Appendix B. DMAIC 4.0 Framework Descriptions

No.	LSS task supported	Purpose	Expected benefit from I4.0 support	Procedure	Supporting I4.0 Technology or Technique
D1	**Project Definition**	Analyse large amounts of texts and data, e.g. quality reports, customer reviews/complaints to identify the most severe issues. A new project is defined to address those issues.	Text Mining might reveal information and relationships that would not be detected by traditional LSS techniques.	1) Various text mining techniques can help analyse large amounts of texts and data, e.g. quality reports, customer reviews/complaints. 2a) Use a topic detection algorithm, such as LDA (Latent Dirichlet Allocation), to identify relevant themes in text documents. 2b)Texts can be converted into document vectors so machine learning algorithms can be applied to text data. Use clustering algorithms like DB scan using Levenshtein or Cosine distance to group salient topics. 3) Analyse identified themes/topics, i.e. by sorting or ranking them to define a new project.	**(Big Data) Analytics**, i.e. Text Mining / Analytics tools, such as KNIME or Rapid Miner, R, Python

Appendix B. DMAIC 4.0 Framework Descriptions

No.	LSS task supported	Purpose	Expected benefit from I4.0 support	Procedure	Supporting I4.0 Technology or Technique
D2	**Voice of the Customer (VoC)**	Understand the customer's needs and focus improvements on achieving customer satisfaction.	Gain insights into (large amounts of) textual data more quickly and with less effort. If customer requirements are unknown, text mining can accellerate the interpretation of relevant “textual, unstructured content”.	1) Extract customer feedback data, e.g., from social media or customer interaction systems. 2a) Apply a topic detection algorithm, such as LDA (Latent Dirichlet Allocation), to identify relevant themes discussed about a product or service. 2b) A sentiment analysis can be applied to analyse if customers have positive, negative or neutral opinions. 2c) Texts can be converted into document vectors so machine learning algorithms can be applied to text data. Use clustering algorithms like DB scan using Levenshtein or Cosine distance if you want to make predictions, e.g. forecast customer churn. 3) Use analysis resuls as inputs for the LSS VoC-CTS/CTQ tool.	**(Big Data) Analytics, i.e. Text Mining** / Analytics tools, such as KNIME or Rapid Miner, R, Python

Appendix B. DMAIC 4.0 Framework Descriptions

No.	LSS task supported	Purpose	Expected benefit from I4.0 support	Procedure	Supporting I4.0 Technology or Technique
D3	**Critical to Quality characteristics**	Derive measurable characteristics from customer needs. To prioritize the characteristics, classification algorithms can identify from a huge amount of data which product characteristics lead to a, e.g., buy or re-buy decision without having in-depth knowledge about the business.	CTQ-C's are determined by facts (data) and standardised rules rather than expert knowledge.	1) Collect process data. The output variable can be categorical (e.g. rebuy or return) or continuous (e.g. rating or sales volume). Input variables (features) are preferably categorical (e.g. colour). Continuous data (e.g. brightness in lumen) are discretizised before building the model. 2) Apply a decision tree algorithm. For complex scenarios, ensemble models of decision trees, i.e. random forest can be used. 3) Define project goals according to insights gained.	**Data Mining, e.g. Decision trees** / Analytics tools, such as KNIME or Rapid Miner, or data science development environments (Anaconda, Jupyter Lab; R or python packages and libraries, i.e. Matlab, Seaborn etc.).
D4	**SIPOC/ Process Map**	Illustrate the relevant (high-level) process steps to clarify the project scope and demonstrate the value flow between stakeholders.	Process mining tools visualise process workflows based on system data and are a reliable source for creating SIPOCs and as-is process maps.	1) Install a process mining tool that collects event logs from relevant systems (PM type: discovery) 2) Customise PM tool to extract the workflow containing process steps of interest and visualise the process. Process mining tools trace resources/entities involved in a process so all roles that engage with a certain process are identified. 3) To create a SIPOC, aggregate the process to the most important steps.	**Process Mining** / Process mining software, e.g. Appian, ProM, Celonis, Process Gold, or DISCO.

