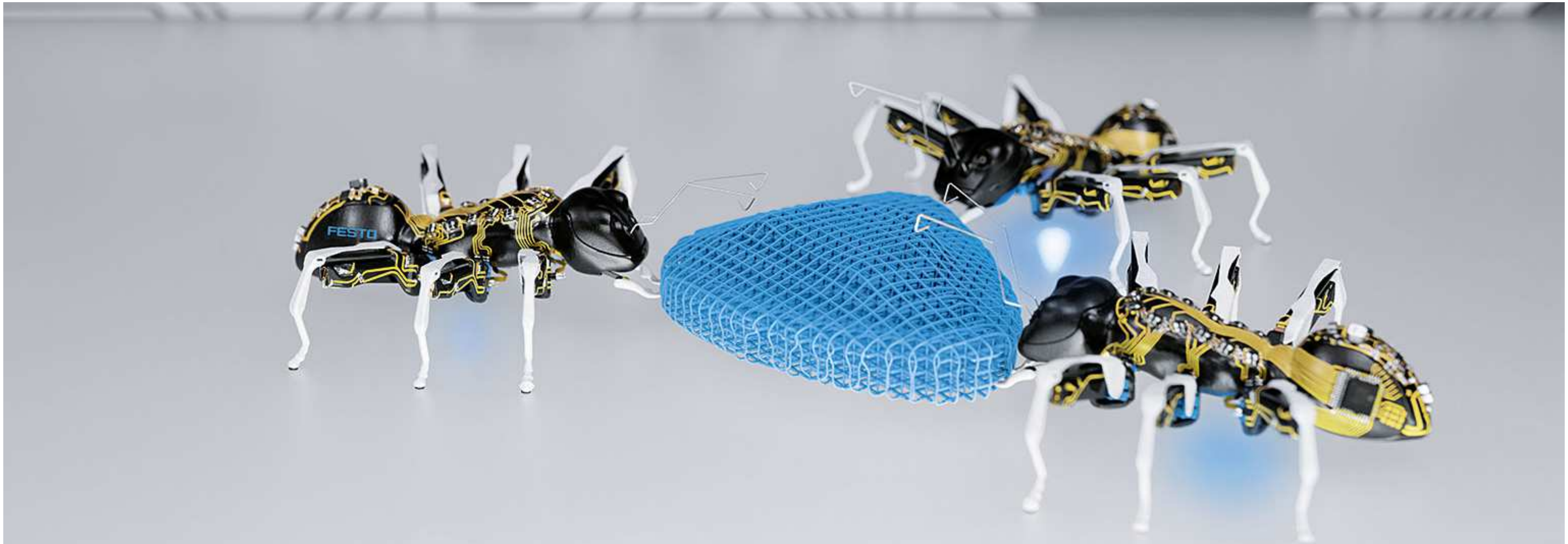
Maintenance strategies



Maintenance: Definition according to DIN 31051:2006-06

„**Maintenance** is the combination of all technical, administrative and management actions during the life cycle of a machine to keep or bring it back in a functional condition.
RAMS: Reliability, availability, maintainability, safety

Five fundamental actions:

- Service
- Inspection
- Repair
- Improvement
- Weak-point analyses

Typical maintenance strategies:

- Reactive maintenance
- Preventive maintenance
- Risk-oriented maintenance
- Predictive maintenance

Term	Definition
Service	All actions taken to increase the lifespan of the machine.
Inspection	Includes all checking and assessment activities carried out to detect wear on certain parts and target them for replacement in good time.
Repair	The actual repair work, restoring the device to functioning condition.
Improvement	Targeted optimization of machines and plants.
Weak point analysis	The process of finding and eliminating potential faults.

Reactive Maintenance

Approach:
- Maintenance activities only in the case of demand

Focus:
- Cost saving

Advantages:
- Low maintenance cost

Disadvantages:
- More unplanned machine faults
- Higher cost in case of downtimes

