5G-ACIA White Paper

Business Value and Return-on-Invest Calculation for Industrial 5G Use Cases

5G Alliance for Connected Industries and Automation

1 Executive Summary

Although the technical maturity of 5G and therefore also the technical maturity of industrial applications based on this technology is steadily and incrementally increasing, companies from the manufacturing sector are still hesitant to adopt the technology. Uncertainties regarding the technical and economic added value that could result from using the technology are often cited as the reason for this hesitancy.

The whitepaper at hand addresses this challenge by describing a method that can be used to estimate the business value of industrial 5G use cases. The method is based on techno-economic goals which are to be achieved through the use of 5G. The degree to which each individual goal is achieved is measured by the utilization of Key Performance Indicators that are based on individual KPI equations. For each component of a KPI equation, the estimated impact of the use of 5G on said component is taken into consideration so that an estimation regarding the influence of 5G on the KPI can be made. The main underlying principle of this method is to take the user benefit that can be achieved through the use of 5G for a specific use case into consideration. The use of estimated values allows for a broad application of the methodology to a variety of different industrial 5G use cases. In this way, estimate-based assumptions regarding the business values of 5G in manufacturing environments can be made.

The methodology is applied to three different exemplary use cases in order to illustrate the underlying principles. The first use case is an intralogistics use case in which automated guided vehicles (AGVs) are utilized for transportation purposes. The second use case is a milling use case in which 5G is employed to improve the inline control of a milling process. The third use case was provided by an automotive OEM focusing on the implementation of a solution of automated valet parking in a car manufacturing facility. For each use case, 5G is employed to tackle existing challenges, so that the (potentially) achievable benefits of the use of the technology are calculated using the described methodology.

About 5G-ACIA

The 5G Alliance for Connected Industries and Automation (5G-ACIA) was established to serve as the central and global forum for addressing, discussing, and evaluating relevant technical, regulatory, and business aspects with respect to 5G for the industrial domain. It reflects the entire ecosystem and all relevant stakeholder groups, including the operational technology (OT) industry (industrial automation companies, engineering companies, production system manufacturers, end users, etc.), the ICT industry (chip manufacturers, network infrastructure vendors, mobile network operators, etc.), academia, research institutes, and other relevant players. The paramount objective of 5G-ACIA is to ensure the best possible applicability of 5G technology and 5G networks to the industrial domain. 5G-ACIA's mission is to make sure the interests and needs of the industrial domain are adequately considered in 5G standardization and regulation and that ongoing 5G developments are understood by and effectively transferred to the industrial domain.

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3 Introduction and Motivation

While many manufacturing companies recognize the value of wireless communication technologies in manufacturing, the adoption rate of 5G within the industry remains relatively low. According to a Bitkom study, more than half of the surveyed companies cited a lack of transparency regarding the economic benefits as a key reason for their reluctance to adopt the technology [1]. This whitepaper was created to address this challenge. Its primary goal is to outline a pragmatic methodology that enables the assessment of the business value generated by implementing 5G-based use cases in manufacturing. The whitepaper draws on various research projects conducted by 5G ACIA partners, as described in [2], [3], and [4].

A core principle guiding the development of this evaluation methodology is finding a balance between accuracy and generalization. Previous methodologies have been developed to quantify the business value of 5G-based use cases across different application areas. However, a major shortcoming of these existing approaches is their focus on specific use cases. While this allows for precise evaluations of individual use cases or applications, it lacks transferability. Since companies typically need to evaluate a variety of different use cases, the lack of transferability hampers the broader adoption of 5G technology in the industry. Therefore, the evaluation methodology presented in this whitepaper utilizes estimation-based assessments to evaluate the benefits achievable through the implementation of 5G-based use cases in manufacturing environments.

Another guiding principle of the developed methodology is its focus on the end user. As the goal is to foster broader 5G adoption in industrial settings, the value proposition for the end user is paramount.

The whitepaper is structured as follows: First, the developed model and its underlying methodology are explained in detail. Second, exemplary calculations using the adapted methodology are presented. The whitepaper concludes with a critical reflection on the results and an outlook on potential next steps.

4 Description of the developed evaluation model

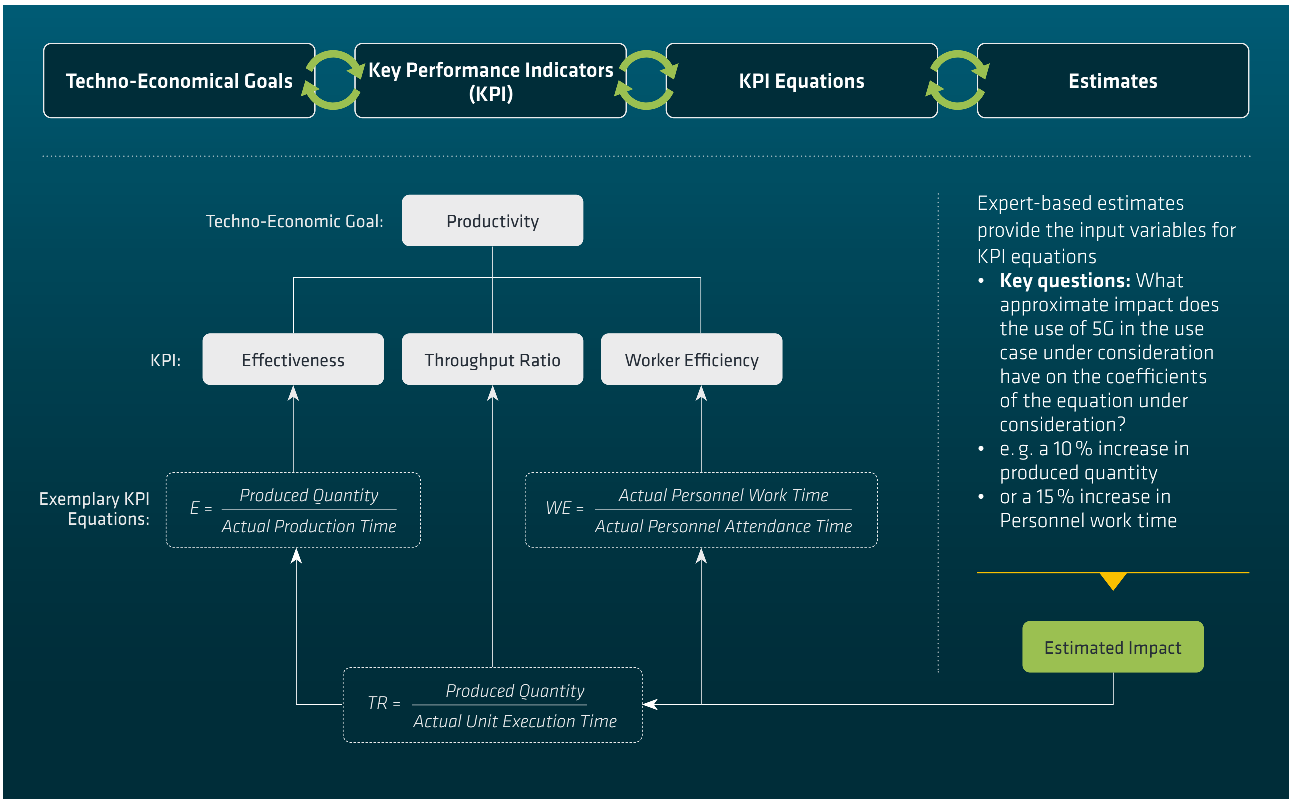
The primary objective of developing the evaluation model was to create a solution that interested companies can use to assess the achievable business value of industrial 5G use cases. To do so, the business value must be viewed from the end user's perspective, as the end user is the one who will implement the technology in their manufacturing facility. For this purpose, techno-economic goals are taken as the main reference point for the evaluation. The guiding question for the evaluation is therefore: “What is the potential impact of 5G usage on the techno-economic goals the end user is pursuing?” Figure 1 illustrates the basic principles of the developed evaluation model, with “Productivity” as an example of a technical goal.