Appendix B. DMAIC 4.0 Framework Descriptions

No.	LSS task supported	Purpose	Expected benefit from I4.0 support	Procedure	Supporting I4.0 Technology or Technique
D5	**Process Visualisation**	Visualise the process to identify problems that eventually require process improvement.	Data is collected and visualised automatically or on demand. Problems are detected more easily and timely.	Prerequisite: a network of interconnected sensors, devices, processing/storage units and applications that allows detection of problems or defects through data transmission on user devices. 1) Define process for monitoring, alerts etc. 2) Define appropriate actions according to observations made	**Internet of Things** / IoT modules with sensors and tablets and smartphones for monitoring

Appendix B. DMAIC 4.0 Framework Descriptions

No.	LSS task supported	Purpose	Expected benefit from I4.0 support	Procedure	Supporting I4.0 Technology or Technique
M1	**Cause and Effect Diagram**	Identify which data to collect	With a big data framework in place, data from multiple data sources is instantly available. Algorithms help gain insights into large amounts of data and identify potential root-causes. For complex processes, this approach is needed to narrow down possible causes to a dimension that is manageable for the brainstorming exercise.	Prerequisite: Big data framework is in place. 1) Extract relevant process parameters. Normalise and/or transform the data if needed. 2) Create a model, e.g. using a random forest algorithm, and identify the parameters with the most significant influence on the output. These are the potential root causes to consider in the brainstorming session. 3) Also brainstorm causes that are outside the dataset analysed using random forest.	**Solution for big data storage and processing; Analytics software tools /** Cloud or internal (big data) storage solutions (e.g. AWS), and processing frameworks (e.g. Hadoop). Analytics tools, such as KNIME or Rapid Miner, or data science development environments (Anaconda, Jupyter Lab; R or python packages and libraries, i.e. Matlab, Seaborn etc.).

Appendix B. DMAIC 4.0 Framework Descriptions

No.	LSS task supported	Purpose	Expected benefit from I4.0 support	Procedure	Supporting I4.0 Technology or Technique
M2	**Data Collection (BDA)**	Collect process and product data automatically (and in real-time)	Big data frameworks provide instant and real-time access to data. This approach reduces time and effort and increases the data quality as opposed to manual data collection.	Prerequisite: Big data framework is in place. 1) Identify process parameters to be collected and respective data sources 2) Extract and merge data as required.	**Solution for big data storage and processing; Analytics software tools** / Massively Parallel Processing (MPP) database systems and MapReduce algorithm for data processing and analysis. Data pipelines.
M3	**Measurement System Analysis (Gage R&R)**	Verify if the data collected is reliable and can be used for analyses.	Large amounts of data from different machines can be tested for reliability, i.e., is there a difference between machines. Traditional methods, such as Gage R&R (Anova), are no longer effective when analysing large datasets, as the p-value is always close to zero.	1) Prepare data from different measurement systems (e.g. machines). Normalise and/or transform the data if needed. 2) Create a model based on a neural network and feed the data from different measurement systems into the model. 3) Calculate the mean squared error to calculate the metric for the similarity between different data sources: MAE in relation to the overall mean (MAE/ mu).	**Machine Learning, Artificial Neural Network, Deep learning** / Analytics tools, such as KNIME or Rapid Miner, or data science development environments (Anaconda, Jupyter Lab; R or python packages and libraries, i.e. Matlab, Seaborn etc.).

Appendix B. DMAIC 4.0 Framework Descriptions

No.	LSS task supported	Purpose	Expected benefit from I4.0 support	Procedure	Supporting I4.0 Technology or Technique
M4	**Data Preparation**	Merge data from different sources and prepare data for analysis.	Modern analytics tools allow preparing and transforming big masses of data. Once set-up, the data is prepared automatically and repetitively. Some of the can be used for free. Traditional statistical tools are not able to handle huge amounts of data and do not offer automation.	1) Access the data and check data structure, number and date format etc. 2) Perform data cleansing. Optional: use an interactive view for data preparation/ cleansing. 3) If the data comes from different sources, perform steps 1 and 2 separately for each source. Then merge the data. 3) Use graphical tools to visualise the data and gain first insights (histogram, run chart, box plot, scatter plot, correlation matrix, time series plot, pareto chart, etc.). 4) Idenfity data distribution, seasonality etc. and choose appropriate analysis techniques 5) Perform further data preparation steps, e.g. interpolate missing data using a prediction algorithm e.g. k-nearest neighbour to calculate missing values from average of existing values.	**Data Mining, graphical analysis** / Analytics tools, such as KNIME or Rapid Miner, or data science development environments (Anaconda, Jupyter Lab; R or python packages and libraries, i.e. Matlab, Seaborn etc.).