Scope:
- Rarely used machines

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Preventive Maintenance

Approach:
- Maintenance activities periodically as service or inspection

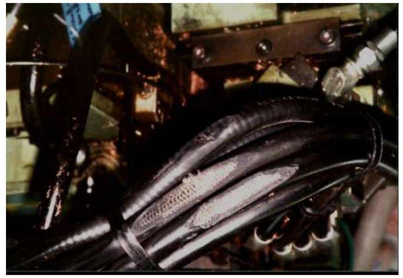
Focus:
- Higher machine availability

Advantages:
- Fewer unplanned stops

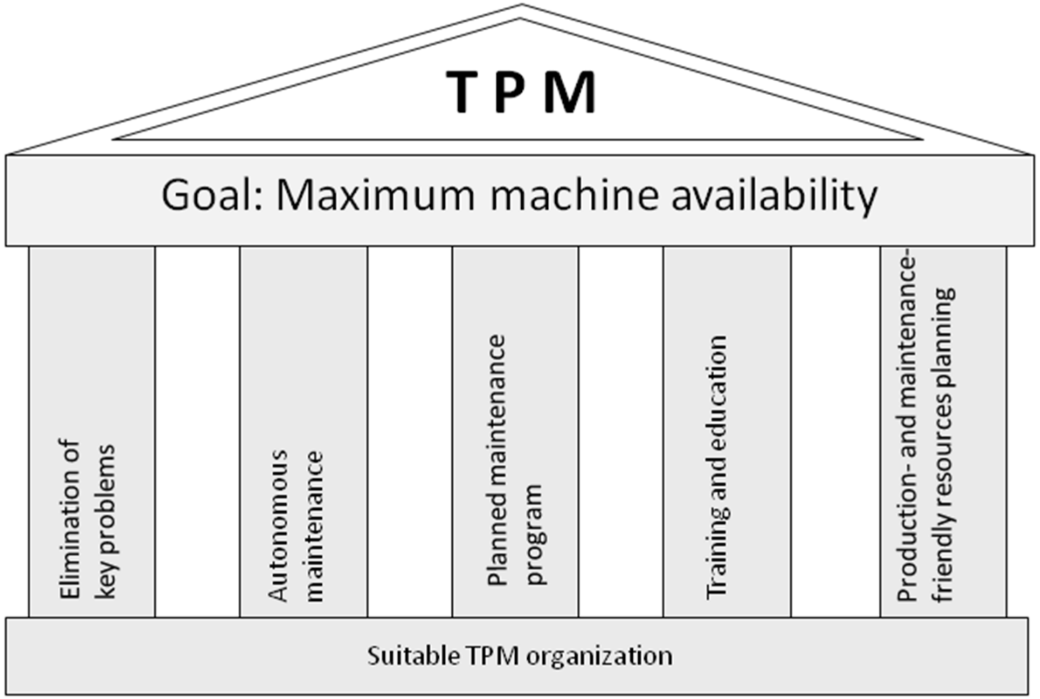
Disadvantages:
- Higher maintenance cost
- No use of remaining service life

Scope:
- Traditional production machines

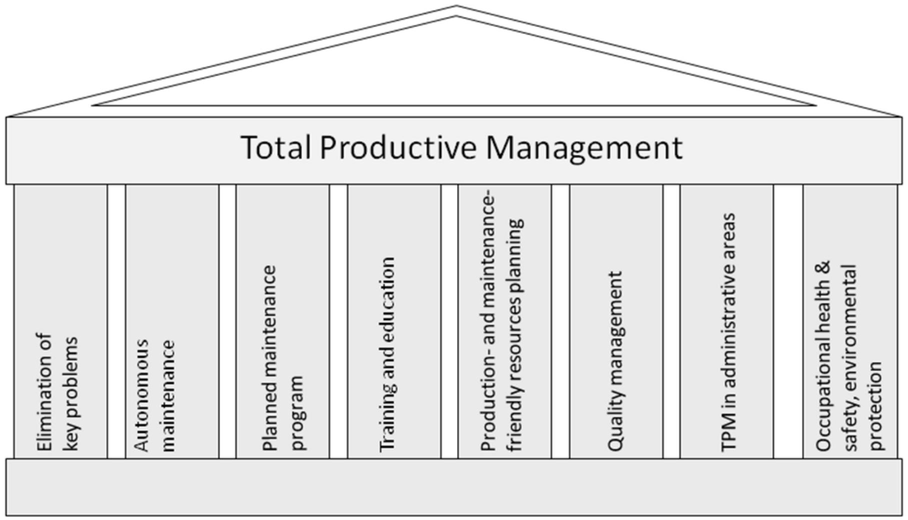
Excursus: Total Productive Maintenance (TPM)



Traditional model:



Adapted model for process industry:



Risk-oriented maintenance

Approach:
- Maintenance should be performed by balancing downtime risks and maintenance cost.