The model follows a stepwise approach, which is summarized in Table 1 and illustrated in Figure 1. In the first step, a technical description of the use case under consideration is created, detailing the evaluation scenario that describes the operational sequence used to execute the use case in the manufacturing environment.

For assessing the business value and calculating the return on investment for industrial 5G use cases, a comparison between a competing (legacy) technology or a manual implementation of the use case and 5G is required. To do this, key performance indicators (KPIs) must be determined for both the implementation using the competing technology (e. g., 4G/LTE-A or manual implementation) and the realization with 5G. The technical advantages of 5G and their impact on the individual KPIs must be considered in order to quantify the overall benefit of 5G compared to the competing technology.

For example, if the KPI for On-Time Delivery (OTD) in an AGV use case is being investigated, an estimate must be made of how 5G impacts the numerator (on-time customer orders) and the denominator (total customer orders) of the OTD equation. Due to 5G's ability to integrate a larger number of devices or machines into a network simultaneously (mMTC), it can be assumed that the overall increase in communication participants leads to a higher number of on-time customer orders, which, in this case, is enabled by more efficient intralogistics.

Figure 1: Basic Principle of the Evaluation Model.



Source: 5G-ACIA / ZVEI e. V.

Table 1: Summary of the stepwise approach for model usage

Step Number/Name	Explanation
Step 1 – Application Specification	Technical description of the application under consideration
Step 2 – 5G-Deployment Goal Selection	Selection of the goals that are to be achieved by implementation of the application
Step 3 – KPI Estimation and Calculation	Preparation of individual estimates and calculations to achieve an overall estimate of the respective KPI
Step 4 – Goal Evaluation	Calculation of the overall impact that is achieved through the impact of the 5G deployment

Source: 5G-ACIA / ZVEI e. V.

In the next step, the techno-economic goals that are to be achieved through implementation and application of the use case are selected. A variety of possible goals, both technical and economic, have already been identified in previous research activities. They are listed in Table 2 and Table 3.

Table 2: Technical Goals of 5G-based Use Case Implementation [5], [3], [6]

Technical Goal	Description	Key Performance Indicator
Flexibility	Ability to process different parts in one manufacturing system	• Machine Flexibility (MF) • Setup Ratio (SUR)
Mobility	Ability of moving and replacing objects on the shopfloor	• Material Handling Mobility (MHM) • On-Time Delivery (OTD) • Space Productivity (SP)
Productivity	Output per unit of input over a specific period; also: production efficiency	• Effectiveness (E) • Throughput Ratio (TR) • Worker Efficiency (WE)
Quality	Degree to which the output of the production process meets the requirements	• First Pass Yield (FPY) • Quality Ratio (QR) • Rework Ratio (RR) • Scrap Ratio (SR)
Safety	Ability of a system to protect itself and the operator from harm or accidents	• Accident Ratio (AR) • Mean Time Between Failures (MTBF) • Mean Time to Repair (MTTR)
Sustainability	Level to which the creation of manufactured products is fulfilled by processes that are nonpolluting	• Compressed Air Consumption Ratio (ACR) • Electric Power Consumption Ratio (ECR) • Gas Consumption Ratio (GCR) • Water Consumption Ratio (WCR)
Utilization	Ratio of actual used machining time compared to the theoretically available time	• Allocation Efficiency (AE) • Availability (A) • Technical Efficiency (TE) • Utilization Efficiency (UE)

Source: 5G-ACIA / ZVEI e. V.

Table 3: Summary of the Economic Goals for the Industrial Use of 5G

Economic Goal	Explanation
Net Present Value (NPV)	Calculation of the present value of future cash flows by discounting these future cash flows back to the present with a specific discount rate
Return on Investment (RoI)	Calculation of the profitability of an investment by consideration of the profit generated from an investment relative to its cost
Operational Expenditure (OpEX)	Mapping of the costs resulting from ongoing expenses that result from the operations of a business
Capital Expenditure (CapEX)	Costs of investments that are made in order to acquire assets that are expected to provide benefits over a certain amount of time

Source: 5G-ACIA / ZVEI e. V.

In addition to the technical goals, economic goals have been defined to assess the economic benefits of implementing the 5G-based use case. The Net Present Value (NPV), Return on Investment (RoI), Operational Expenditures (OpEx), and Capital Expenditure (CapEx) are used to evaluate the profitability of an investment. Table 3 summarizes the economic goals.