Appendix B. DMAIC 4.0 Framework Descriptions

No.	LSS task supported	Purpose	Expected benefit from I4.0 support	Procedure	Supporting I4.0 Technology or Technique
M5	**Current State**	Determine the as-is process performance i.e. process stability, variation etc.	Modern analytics tools can generate charts automatically and repeatedly without manual rework.	1) Load data into analytics tool. 2) Use graphical tools to create a run or control chart, histogram etc.) and document the performance. 3) Optional: Create a dashboard with graphs and figures from step 2	**Data Mining, graphical analysis** / Analytics tools, such as KNIME or Rapid Miner, or data science development environments (Anaconda, Jupyter Lab; R or python packages and libraries, i.e. Matlab, Seaborn etc.).
M6	**Process Capability**	Determine the process capability, i.e. check if the process outputs meet the customer requirements.	Modern analytics tools can generate charts automatically and repeatedly without manual rework.	1) Load data into analytics tool. The process capability is usually calculated using a limited number of data points. No big data is required here. 2) Create a histogram with a fitted curve. 3) Calculate process performance Cp, Cpk, Pp, Ppk 4) Optional: Create a dashboard with graphs and figures from step 2 Remark: Steps 1-4 have to be performed only once.	**Data Mining, graphical analysis** / Analytics tools, such as KNIME or Rapid Miner, or data science development environments (Anaconda, Jupyter Lab; R or python packages and libraries, i.e. Matlab, Seaborn etc.).

Appendix B. DMAIC 4.0 Framework Descriptions

No.	LSS task supported	Purpose	Expected benefit from I4.0 support	Procedure	Supporting I4.0 Technology or Technique
M7	**Data collection (PM)**	Collect process data automatically to reduce time and effort and increase data quality.	Discovery of the 'real' as-is processes without having to interview process owners. Process owners might have a different view on how the process works.	Prerequisite: a process mining tool that collects event logs from relevant systems is installed. (PM type: discovery) 1) Customise PM tool to extract and display additional workflows and more detailed information from the source data (event logs) 2) Extract the workflow containing process steps of interest and visualise the detailed process with roles/organisations involved.	**Process Mining** / Process mining software, e.g. Appian, ProM, Celonis, Process Gold, or DISCO.
M8	**Process Map / Measure cycle times**	Illustrate the relevant (detailed) process steps to capture the as-is process flows. Determine process participants / roles / organisations.	Process mining applications visualize as-is processes, which can be used directly as process maps or as an input for modelling process maps with other tools. The times spent for each step are available and do not have to be documented manually.	1) Optional: Create a process map in corporate process modelling tool based on workflows extracted from the PM tool. 2) Event logs collected from enterprise and/or manufacturing systems provide time stamps that can be used to calculate the duration of a process end-to-end or between certain process steps. Customise the PM tool to calculate the duration between process steps of interest. 3) Calculate lead or cycle times	**Process Mining** / Process mining software, e.g. Appian, ProM, Celonis, Process Gold, or DISCO.

Appendix B. DMAIC 4.0 Framework Descriptions

No.	LSS task supported	Purpose	Expected benefit from I4.0 support	Procedure	Supporting I4.0 Technology or Technique
M9	**Data Collection (IoT)**	Collect process and product data	Data is collected automatically through smart devices, which reduces time and effort and increases data quality.	Prerequisite: Sensors, cameras, smart devices etc. collect process and product parameters on an ongoing basis. A network connects the devices with an operating platform or database. 1) Identify process parameters to be collected 2) Extract and merge data as required.	**RFID, Sensors, Networks, Smart Devices** / Network with interconnected sensors and/or (hand-held/wearable) devices, supported by analytics tools (optional)
M10	**Value Stream Map / Process Map**	Illustrate the flow of materials and/or information, i.e. the value streams. Measure the time spent on each process step (process time and cycle time). Identify waiting times (waste).	The time each part spends at each step is automatically recorded and can be used as inputs for value stream maps.	Prerequisite: Sensors, cameras, smart devices etc. collect process and product parameters on an ongoing basis. A network connects the devices with an operating platform or database: 1) Identify value-adding process steps. 2) Extract time stamps for each step. 3) Optional: Create a smart VSM using data collected and transmitted automatically and continuously at subsequent stations in the production line.	**RFID, Sensors, Networks, Smart Devices** / Network with interconnected sensors and/or (hand-held/wearable) devices, supported by analytics tools (optional)