Focus:
- Find an optimum proportion between unplanned stops and maintenance cost

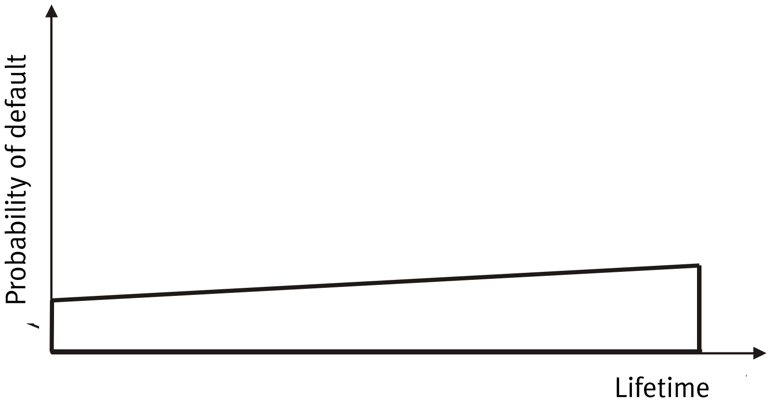
Advantages:
- The compromise

Disadvantages:
- The compromise

Scope:
- Building, ships, cranes...

Excursus: Reliability Centered Maintenance (RCM)

This failure pattern occurs only in 5% of all cases!



1. What features and performance standards exist for the equipment components under current operating conditions?
2. How does a piece of equipment fail in the execution of its function?
3. What is the cause of the failure?
4. What happens if the equipment fails?
5. What impact does the failure have?
6. What can be done to prevent the failure?
7. What should be done if no acceptable solution can be found?

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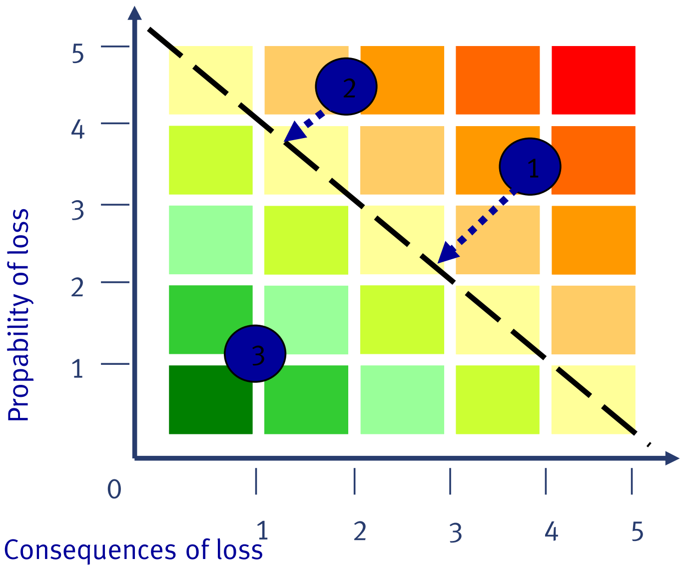
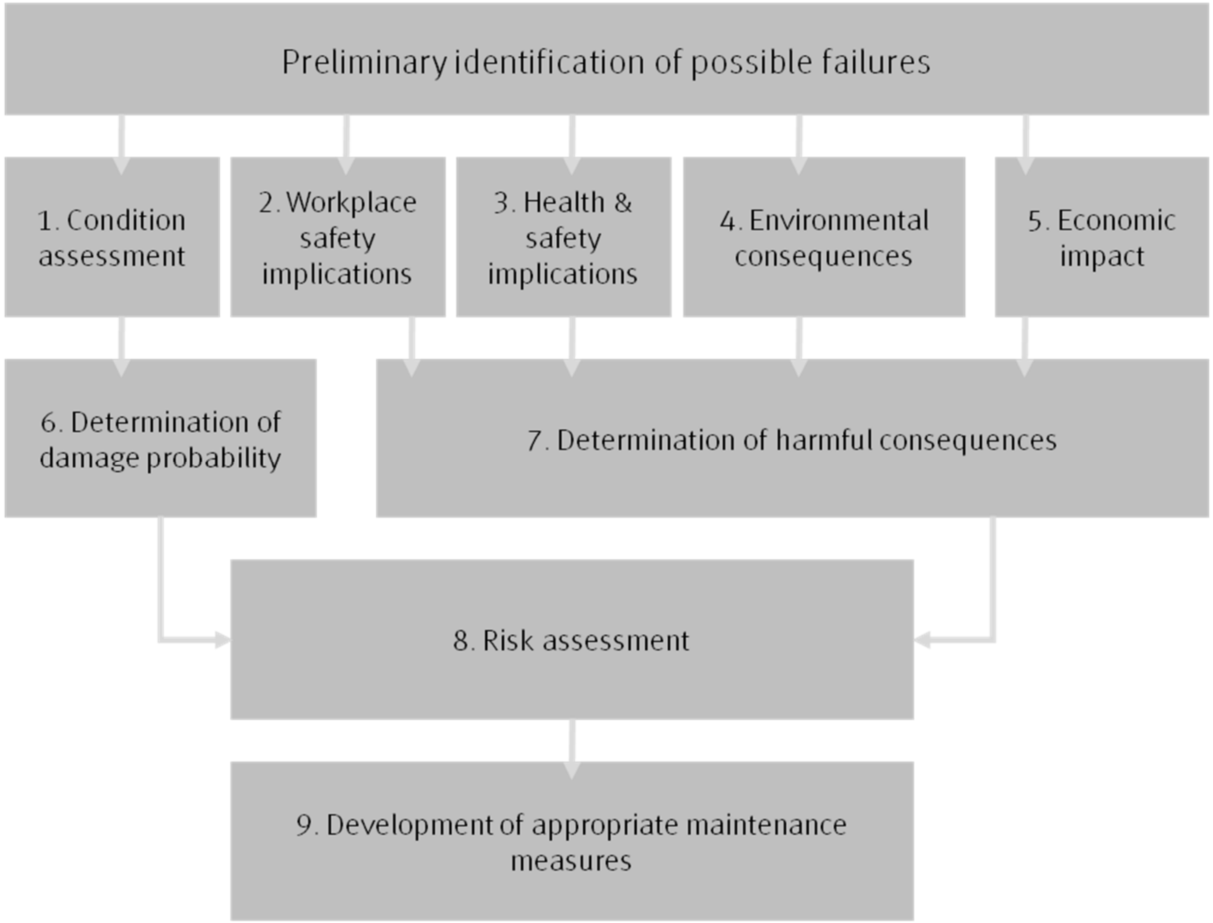
Excursus: Risk Based Maintenance (RBM)