In the third step, KPI estimation and calculation are carried out. After selecting the techno-economic goals, the relevant Key Performance Indicators (KPIs) are chosen. Figure 1 illustrates the exemplary selection of the technical goal "Productivity." The extent to which productivity can be improved is defined through the calculation of the associated KPIs, such as "Effectiveness," "Throughput Ratio," and "Worker Efficiency."

For each KPI, underlying (generic) equations have been defined to enable the calculation of a concrete value for the KPI. Following the principle of balancing accuracy and generalization, the model uses estimates for the individual components of the equations to provide an estimate of the KPI's value. The key question is: "What approximate impact does the use of 5G in the use case under consideration have on the coefficients of the equation?" This question must be answered by domain experts with a deep understanding of the use case, who can provide expert opinions on the impact of 5G on the individual parameters that define the overall performance of the use case.

Table 4 summarizes the predefined technical goals, associated KPIs, and the generic equations that have been defined for the estimation-based calculations of the KPIs.

Table 4: Goal, KPI and the Underlying Equations for KPI Calculation

Technical Goal	Key Performance Indicator	Equation
Flexibility	• Machine Flexibility (MF)	$MF = \frac{\text{Potential Product Variants}}{\text{Machines}}$
	• Setup Ratio (SUR)	$SUR = \frac{\text{Actual Unit Setup Time}}{\text{Actual Unit Processing Time}}$
Mobility	• Material Handling Mobility (MHM)	$MHM = \frac{\text{Paths Supported by System}}{\text{Total Number of Paths}}$
	• OnTime Delivery (OTD)	$OTD = \frac{\text{On-Time Customer Orders}}{\text{Total Customer Orders}}$
	• Space Productivity (SP)	$SP = \frac{\text{Production Area-Repair Area}}{\text{Production Area}}$
Productivity	• Effectiveness (E)	$E = PRTI * \frac{\text{Produced Quantity}}{\text{Actual Production Time}}$
	• Throughput Ratio (TR)	$TR = \frac{\text{Produced Quantity}}{\text{Actual Unit Execution Time}}$
	• Worker Efficiency (WE)	$WE = \frac{\text{Actual Personnel Work Time}}{\text{Actual Personnel Attendance Time}}$
Quality	• First Pass Yield (FPY)	$FPY = \frac{\text{First Time Good Quantity}}{\text{Inspected Quantity}}$
	• Quality Ratio (QR)	$QR = \frac{\text{Good Quantity}}{\text{Produced Quantity}}$
	• Rework Ratio (RR)	$RR = \frac{\text{Rework Quantity}}{\text{Produced Quantity}}$
	• Scrap Ratio (SR)	$SR = \frac{\text{Scrap Quantity}}{\text{Produced Quantity}}$
Safety	• Accident Ratio (AR)	$AR = \frac{\text{Number of Accidents}}{\text{Actual Personell Attendance Time}}$
	• Mean Time Between Failures (MTBF)	$MTBF = \frac{\text{Time Between Failures}}{\text{Failure Effects+1}}$
	• Mean Time to Repair (MTTR)	$MTTR = \frac{\text{Time to Repair}}{\text{Total Number of Repairs}}$
Sustainability	• Compressed Air Consumption Ratio (ACR)	$ACR = \frac{\text{Compressed Air Consumption}}{\text{Produced Quantity}}$
	• Electric Power Consumption Ratio (ECR)	$ECR = \frac{\text{Electric Power Consumption}}{\text{Produced Quantity}}$
	• Gas Consumption Ratio (GCR)	$GCR = \frac{\text{Gas Consumption}}{\text{Produced Quantity}}$
	• Water Consumption Ratio (WCR)	$WCR = \frac{\text{Water Consumption}}{\text{Produced Quantity}}$
Utilization	• Allocation Efficiency (AE)	$AE = \frac{\text{Actual Unit Busy Time}}{\text{Planned Unit Busy Time}}$
	• Availability (A)	$A = \frac{\text{Actual Production Time}}{\text{Planned Unit Busy Time}}$
	• Technical Efficiency (TE)	$TE = \frac{\text{Actual Production Time (APT)}}{\text{APT+Actual Unit Delay Time}}$
	• Utilization Efficiency (UE)	$UE = \frac{\text{Actual Production Time (APT)}}{\text{APT+Actual Unit Delay Time}}$

PRTI: planned runtime per item

Source: 5G-ACIA / ZVEI e. V.

In the fourth and final step, the goal evaluation is carried out. For this purpose, the overall impact of the 5G deployment is calculated and interpreted. This allows for an estimation-based calculation of the achievable values that the use of 5G promises.

Following the introductory description of how the model works, the model and its functionality are explained in more detail in the next chapter, using three application examples of use cases from industrial settings.

5 Exemplary Calculations

In this section, exemplary calculations using the developed model will be conducted to demonstrate the applicability of the described approach. The numbers presented here are purely illustrative and are intended to showcase the potential application of the methodology. The chapter begins with the analysis of an AGV use case, first described in [3] (Chapter 5.1). Next, a milling use case, initially described in [4], is analyzed in Chapter 5.2. The third and final use case was analyzed in collaboration with an automotive OEM during a series of bilateral meetings between 5G-ACIA WG 5 personnel and the automotive OEM team in the fourth quarter of 2024. This use case is described in Chapter 5.3.

5.1 AGV Use Case

Step 1: Application Specification
For this analysis, the implementation of a centralized AGV control system is chosen. This means that a single central 5G-based communication network is used to control the entire AGV fleet operating within the production environment. Additionally, 4G is selected as the communication technology to which 5G will be compared.

Step 2: 5G-Deployment Goal Selection
The goals to be addressed through the 5G-based realization of the AGV use case include increases in mobility, productivity, and safety. Mobility is expected to improve due to more precise and direct control of the AGVs, enabling them to navigate more complex and narrower paths. Productivity is expected to increase due to reduced communication latency, allowing higher AGV speeds and faster transportation of goods in shorter cycle times. Safety improvements are anticipated due to the increased reliability of the 5G network, reducing signal loss and the frequency of AGV traffic interruptions. Therefore, mobility, productivity, and safety are the selected goals for this analysis.