Appendix B. DMAIC 4.0 Framework Descriptions

No.	LSS task supported	Purpose	Expected benefit from I4.0 support	Procedure	Supporting I4.0 Technology or Technique
A1	**Statistical analysis**	Perform statistical tests (with large data sets) to understand influencing factors and predict process outcomes	Big data analytics enables processing huge amounts of data and gaining insights into complex processes.	Prerequisite: Big data framework is in place. 1) Select the appropriate algorithm (based on data and purpose) 2) Perform statistical analysis using the selected algorithm(s), e.g. Regression, k-nearest neighbour, Bayesian net, association rule, Support Vector Machine 3) Interpret results. Eventually, apply other techniques and compare with results of other techniques	**Solution for big data storage and processing;** **Analytics software tools /** Cloud or internal (big data) storage solutions (e.g. AWS), and processing frameworks (e.g. Hadoop) Analytics tools, such as KNIME or Rapid Miner, or data science development environment, e.g. Jupyter Lab, using R or python packages and libraries.

Appendix B. DMAIC 4.0 Framework Descriptions

No.	LSS task supported	Purpose	Expected benefit from I4.0 support	Procedure	Supporting I4.0 Technology or Technique
A2	**Root-cause Analysis**	Identify root-causes for a problem	Machine learning models facilitate the root-cause analysis for complex processes as they reduce the number of potential root-causes.	1) Select the appropriate algorithm (based on the nature of the data) 2) Create a model, e.g. regression, recursive partitioning, classification tree, clustering etc. to identify which factors have the biggest influence on the output. For complex processes, use a neural network. 3) Transfer to an Ishikawa diagram to refine and conclude the analysis	**Machine Learning, Artificial Neural Network, Deep learning /** Analytics tools, such as KNIME or Rapid Miner, or data science development environments (Anaconda, Jupyter Lab; R or python packages and libraries, i.e. Matlab, Seaborn etc.).
A3	**(Multi-variate) Regression**	Predict process output / performance considering multiple variables	Deep neural networks can replace traditional multivariate regressions in predicting process outputs where traditional tools cannot handle the amount of data and/or the number of process variables.	1) Create a deep neural network 2) Train the model and check how it performs (e.g. Mean squared error, performance function) 3) Optimise model, e.g. (Levenberg-Marquardt training function) 4) Test and deploy the model	**Machine Learning, Artificial Neural Network, Deep learning /** Analytics tools, such as KNIME or Rapid Miner, or data science development environments (Anaconda, Jupyter Lab; R or python packages and libraries, i.e. Matlab, Seaborn etc.).

Appendix B. DMAIC 4.0 Framework Descriptions

No.	LSS task supported	Purpose	Expected benefit from I4.0 support	Procedure	Supporting I4.0 Technology or Technique
A4	**DOE / Taguchi design**	Determine the optimal parameter settings	Artificial neural networks can predict outcomes according to the DOE plan. This approach reduces the number of experiments and, therefore, saves time and costs.	1) Configure a neural network to predict outputs for different combinations of input settings. 2) Simulate output according to initial DOE plan 3) Reduce DOE plan 4) Conduct physical experiments according to the reduced DOE plan 5) Verify model performance (compare to DOE results)	**Machine Learning, Artificial Neural Network, Deep learning /** Analytics tools, such as KNIME or Rapid Miner, or data science development environments (Anaconda, Jupyter Lab; R or python packages and libraries, i.e. Matlab, Seaborn etc.).
A5	**Principal component analysis**	Identify the most vital (few) input variables for high-dimensional data (complex processes)	Modern analytics software tools can effortlessly process large amounts of data and process variables, while traditional tools are less performant.	1) Perform dimensionality reduction by low variance and linear correlation on training data. (filter variables with low variance and low correlation) 2) Perform PCA on training data (numeric columns are replaced by principal components) 3) Apply techniques performed in1) and 2) on test set	**Machine Learning, Artificial Neural Network, Deep learning /** Analytics tools, such as KNIME or Rapid Miner, or data science development environments (Anaconda, Jupyter Lab; R or python packages and libraries, i.e. Matlab, Seaborn etc.).