RPZ		von	bis
Bewertung	Beschreibung		
1	sehr gering	1	10
2	gering	11	25
3	mittelschwer	26	45
4	schwer	46	80
5	sehr schwer	81	160



Smart Maintenance / Predictive Maintenance

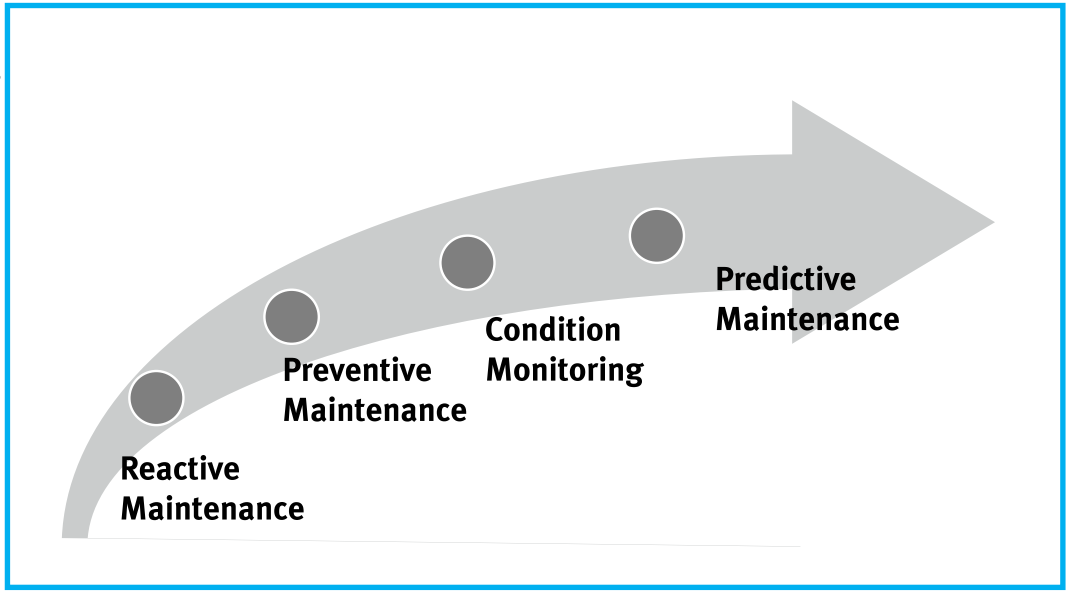
Approach:
The synthesis of Condition Monitoring, data analysis and data correlation as well as computing algorithm enables a predictive maintenance.