Step 3: KPI Estimation and Calculation
With the selection of the goals – mobility, productivity, and safety – the following KPIs listed in Table 5 and their corresponding equations will be applied to evaluate the AGV use case.

Table 5: Selected goals, KPIs and their equations for the evaluation of the AGV use case

Technical Goal	Key Performance Indicator	Equation
Mobility	• Material Handling Mobility (MHM)	$MHM = \frac{\textit{Paths Supported by System}}{\textit{Total Number of Paths}}$
	• OnTime Delivery (OTD)	$OTD = \frac{\textit{On Time Customer Orders}}{\textit{Total Customer Orders}}$
	• Space Productivity (SP)	$SP = \frac{\textit{Production Area-Repair Area}}{\textit{Production Area}}$
Productivity	• Effectiveness (E)	$E = PRTI * \frac{\textit{Produced Quantity}}{\textit{Actual Production Time}}$
	• Throughput Ratio (TR)	$TR = \frac{\textit{Produced Quantity}}{\textit{Actual Unit Execution Time}}$
	• Worker Efficiency (WE)	$WE = \frac{\textit{Actual Personnel Work Time}}{\textit{Actual Personnel Attendance Time}}$
Safety	• Accident Ratio (AR)	$AR = \frac{\textit{Number of Accidents}}{\textit{Actual Personell Attendance Time}}$
	• Mean Time Between Failures (MTBF)	$MTBF = \frac{\textit{Time Between Failures}}{\textit{Failure Effects+1}}$
	• Mean Time to Repair (MTTR)	$MTTR = \frac{\textit{Time to Repair}}{\textit{Total Number of Paths}}$

Source: 5G-ACIA / ZVEI e. V.

A total of nine KPIs need to be calculated using estimated values. For this purpose, each dividend and divisor in the equations from Table 5 must be assessed to determine whether it is impacted by the use of 5G. These assumptions must be based on both fact-based and experience-based estimates provided by domain experts. For the AGV use case, intralogistics personnel (specialists and managers) should be interviewed to gather their insights.

For the AGV use case of this Work Item, the following exemplary assumptions are made:

- **Mobility:** A positive influence on the KPI OTD (On-Time Delivery) is expected due to increased AGV travel speeds and reduced downtime caused by unforeseen failures.
- **Productivity:** A positive influence on the KPIs E (Effectiveness) and TR (Throughput Ratio) is expected due to an increase in produced quantities.
- **Safety:** A positive influence on the KPI AR (Accident Ratio) is expected due to the higher availability and reliability of the 5G communication network compared to 4G, resulting in fewer interruptions in control signal transmission.

At this point, it is important to emphasize that the assumptions described should only be used as examples to illustrate the basic concept of the evaluation. These assumptions are not universally applicable to all AGV use cases. Therefore, individual assumptions must be made for each specific use case.

Next, number-based assumptions must be made regarding the impact of 5G. As stated above, these assumptions should be based on input from domain experts. For this purpose, intralogistics experts must assess how the technical advantages of the technology are reflected in the selected KPIs. To make precise and realistic assumptions, the domain expert knowledge must be combined with specialized expertise on the industrial application of 5G in production.

For the use case in question, the following exemplary assumptions are made:

- **Mobility:** The impact of 5G, compared to 4G, is expected to lead to an overall increase. Due to enhanced control capabilities, the number of paths supported by the system is expected to increase by 20 %, as 5G-controlled AGVs are not limited to predefined paths, allowing for more variability in the paths they can take. It is important to emphasize that this expected increase is a hypothetical example. For a real evaluation, a process expert is needed to leverage their domain knowledge to estimate how 5G features (compared to 4G) positively impact key characteristics of the specific use case.
  For this example, the KPI **MHM (Material Handling Metric)** is expected to increase by 20 % compared to a solution implemented with 4G, due to the increased variability in the paths supported by the system, which results from enhanced control capabilities. In addition to the increase in MHM, the increased travel speeds of the AGVs are also expected to lead to a 10 % increase in **OTD (On-Time Delivery)**. Regarding the KPI **SP (Safety Performance)**, no change is expected in this scenario.
- **Productivity:** A positive impact on the KPIs **E (Effectiveness)** and **TR (Throughput Ratio)** is expected, as goods will travel faster and with greater flexibility through the production facility. This results in an increase in the availability of materials and goods required for production processes, thus positively impacting the KPIs. For this scenario, a 5 % increase in both KPIs is assumed. The KPI **WE (Worker Efficiency)** is assumed to remain unaffected by the use of 5G in this scenario.
- Safety: The enhanced control capabilities of the system are expected to positively impact the **MTBF (Mean Time Between Failures)**, as fewer breakdowns of the AGVs will occur due to control issues or malfunctions. Therefore, an overall improvement of 5 % in MTBF is assumed for this use case. The KPIs AR (Accident Ratio) and MTTR (Mean Time to Repair) are assumed to remain unaffected by the use of 5G in this scenario.

Table 6: Estimated Impact of 5G vs. 4G for the AGV Use Case

Goal	Key Performance Indicator	Estimated Impact of 5G vs. 4G
Mobility	• Material Handling Mobility (MHM)	+ 20 %
	• OnTime Delivery (OTD)	+ 10 %
	• Space Productivity (SP)	No impact
Productivity	• Effectiveness (E)	+ 5 %
	• Throughput Ratio (TR)	+ 5 %
	• Worker Efficiency (WE)	No impact
Safety	• Accident Ratio (AR)	No impact
	• Mean Time Between Failures (MTBF)	+ 5 %
	• Mean Time to Repair (MTTR)	No impact

Source: 5G-ACIA / ZVEI e. V.

For the calculation of the goal achievement rate, the change in each individual KPI is used to calculate the average change resulting from the impact of the use of 5G. For the Mobility goal, the following equation is used:

$$\Delta\ Mobility = \frac{\Delta\ MHM + \Delta\ OTD + \Delta\ SP}{3}$$

$$\Delta\ Mobility = \frac{0.2 + 0.1 + 0}{3} = 0.1$$

Step 4: Goal Evaluation

Based on the calculations from Step 3, the following results can be determined. The expected increase in mobility, based on the exemplary assumptions, is 10 %. For productivity, an increase of 3.33 % can be assumed, while for safety, an increase of 1.66 % is expected. These estimates demonstrate how the developed approach can be used to calculate approximate values for the business value of the industrial use of 5G.

