefore, the quantification of the work accident rate can be seen as a basis for the implementation of robotics use cases and the realization of the expected technical benefits.

3.5.4.5 Description of the Business Potential

For the assessment of the business potential of the developed use cases, a two-fold guiding question has been developed:

"What steps are necessary to transfer the solution to industry and how can industry users realize the value proposition of the use case?"

As the 5G for Safety Assistant System use case focuses on the implementation of a safety feature, extensive testing in both test environments as well as industrial environments is necessary to validate the feasibility, safety, and reliability of the developed solution. The current technical maturity is in a prototypical state that requires further development next to extensive testing so that a technical maturity high enough for industrial deployment can be achieved. The value proposition that can be realized by industry users includes not only the increase of worker safety but also increases in efficiency and productivity as workers can focus their attention more on value-adding tasks. In this way, the use case addresses two significant pain points currently existing in the construction industry.

4 Conclusion and Outlook

The deliverable at hand provides a comprehensive overview over the results that have been achieved within work package 1 in the second project year of TARGET-X. Based on the increasing technical maturity of the individual use cases, the MAF was further developed with the objective to enable the quantification of a use case's value proposition from the techno-economic as well as from the societal perspective. For this purpose, the evaluation methodology of the use cases was tailored to the point of view of a potential end user, that employs the use case in an industrial setting. In this way, a strong emphasize is placed on the user experience, which is in line with the premise that only a good user experience enables the broad application of innovate solutions in different verticals. This principle is also reflected by adaptions of the naming of the KPI and KVI, as they are now called User-KPI and User-KVI. In this way, one of the key objectives of TARGET-X which is to transfer digitalization solutions into industry (digital transformation) and strengthen the European economy is addressed.

The developed MAF was presented in different settings to different audiences outside of the project consortium (5G-ACIA, 6G-IA, automotive companies) and thus validated by various actors and their feedback. Regarding the value proposition that is achieved by a use case, a differentiation between implicit and explicit value propositions was introduced to address the fact that some benefits a use case has to offer can be realized earlier and more easily than others which still require the use case to be developed further.

For all twelve use cases, individual equations have been defined for the User-KPI and User-KVI which will be calculated to quantify the value propositions of each individual use case. Moreover, it was defined for each use case which steps are necessary to transfer the developed solutions to industrial applications, paving the way for the creation of new business models that utilize the developed solutions and enhance the degree to which 5G-based solutions are used in industrial and commercial settings.

In the final project phase, the iterative assessment of all TARGET-X use case will be carried out following the evaluation scenarios described in this deliverable for each use case. Together with the respective use case owners, all use cases will be examined with the defined User-KPI and User-KVI to calculate the impact of the results that have been achieved in this project. By application of the defined equations, these will be validated and modified, if necessary. In this way, the developed MAF will be tested regarding its functionality so that it can be presented in its final form at the end of the project. The assessment results will be used to derive development approaches for innovative and viable business models based on the solutions achieved in the project which represent an important outcome of the project. Finally, the developed MAF will be transferred into a web-based tool, to enable its application to other use cases as well.

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