Focus:
- Complete prevention of unplanned downtimes with simultaneous low maintenance cost.

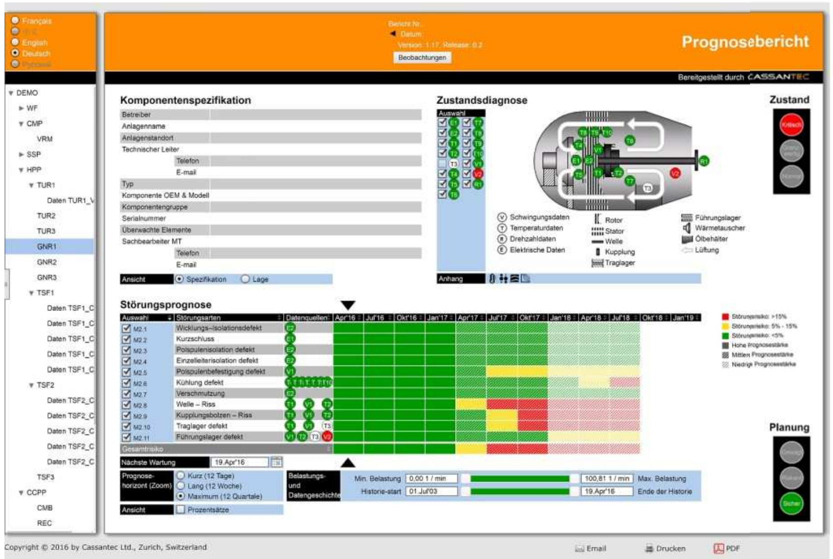
Advantages:
- Punctual detection of potential faults
- Full use of remaining service life

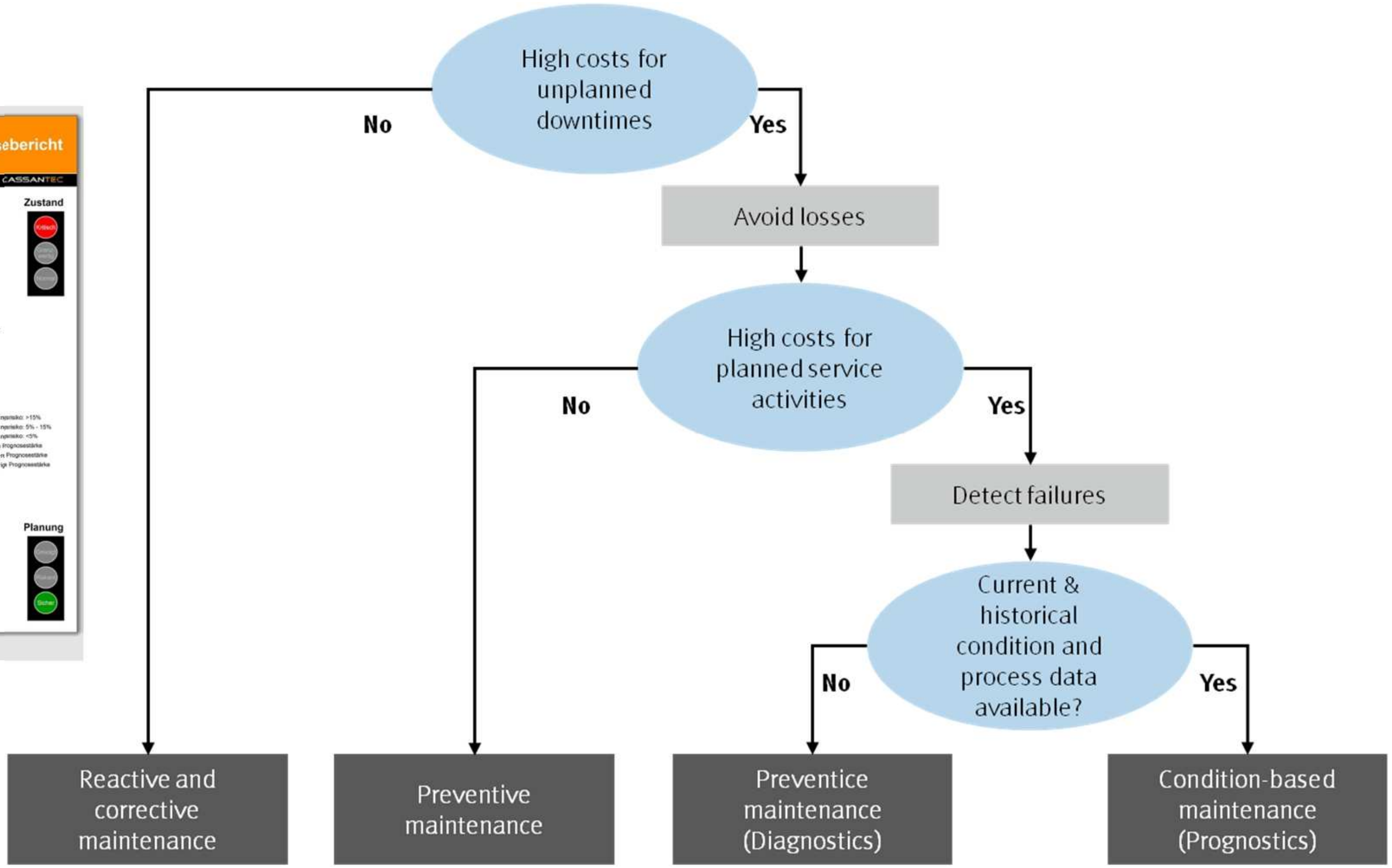
Disadvantages:
- Investments for sensors, data collection and analysis