Depending on the desired level of detail, additional equations for the KPIs can be defined to improve the accuracy of the calculations. For example, the coefficient "Produced Quantity" in the KPI **Throughput Ratio** can be represented by the following equation:

$$Produced\ Quantity = Production\ Rate * Production\ Time$$

The influence of 5G can also be mapped in this equation by determining the impact of 5G usage on the production rate. This can either be done through an additional estimate or by using further equations, examining which production process parameters are affected by 5G and to what extent. In this way, the method described can be refined as needed by the user, with increasingly detailed equations that bring the values used for the estimates closer to the actual production process. However, it is important to note that this approach increases the complexity of the model, as more nested equations must be solved.

Based on the technical goals, the achievement of economic goals can also be quantified. For example, OpEx (Operational Expenditures) is positively influenced if material handling costs (intralogistics) are reduced due to more efficient transportation methods. In the example at hand, the 5G-based AGV use case will have a positive impact on OpEx, as waiting times caused by the unavailability of material at workstations are reduced. This reduction is due to the increased MHM and OTD (cf. Table 6), allowing more goods to be produced with the same operational expenditures.

5.2 Milling Use Case

Step 1: Application Specification

For this use case, a closed-loop control system utilizing wireless communication is implemented to create the feedback loop. This closed-loop control system is used to monitor a milling process in which a **blisk** (bladed disk), a turbomachine component, is milled from a single metal block. To achieve this, an acoustic emission sensor is integrated into the milling process. The sensor picks up ultrasonic signals from the milling operations and is attached to the workpiece (the blisk). The acoustic sensor is connected to a user equipment (UE) with 5G capability, establishing a wireless connection between the remote process controller and the workpiece.

If the frequency of the measured acoustic signal deviates from the allowed target range, indicating a potential loss in product quality, the remote controller can proactively adjust the process parameters. This adjustment helps to prevent product quality degradation, such as the formation of chatter marks on the product surface. In other words, 5G-based communication enables an inline quality control system that monitors the process in real time and intervenes when deviations from the desired state are detected. This setup is compared to a solution that employs Ethernet for communication.

Step 2: 5G-Deployment Goal Selection

For this use case, productivity, quality, and sustainability are selected as the technical goals, with the expectation of positive impacts in each of these areas through the use of 5G.

- **Productivity** is expected to improve due to an increase in the number of good units produced within a specified time frame.
- **Quality** is anticipated to improve thanks to optimized quality control and the ability to avoid surface defects like chatter marks, enabled by the inline quality control system.
- **Sustainability** is addressed through a more resource-efficient process. The closed-loop control system enables a process that generates less waste and scrap material, contributing to improved sustainability.

Step 3: KPI Estimation and Calculation

Based on the selection of the goals – productivity, quality, and sustainability – the KPIs listed in Table 7 and their respective equations will be applied for the evaluation of the milling use case.

In total, eleven KPIs need to be calculated based on estimated values, as shown in Figure 1. For each dividend and divisor in the equations from Table 7, domain experts must determine whether the use of 5G influences this parameter, and if so, estimate the approximate magnitude of this influence.

- **Productivity:** A positive influence on the KPI **TR (Throughput Ratio)** is expected, as process parameters affecting throughput can be adjusted based on the enhanced monitoring and control. This adjustment will increase throughput without compromising surface quality. Additionally, an increase in the KPI **WE (Worker Efficiency)** is anticipated, as workers will spend less time on process monitoring and can focus more on other tasks.
- **Quality:** Positive impacts are expected on the KPIs **RR (Rework Ratio)** and **SR (Scrap Ratio)**, as the improved quality control system will significantly reduce the need for rework and the production of scrap.

Table 7: Selected goals, KPIs and their equations for the evaluation of the milling use case

Technical Goal	Key Performance Indicator	Equation
Productivity	• Effectiveness (E)	$E = PRTI * \frac{\textit{Produced Quantity}}{\textit{Actual Production Time}}$
	• Throughput Ratio (TR)	$TR = \frac{\textit{Produced Quantity}}{\textit{Actual Unit Execution Time}}$
	• Worker Efficiency (WE)	$WE = \frac{\textit{Actual Personnel Work Time}}{\textit{Actual Personnel Attendance Time}}$
Quality	• First Pass Yield (FPY)	$FPY = \frac{\textit{First Time Good Quantity}}{\textit{Inspected Quantity}}$
	• Quality Ratio (QR)	$QR = \frac{\textit{Good Quantity}}{\textit{Produced Quantity}}$
	• Rework Ratio (RR)	$RR = \frac{\textit{Rework Quantity}}{\textit{Produced Quantity}}$
	• Scrap Ratio (SR)	$SR = \frac{\textit{Scrap Quantity}}{\textit{Produced Quantity}}$
Sustainability	• Compressed Air Consumption Ratio (ACR)	$ACR = \frac{\textit{Compressed Air Consumption}}{\textit{Produced Quantity}}$
	• Electric Power Consumption Ratio (ECR)	$ECR = \frac{\textit{Electric Power Consumption}}{\textit{Produced Quantity}}$
	• Gas Consumption Ratio (GCR)	$GCR = \frac{\textit{Gas Consumption}}{\textit{Produced Quantity}}$
	• Water Consumption Ratio (WCR)	$WCR = \frac{\textit{Water Consumption}}{\textit{Produced Quantity}}$

Source: 5G-ACIA / ZVEI e. V.

- **Sustainability:** Positive impacts are expected on the KPI related to resource use, specifically electrical power. The process will be more efficient, making better use of resources and thus positively influencing sustainability.

As with the AGV use case, the authors of this whitepaper want to emphasize that the assumptions described for the milling use case should only be used as examples to explain the underlying concepts of the evaluation. These assumptions are not universally applicable to all milling use cases that utilize 5G technology for closed-loop control of critical process parameters.

In the next step, the number-based assumptions for the impact of 5G on each component of the selected equations must be made.