Appendix B. DMAIC 4.0 Framework Descriptions

No.	LSS task supported	Purpose	Expected benefit from I4.0 support	Procedure	Supporting I4.0 Technology or Technique
A6	**Response Surface Method (RSM)**	Optimise parameter setting for non-linear models	Deep neural networks yield better results in predicting outputs for processes with non-linear relationships than the traditional RSM method.	1) For models with non-linear relationships between input and output variables. 2) Configure a neural network and apply an algorithm to predict outputs for different combinations of input settings. 3) Choose parameter setting for an optimal output.	**Machine Learning, Artificial Neural Network, Deep learning /** Analytics tools, such as KNIME or Rapid Miner, or data science development environments (Anaconda, Jupyter Lab; R or python packages and libraries, i.e. Matlab, Seaborn etc.).
A7	**Taguchi loss function**	Modelling complex relationships between variables to reduce defects	ANNs can analyse non-linear and complex relationships between inputs and outputs better than Taguchi's loss function.	1) Transform data to help ANN learn better, e.g. convert to polar coordinates around the mean values. 2) Configure an ANN and use labelled data (ok/not ok) to train. 3) Validate the model and evtl. retrain Plot an ANN-based cost surface (3D) 4) Match (superimpose) ANN cost surface with data 5) Retrieve parts that do not comply (not ok). Evtl. adjust threshold level.	**Machine Learning, Artificial Neural Network, Deep learning /** Analytics tools, such as KNIME or Rapid Miner, or data science development environments (Anaconda, Jupyter Lab; R or python packages and libraries, i.e. Matlab, Seaborn etc.).

Appendix B. DMAIC 4.0 Framework Descriptions

No.	LSS task supported	Purpose	Expected benefit from I4.0 support	Procedure	Supporting I4.0 Technology or Technique
A8	**Cause and Effect Diagram**	Identify which (few) input variables have the greatest impact on the output	For high-dimensional data (complex processes), decision trees are more effective than traditional tools.	1) Collect process data. The output variable can be categorical (e.g. rebuy or return) or continuous (e.g. rating or sales volume). Input variables (features) are preferably categorical (e.g. colour). Continuous data (e.g. brightness in lumen) are discretised before building the model. 2) Use a decision tree algorithm, e.g. chi-squared automatic interaction detection (CHAID) to identify variables with the biggest effect on the process output. 3) Proceed with the analysis using the most relevant factors (the higher the factors in the tree, the more relevant).	**Data Mining classification algorithms, e.g. decision trees** / Analytics tools, such as KNIME or Rapid Miner, or data science development environments (Anaconda, Jupyter Lab; R or python packages and libraries, i.e. Matlab, Seaborn etc.).
A9	**DOE (Data Mining)**	Select the most important variables for reducing the DOE scope and, therefore, saving time and costs	Decision trees can predict outcomes according to the DOE plan. This approach reduces the number of experiments and, therefore, saves time and costs.	1) Collect process data and prepare the data 2) Create a model: use a decision tree algorithm, e.g. chi-squared automatic interaction detection (CHAID) or recursive partitioning to identify variables with the biggest effect on the process output. 3) Identify factor levels for DOE and create DOE plan accordingly.	**Data Mining classification algorithms, e.g. decision trees** / Analytics tools, such as KNIME or Rapid Miner, or data science development environments (Anaconda, Jupyter Lab; R or python packages and libraries, i.e. Matlab, Seaborn etc.).

Appendix B. DMAIC 4.0 Framework Descriptions

No.	LSS task supported	Purpose	Expected benefit from I4.0 support	Procedure	Supporting I4.0 Technology or Technique
A10	**Statistical analysis (DM)**	Find the most important factors that influence the process output, e.g which variables influence the customer demand	Decision trees are superior to traditional statistical tools for gaining insight into large or high-dimensional data sources.	1) Collect process data and prepare the data 2) Use the decision tree method and a data mining classification algorithm to find the most important factors that influence the process output. The output can also be a demand. 3) Proceed with the analysis (for decision making) using the most relevant factors (the higher the factors in the tree, the more relevant).	**Data Mining classification algorithms, e.g. decision trees** / Analytics tools, such as KNIME or Rapid Miner, or data science development environments (Anaconda, Jupyter Lab; R or python packages and libraries, i.e. Matlab, Seaborn etc.).
A11	**(Multi-variate / Logistic) Regression**	Analyse influence of product-related parameters on operational KPIs, e.g. ordering time	Process mining software tools reveal which parameters have an impact on operational KPIs which might other methods or data sources might not reveal.	1) Extract product-related characteristics from PM software. 2) Use data to perform multi-variate regression, e.g. ordinary least square. Forecast ideal ordering time based on product-related characteristics. 3) Use data to perform logistic regression to analyse the probability of an event occuring.	**Process Mining** / Process mining software, e.g. Appian, ProM, Celonis, Process Gold, or DISCO.