Scope:
- Smart Factory



Smart Maintenance / Predictive Maintenance





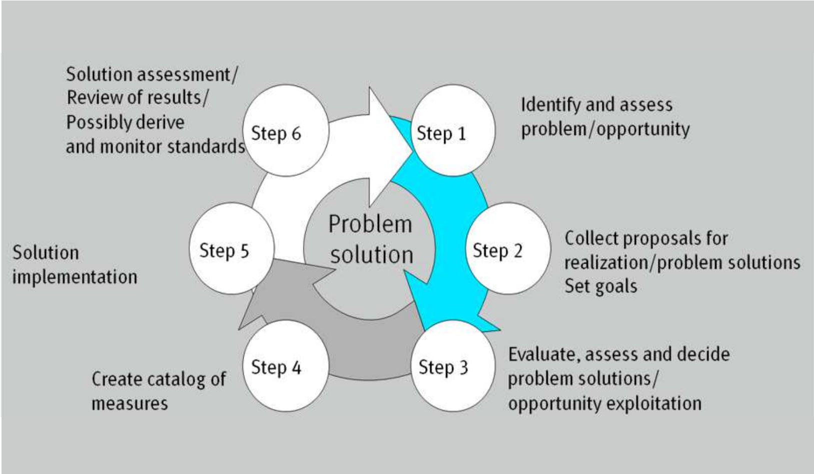
Lean Maintenance

Approach:
No maintenance strategy. Instead, more a method to find the right maintenance strategy.

Focus:
- The maintenance strategy does not only depend on the machine but also on the importance of the value stream, the production system and the customer.

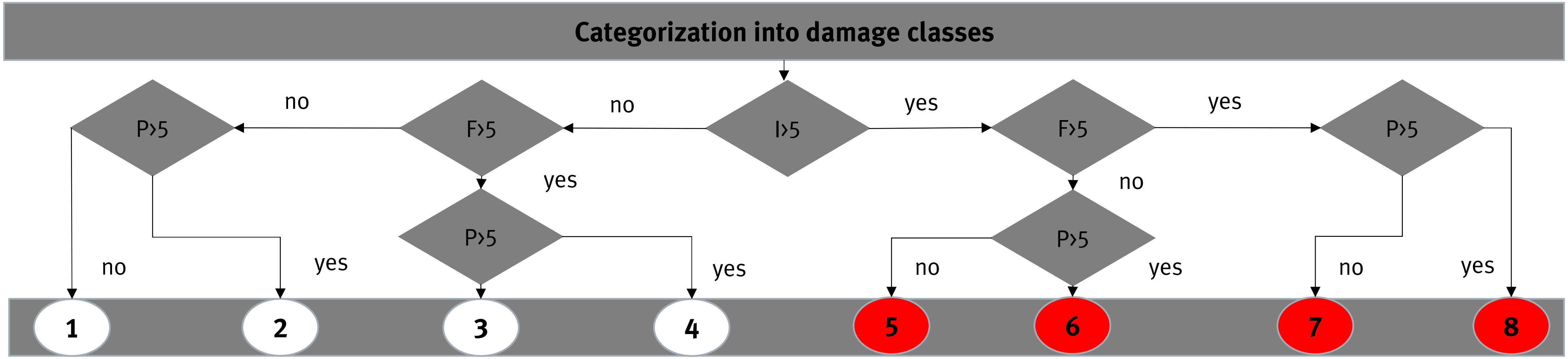
Advantage:
- Target-oriented selection
- Efficient use of resources