The procedure for this is identical to the one described in Chapter 5.1: Domain experts, specifically experts in milling processes, must estimate how the technical advantages of 5G will impact the selected KPIs. To ensure precise and realistic assumptions, the domain experts' knowledge must be combined with specific expertise on the industrial application of 5G in production. As previously mentioned, the scenario using Ethernet instead of 5G serves as the baseline, against which the 5G-based solution will be compared. The estimated impacts of 5G vs. the realization with Ethernet is summarized in Table 8.

The entries from Table 8 are used in the fourth step to evaluate the degree to which the selected goals will be achieved through the use of 5G.

Table 8: Estimated impact of 5G vs. Ethernet for the milling use case

Goal	Key Performance Indicator	Estimated Impact of 5G vs. Ethernet
Productivity	• Effectiveness (E)	No impact
	• Throughput Ratio (TR)	+ 5 %
	• Worker Efficiency (WE)	+ 2 %
Quality	• First Pass Yield (FPY)	+ 10 %
	• Quality Ratio (QR)	+ 5 %
	• Rework Ratio (RR)	- 25 %
	• Scrap Ratio (SR)	- 80 %
Sustainability	• Compressed Air Consumption Ratio (ACR)	- 5 %
	• Electric Power Consumption Ratio (ECR)	- 5 %
	• Gas Consumption Ratio (GCR)	No impact
	• Water Consumption Ratio (WCR)	- 2 %

Source: 5G-ACIA / ZVEI e. V.

Step 4: Goal Evaluation
Similar to the AGV use case, the goal achievement rate for the milling use case is calculated by determining the percentage change for each KPI and averaging it for each selected technical goal. The following equations can then be used to represent the technical goals:

$$\Delta\ Productivity = \frac{\Delta\ E + \Delta\ TR + \Delta\ WE}{3}$$

$$\Delta\ Productivity = \frac{0 + 0.05 + 0.2}{3} = 0.023 = 2.3\,\%$$

$$\Delta\ Quality = \frac{\Delta\ FPY + \Delta\ QR + \Delta\ RR + \Delta\ SR}{4}$$

$$\Delta\ Quality = \frac{0.1 + 0.05 + 0.25 + 0.8}{4} = 0.3 = 30\,\%$$

$$\Delta\ Sustainability = \frac{\Delta\ ACR + \Delta\ ECR + \Delta\ GCR + \Delta\ WCR}{4}$$

$$\Delta\ Sustainability = \frac{0.05 + 0.05 + 0 + 0.02}{4} = 0.03 = 3\,\%$$

As a result, it can be stated that a 2.3 % increase is expected in productivity, while a 30 % increase is expected in quality and a 3 % increase is expected in sustainability.

5.3 Automotive Use Case

The description and calculated results of this use case have been anonymized and abstracted for confidentiality reasons.

Step 1: Application Specification
For the validation of the business value calculation, an automated valet parking use case in the context of intralogistics for manufacturing passenger vehicles using wireless communication via 5G was chosen. Specifically, a comparison was made between manual and automated valet parking. The business value calculation was carried out in close cooperation with an automotive OEM.

In the manual valet parking use case, vehicles are picked up by drivers after quality control at the production line and manually driven to their designated parking spaces. To maintain a high production rate, a sufficient number of staff must be employed. After delivering the vehicles to their parking spaces, employees are required to return to the production line. This creates idle time, negatively impacting process efficiency and potentially leading to a higher demand for personnel based on the specified production rate.

For the automated valet parking use case, the automated driving functions are processed locally within the vehicle, enabling the vehicle to drive itself to its parking space without the need for a driver. Each vehicle is equipped with user equipment (UE) that connects to a private 5G network, facilitating real-time communication. This wireless connection provides information about the route and destination parking spot. At the same time, information is exchanged between the vehicle and intelligent infrastructure (V2X) to support the autonomous driving functions, utilizing both onboard sensors and external infrastructure. A control system in the backend is responsible for selecting a suitable parking space and determining the optimal route for each vehicle as it drives to the parking lot.

In the following sections, a comparison of key performance indicators (KPIs) and return on investment (ROI) between manual and automated valet parking is conducted.

Step 2: 5G-Deployment Goal Selection
For this use case, **mobility** is selected as the main technical goal, with the expectation that the use of automated valet parking via 5G will have a positive impact. As a sub-goal, **productivity** is also considered.

- **Mobility:** Improvements in mobility are expected through increased **space productivity (SP)** and **mobility efficiency (ME)**, as automated valet parking does not require the same number of parking spaces as manual valet parking, thereby reducing fluctuations. Additionally, the flexibility of the automated solution is enhanced through optimal route planning.
- **Productivity:** Gains in productivity, assessed via **worker efficiency (WE)**, are anticipated due to reduced per-

sonnel requirements associated with automated valet parking. The adoption of automated valet parking also helps distribute workloads more equitably among staff, effectively eliminating idle time tied to manual valet parking processes.

Step 3: KPI Estimation and Calculation
Given the selection of mobility and productivity as goals, the KPIs listed in Table 9 and their respective equations will be applied to evaluate automated valet parking in comparison to the manual valet parking use case.

Table 9: Selected goals, KPIs and their equations for the evaluation of the automated valet parking use case.

Goal	Key Performance Indicator	Equation
Mobility	• Material Handling Mobility (MHM)	$MHM = \frac{\textit{Paths Supported by System}}{\textit{Total Number of Paths}}$
	• OnTime Delivery (OTD)	$OTD = \frac{\textit{On Time Customer Orders}}{\textit{Total Customer Orders}}$
	• Space Productivity (SP)	$SP = \frac{\textit{Production Area-Repair Area}}{\textit{Production Area}}$
	• Mobility Efficiency (ME)	$ME = \frac{\textit{System Flexibility Score}}{\textit{Max. Flexibility Score (10)}}$
Productivity	• Effectiveness (E)	$E = PRTI * \frac{\textit{Produced Quantity}}{\textit{Actual Production Time}}$
	• Throughput Ratio (TR)	$TR = \frac{\textit{Produced Quantity}}{\textit{Actual Unit Execution Time}}$
	• Worker Efficiency (WE)	$WE = \frac{\textit{Actual Personnel Work Time}}{\textit{Actual Personnel Attendance Time}}$

Source: 5G-ACIA / ZVEI e. V.