Appendix B. DMAIC 4.0 Framework Descriptions

No.	LSS task supported	Purpose	Expected benefit from I4.0 support	Procedure	Supporting I4.0 Technology or Technique
A12	**Root-cause Analysis (PM)**	Identify root-causes for a problem	Workflows visualized through Process mining software tools reveal deviations from the standard process. With this approach, bottlenecks and idle times (waste) are identified easily.	Prerequisite: Process discovery performed to explore as-is processes. Standard process is defined in PM tool. 1) Perform conformance checking 2) Analyse deviations from the standard process and determine potential root-causes, e.g. analyse idle times and bottlenecks	**Process Mining** / Process mining software, e.g. Appian, ProM, Celonis, Process Gold, or DISCO.
A13	**Root-cause Analysis (IoT)**	Identify root-causes for a problem	The root-cause analysis is based on systemic data, and therefore, potential bias from expert opinions is reduced.	Prerequisite: Data is provided through a network that connects devices with an operating platform or database. 1) State which problem should be analysed, e.g. long waiting times 2) Gather process steps that influence the wait time. Extract time stamps for each step. 3) Determine potential root-causes, e.g. analyse idle times and bottlenecks	**Sensors, Networks, Smart Devices** / Network with interconnected sensors and (hand-held/wearable) devices, supported by analytics tools (optional)

Appendix B. DMAIC 4.0 Framework Descriptions

No.	LSS task supported	Purpose	Expected benefit from I4.0 support	Procedure	Supporting I4.0 Technology or Technique
I1	**Simulation**	Simulate process outcomes for different parameter settings	Big data analytics enables predicting comes of complex processes (with many input variables).	Prerequisite: Big data architecture is in place. 1) Identify relevant process parameters. Normalise and/or transform the data if needed. 2) Create a model for simulation or reuse the model from cause and effect diagram from the Measure phase (e.g. random forest). 3) Simulate the effects of changing explanatory variable settings on the target variable.	**Solution for big data storage and processing;** **Analytics software tools /** Cloud or internal (big data) storage solutions (e.g. AWS), and processing frameworks (e.g. Hadoop) Analytics tools, such as KNIME or Rapid Miner, or data science development environment, e.g. Jupyter Lab, using R or python packages and libraries.

Appendix B. DMAIC 4.0 Framework Descriptions

No.	LSS task supported	Purpose	Expected benefit from I4.0 support	Procedure	Supporting I4.0 Technology or Technique
I2	**Poka Yoke**	Avoid errors	Machine learning techniques help avoid (human) errors by predicting them.	Prerequisite: Data is already collected. 1) Define error that should be avoided (how do process parameters look like when an error occurs?) 2) Generate test data with known error sequences 3) Create a deep neural network and train the model 4) Test model with new (unlabelled) data and eventually retrain the model. 5) Integrate model with user-friendly devices, e.g. LED signals or vibration alert	**Artificial Neural Network, Deep learning** / Analytics tools, such as KNIME or Rapid Miner, or data science development environments (Anaconda, Jupyter Lab; R or python packages and libraries, i.e. Matlab, Seaborn etc.). Keras and Tensorflow for deep learning