Disadvantages:
- Effort for planning
- Has to adapt dynamically according to the market demand and the value streams



Lean Maintenance: identifying the damage factors – evaluating the fault

Criterion	Score
Impact on system operation (I)	From 1 (almost no impact, no downtime) to 10 (severe impact, system fully out of operation for extended period)
Predictability (P)	From 1 (highly predictable) to 10 (impossible to predict)
Incidence of failure (F)	From 1 (unlikely) to 10 (highly likely)



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Definition of damage classes according to lean management 1

Da-mage class	Impact on system operation (I)	Incidence of failure (F)	Predictability (P)	Strategic recommendation
1-4				No actions
5	Severe disruption in the event of failure	low	Can be foreseen at early time	• Predictive, condition-based maintenance • Regular maintenance • Mobile diagnostics for capturing measured data • No spare parts in store • Possible to use external technical service providers
6	Severe disruption in the event of failure	low	Not predictable	• Incident-based maintenance • Routine maintenance • Not necessary to acquire technical expertise • Call center service provided • Necessary to keep spare parts in store • Close cooperation with manufacturer • Time to repair under formula 1 – conditions

Definition of damage classes according to lean management 2

Da-mage class	Impact on system operation (I)	Incidence of failure (F)	Predictability (P)	Strategic recommendation
7	Severe disruption in the event of failure	high	Can be foreseen at early time	• Predictive, condition-based maintenance • High level of service from spare parts supplier • Specification of diagnostic intervals of any duration or deployment of online diagnostic equipment • Drafting of root cause analysis with avoidance strategy available for immediate implementation
8	Severe disruption in the event of failure	high	Not predictable	• Incident-based maintenance • Redundancies where possible, or else 100-percent availability on site and repairs under the conditions in the Formula 1 • Effectively ensure fast replacement • Acquisition of technical expertise in production and maintenance • Drafting of root cause analysis with avoidance strategy available for immediate implementation • Routine scheduled preventive replacement

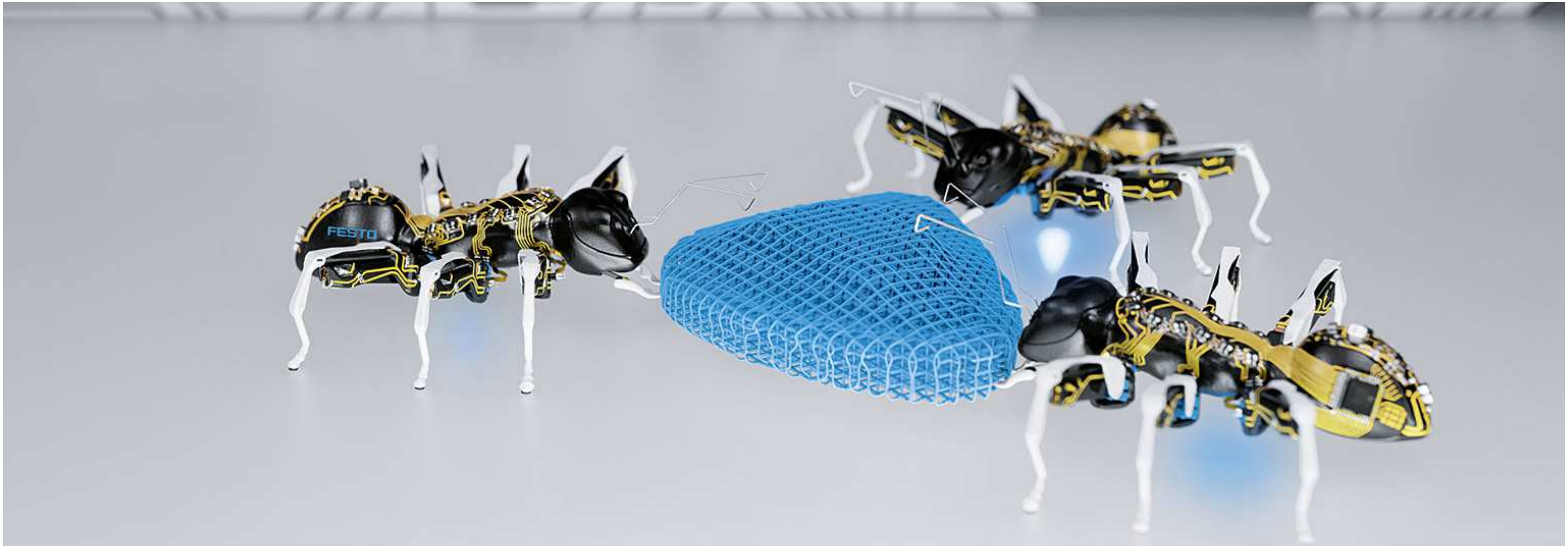
Exercise: The right maintenance strategy for the right application

Competencies:
Once you have completed this task,
- you know the approach for selecting an effective maintenance strategy.
- you can calculate the time to repair.
- you are able to work on implementing maintenance strategies.