A total of seven Key Performance Indicators (KPIs) need to be calculated based on the estimated values presented in Figure 1. For each dividend and divisor in the equations outlined in Table 9, domain experts were interviewed to assess the impact of these parameters and estimate the extent of this influence.

For the automated valet parking use case, compared to the manual valet parking use case, the following exemplary assumptions are made:

- **Mobility:** A positive influence on the KPI **SP (Space Productivity)** is expected, as parking spaces at the production line will no longer be required with the implementation of the automated valet parking system. This allows the available space to be repurposed to improve efficiency, such as by optimizing the production rate. Additionally, the new KPI ME (Mobility Efficiency) emerged from the interviews, which compares the solution's flexibility with the optimal level of flexibility. An improvement in this KPI is expected for the automated valet parking system.
- **Productivity:** A positive influence on the KPI **WE (Worker Efficiency)** is expected, as fewer workers are needed for the automated valet parking process, and the idle time associated with manual valet parking can be reduced.

In the next step, number-based assumptions were made regarding the impact of the automated valet parking system utilizing 5G. The procedure followed is the same as described in Chapter 5.1: Domain experts, particularly in intralogistics, estimate how the technical advantages of 5G influence the selected KPIs. To ensure precise and realistic assumptions, the experts' knowledge is combined with specialized expertise in the industrial application of 5G in production. As previously mentioned, the realization of the intralogistics process using automated valet parking with 5G is compared to the manual valet parking system. The estimated impacts are summarized in Table 10.

Table 10: Estimated impact of automated valet parking with 5G vs manual valet parking.

Goal	Key Performance Indicator	Estimated Impact of 5G vs. Manual Parking
Mobility	• Material Handling Mobility (MHM)	No impact
	• OnTime Delivery (OTD)	No impact
	• Space Productivity (SP)	+ 90 %
	• Mobility Efficency (ME)	+ 50 %
Productivity	• Effectiveness (E)	No impact
	• Throughput Ratio (TR)	No impact
	• Worker Efficiency (WE)	+ 30 %

Source: 5G-ACIA / ZVEI e. V.

In addition to the technical goals, economic goals were calculated to assess the economic benefit of the 5G-based automated valet parking use case in comparison to manual valet parking. In this context, the calculation of the **NPV (Net Present Value)** was chosen, in accordance with Table 3. The calculation is based on the following formula:

$$\Delta\ NVP = \sum \frac{Cash\ Flow\ (AVP - MVP)_{years}}{(1 + Discout\ Rate)^{years}}$$

The calculation compares the differences in **NPV (Net Present Value)** between automated valet parking (AVP) and manual valet parking (MVP) over a period of 10 years. In calculating cash flow, ongoing costs such as employee salaries, maintenance, and electricity were taken into account. For the investment calculation, one-time expenses related to the 5G system and smart infrastructure were included in the estimation. The results of the economic analysis are presented in Table 11.

Finally, an estimation of the break-even point was performed alongside the NPV calculation. The corresponding graph for the break-even point calculation is shown in Figure 2.

Table 11: Economic goals and results.

Economic Goal	Results
$\Delta\ NVP$ (time = 10 years)	+ 1.2 M €
Amortization Time	5 years
Difference in OPEX per product $\Delta \frac{OPEX}{Product}$	$\frac{OPEX_{AVP} - OPEX_{MVP}}{Product}$ = – 5.00 €
Return on Investment (ROI)	+ 130 %

Source: 5G-ACIA / ZVEI e. V.

The authors of this white paper wish to emphasize that, while the assumptions for the automated valet parking use case were developed in collaboration with domain experts, certain parameters were adjusted to protect intellectual property. These assumptions are not applicable to all use cases involving 5G in the context of automated valet parking and were developed based on the specific information provided.

The entries from Table 10 and Table 11 are used in the fourth step to evaluate the extent to which the selected goals will be achieved through the use of 5G.

Step 4: Goal Evaluation
As with the AGV and milling use cases, the goal achievement rate for the automated valet parking use case is calculated by determining the percentage change of each KPI and averaging it for each selected technical goal.

$$\Delta\, Mobility = \frac{\Delta\, MHM + \Delta\, OTD + \Delta\, SP + ME}{4}$$

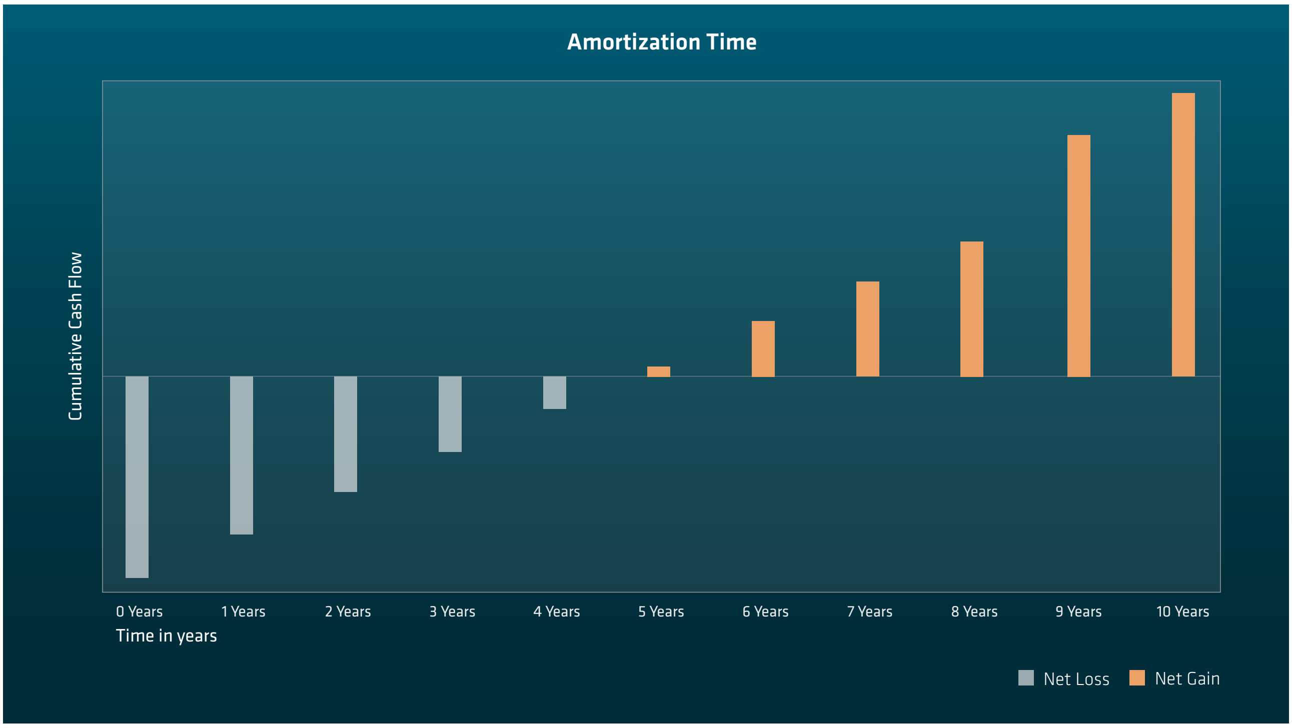
$$\Delta\, Mobility = \frac{0 + 0 + 0.9 + 0.5}{4} = 0.35 = 35\,\%$$