Appendix B. DMAIC 4.0 Framework Descriptions

No.	LSS task supported	Purpose	Expected benefit from I4.0 support	Procedure	Supporting I4.0 Technology or Technique
I3	**Simulation (replace)Select the best solution**	Support decision-making or planning process by forecasting possible outputs.	Data mining techniques facilitate the prediction of possible outcomes, also when given high-dimensional data and large data volumes.	1) Collect process data and prepare the data 2) Use the decision tree method and a data mining classification algorithms to predict the process output. e.g., number of resources required or customer demand. 3) Evaluate forecasts, e.g. by comparing plan without forecast with forecasted outputs.	**Data Mining** / Analytics tools, such as KNIME or Rapid Miner, or data science development environments (Anaconda, Jupyter Lab; R or python packages and libraries, i.e. Matlab, Seaborn etc.). Keras and Tensorflow for deep learning
I4	**Process redesign**	Optimise the process flow and avoid waste	Process mining software tools detect if processes are executed correctly or if they deviate from the standard. Based on these insights, the process can be optimised.	Prerequisite: Process discovery performed to explore as-is processes. Standard process is defined in PM tool. 1) Perform conformance checking. 2) Analyse deviations from the standard process and design process improvements where processes are not conformant. Also pay attention to to bottle-necks and idle times identified. 3) Change workflows and communicate new process	**Process Mining** / Process mining software, e.g. Appian, ProM, Celonis, Process Gold, or DISCO.

Appendix B. DMAIC 4.0 Framework Descriptions

No.	LSS task supported	Purpose	Expected benefit from I4.0 support	Procedure	Supporting I4.0 Technology or Technique
I5	**SMED**	Reduce set-up time / cycle time	Process mining software tools help detect idle times and bottlenecks. These details can be used to improve the SMED concept.	Prerequisite: Process data with time stamps is available 1) Prepare process data 2) Upload data into PM tool 3) Visualise process steps and calculate durations 4) Analyse resource allocated and time spent in each process step 5) Modify SMED concept according to insights gained, e.g., share resources, multi-machine set-up etc.	**Process Mining** / Process mining software, e.g. Appian, ProM, Celonis, Process Gold, or DISCO.
I6	**Poka Yoke**	Avoid errors	IoT technologies and smart devices to reduce errors help avoid (human) errors by showing/alerting them prematurely.	Smart devices can be used as error proofing, e.g., 1) Apply Augmented Reality technologies (e.g. holo lens) for repetitive and delicate work 2) IoT modules with sensors and tablets or smartphones for monitoring 3) Detection of problems or defects through data transmission on user devices	**Internet of Things** / Sensors, networks, smart devices, cameras etc.

Appendix B. DMAIC 4.0 Framework Descriptions

No.	LSS task supported	Purpose	Expected benefit from I4.0 support	Procedure	Supporting I4.0 Technology or Technique
I7	**5S**	Improve productivity through visual management (Sort, Straighten, Shine, Standardize, Sustain)	RFID chips and smart sensors track material movement. This information can be visualised and used to improve 5S practice.	1) Use RFID technology and smart sensors to track and visualise material movement 2) Use data to improve 5S practice	**Internet of Things** / RFID Technology and smart sensors
I8	**5S**	Use Virtual Reality technology for remote team creativity sessions	Using VR technology enables remote or international to collaborate. It is more engaging compared to video conferences and is likely to deliver better work results.	Prerequisite: VR equipment is available to team members. VRs can be used to support work sessions of remote teams so everyone can be in the same virtual room. Creativity tools for finding the best solution, such as Brainstorming, Brainwriting, 6 – 3 – 5 method, Six thinking hats etc. are applied in VR meeting sessions. There are also other opportunities, such as training sessions or walking the process.	**Internet of Things** / Virtual Reality technology and devices

Appendix B. DMAIC 4.0 Framework Descriptions

No.	LSS task supported	Purpose	Expected benefit from I4.0 support	Procedure	Supporting I4.0 Technology or Technique
C1	**Process monitoring**	Monitor improved process to sustain improvement	Real-time process monitoring based on big data analytics helps sustain improvements by alerting out-of-control states before they occur. This approach can also enable event-based inspection and predictive maintenance.	Prerequisite: Data pipeline to process real-time data. Control variables (also input variables) are identified. Data for model training and testing is available. 1a) Implement settings from simulation task in Analyse. Implement control charts, e.g., one-class classification (OCC)-based control charts based on continuous and profile monitoring algorithms to monitor system processes and identify issue areas. 1b) Alternatively, create a new model, e.g. using an anomaly detection algorithm. 2) Deploy model to use on real-time data 3) Implement a real-time notification system (alarm system, dashboards)	**Big Data Analytics (Predictive / Prescriptive Analytics)** / Cloud or internal (big data) storage solutions (e.g. AWS) and processing frameworks (e.g. Hadoop) Analytics tools, such as KNIME or Rapid Miner, or data science development environment, e.g. Jupyter Lab, using R or python packages and libraries.