$$\Delta\, Productivity = \frac{\Delta\, E + \Delta\, TR + \Delta\, WE}{3}$$

$$\Delta\, Productivity = \frac{0 + 0 + 0.3}{3} = 0.1 = 10\,\%$$

As a result, it can be concluded that a 35 % increase is expected in mobility, while a 10 % increase is anticipated in productivity. Based on the data sets considered, the investment in the automated valet parking use case utilizing 5G becomes profitable after 5 years. It is important to note that the effects of other factors, such as a higher production rate, have been excluded from this calculation. These factors could potentially lead to faster amortization.

Figure 2: Amortization Time of Automated Valet Parking vs Manual Valet Parking.



Source: 5G-ACIA / ZVEI e. V.

5.4 Interim Conclusion

The description of the three selected, exemplary use cases demonstrates how the developed methodology can be applied to a wide range of industrial 5G use cases with relatively low effort. To begin, a simple spreadsheet can be used to define the KPI equations and perform calculations based on the estimated impacts of 5G on critical process parameters. The contents of these spreadsheets can then be transferred into a software solution (e. g., a web tool) to implement a more comprehensive approach.

As shown in the "Goal Evaluation" sections of each use case, percentage improvements in goals such as "mobility," "productivity," or "sustainability" were calculated. In addition to calculating economic goals like **NPV** or **RoI**, companies can also assign a monetary value to the achievable improvements by calculating, for example, what a 10 % increase in productivity would mean in financial terms. This can then be used to estimate the positive effect such an increase would have on the company's **EBITDA**. Since this calculation is highly specific to each company, it has not been performed for the exemplary use cases in this whitepaper.

6 Summary and Outlook

The main objective of this whitepaper is to describe a methodology for the estimation-based evaluation of the business value of industrial 5G use cases. This is crucial because industrial companies remain hesitant to invest in the expansion of 5G infrastructures due to a lack of transparency regarding the business value of 5G applications. While past research has focused on business value and return on investment calculations, a generalizable method to capture the value proposition of a 5G-based use case is still lacking. The methodology presented in this whitepaper aims to address this gap.

To this end, a detailed description of the underlying principles of the methodology are provided, illustrated through the application of the method to three different industrial 5G use cases. By utilizing the principles described and applying them to these use cases, interested companies can begin their own evaluations of potential use cases by defining techno-economic goals, associated KPIs, underlying equations, and the estimated impacts of 5G technology on the components of these equations.

In this way, the whitepaper aims to contribute to the broader adoption of 5G technology and support the acceleration of the digital transformation in industry. To illustrate the application of the methodology, three exemplary use cases are presented, with assumptions made regarding the impacts of 5G on critical parameters. The first two use cases have a traditional manufacturing background: the first being an AGV use case that highlights the application potential of 5G in intralogistics, and the second focusing on the direct integration of 5G technology into manufacturing processes, described through a milling use case for the production of turbomachinery components. These two use cases are still in the prototypical stage regarding their technical maturity, as they have not yet been deployed in active manufacturing environments.

The third use case – automated valet parking – is already deployed in an operational production environment at an automotive manufacturing facility. The analysis of this use case demonstrates the potential that 5G already has today to significantly impact critical production system parameters in a positive way.

Interested organizations and groups are encouraged to contact the 5G-ACIA office to learn more about applying the methodology and conducting individual analyses aimed at calculating the business value of industrial 5G use cases in production.

7 Abbreviations

5G-ACIA	5G Alliance for Connected Industries and Automation
AGV	Automated guided vehicle
A	Availability
ACR	Compressed Air Consumption Ratio
AE	Allocation Efficiency
AR	Accident Ratio
BLISK	Bladed Disk
CapEX	Capital Expenditure
E	Effectiveness
ECR	Electric Power Consumption
FPY	First Pass Yield
GCR	Gas Consumption Ratio
IT/OT	Information Technology/ Operation Technology
KPI	Key Performance Indicator
MF	Machine Flexibility
MHM	Material Handling Mobility
mMTC	Massive Machine Type Communication
MTBF	Mean Time Between Failures
MTTR	Mean Time to Repair
NPV	Net Present Value
On-Time Delivery	OTD
OpEX	Operational Expenditure
QR	Quality Ratio
RoI	Return on Invest
RR	Rework Ratio
SP	Space Productivity
SR	Scrap Ratio
SUR	Setup Ratio
TE	Technical Efficiency
TR	Throughput Ratio
UE	Utilization Efficiency
WCR	Water Consumption Ratio
WE	Worker Efficiency

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- ifm
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KETI	KEYSIGHT	kontron	MITSUBISHI ELECTRIC
MOXA	MUGLER TELCO NETWORKS.	NOKIA	NXP
OMRON	orange	PEPPERL+FUCHS	PHŒNIX CONTACT
Qualcomm	RELIABLE REAL-TIME RADIO	Radisys	Rockwell Automation
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