Appendix B. DMAIC 4.0 Framework Descriptions

No.	LSS task supported	Purpose	Expected benefit from I4.0 support	Procedure	Supporting I4.0 Technology or Technique
C2	**Multivariate SPC**	Predict out-of-control states considering multiple variables and with signals that are easy to interpret.	Machine learning models enable real-time process monitoring and are more dynamic (the model evolves with new data) than traditional SPC.	Prerequisite: Control variables (also input variables) are identified. Data for model training and testing is available. 1) Create multivariate SPC charts based on predictive models, e.g., using Partial Least Squares algorithm or ANNs 2) Enhance algorithm based on the nature of the data, e.g. with a bootstrap technique for small samples 3) Establish a methodology to interpret predicted out-of-control signals and make adjustments 4) Establish email notifications for control limit breaches 5) Automate data collection for real-time monitoring	**Machine Learning, Artificial Neural Network /** Analytics tools, such as KNIME or Rapid Miner, or data science development environments (Anaconda, Jupyter Lab; R or python packages and libraries, i.e. Matlab, Seaborn etc.).

Appendix B. DMAIC 4.0 Framework Descriptions

No.	LSS task supported	Purpose	Expected benefit from I4.0 support	Procedure	Supporting I4.0 Technology or Technique
C3	**Predictive Maintenance**	Predict the ideal time to maintain or replace machine parts	Machine learning algorithms can detect anomalies and to predict undesired machine states.	Prerequisite: Relevant data (input and output variables) is provided continuously and automatically. 1) Visualise data using run charts or box plots to understand the data and eventually detect seasonality 2) Use anomaly detection to label data indicating that maintenance may be required 3) Create a prediction model for time series data. e.g. ARIMA/SARIMA 4) If the model performance is good, deploy the model 5) Establish a notification system to alert when maintenance is required	**Machine Learning, Artificial Neural Network /** Analytics tools, such as KNIME or Rapid Miner, or data science development environments (Anaconda, Jupyter Lab; R or python packages and libraries, i.e. Matlab, Seaborn etc.).

Appendix B. DMAIC 4.0 Framework Descriptions

No.	LSS task supported	Purpose	Expected benefit from I4.0 support	Procedure	Supporting I4.0 Technology or Technique
C4	**Process monitoring**	Monitor improved process to sustain improvement	Process mining software tools enable automated process monitoring. Alerts can be customized as needed.	Prerequisite: Process discovery performed to explore as-is processes. Standard process is defined in PM tool. 1) Define key performance metrics 2) Perform conformance checking through event logs 3) Implement a dashboard for KPI monitoring, e.g. for detection of process deviations, idle times and bottle-necks 4) Alert on detection of new process variants or non-regular process executions	**Process Mining** / Process mining software, e.g. Appian, ProM, Celonis, Process Gold, or DISCO.
C5	**Process monitoring/ Visual management**	Monitor improved process to sustain improvement	Intelligent monitoring systems alert on (future) out-of-specification situations	Prerequisite: Data is provided through a network that connects devices with an operating platform or database. 1) Define Define key performance metrics (desired state) 2) Create a model for condition-based monitoring for each metric 3) Implement a live graphical analytics and reporting dashboard	**Internet of Things** / IoT modules with sensors, cameras, data pipelines and interconnected systems. Devices, e.g., tablets and smartphones for reporting and monitoring

Appendix B. DMAIC 4.0 Framework Descriptions

No.	LSS task supported	Purpose	Expected benefit from I4.0 support	Procedure	Supporting I4.0 Technology or Technique
C6	**Process documentation**	Document out-of-control states, special events etc. according to the Out-of-control action plan (OCAP)	Automated tracking of critical parameters saves time and effort for operators compared to manual documentation.	1) Define a structure for documenting out-of-specification events as outlined in OCAP, ideally with issue type and reason, eliminates operators' manual efforts for documentation. 2) Implement report with defined structure and make it accessible, e.g. in a file system.	**Internet of Things** / IoT modules with sensors, cameras, data pipelines and interconnected systems. Devices, e.g., tablets and smartphones, for reporting and monitoring