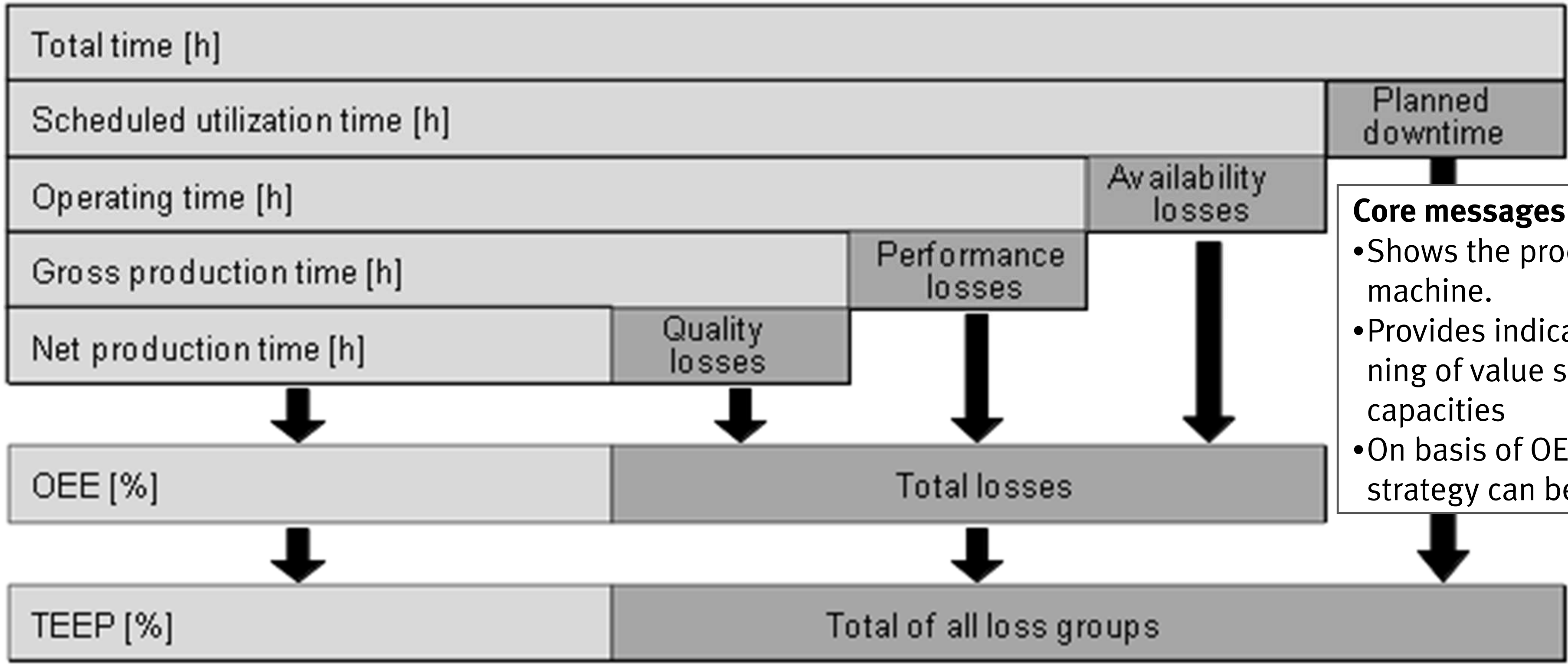
Problem:
The optimum maintenance strategies must be determined for applications in a CP Factory. The production orders from the last month are to be evaluated for this purpose.

Work orders:
1. Determine the applications which are subject to the highest loads.
2. Determine possible risks of failure for the most frequently loaded applications.
3. Develop proposals for respective maintenance strategies.
4. Determine the time for repair.
5. Carry out the first steps of total productive maintenance (TPM) strategies.
6. Define measures for maintenance according to reliability-centered maintenance (RCM).

Smart Maintenance: Key Performance Indicators



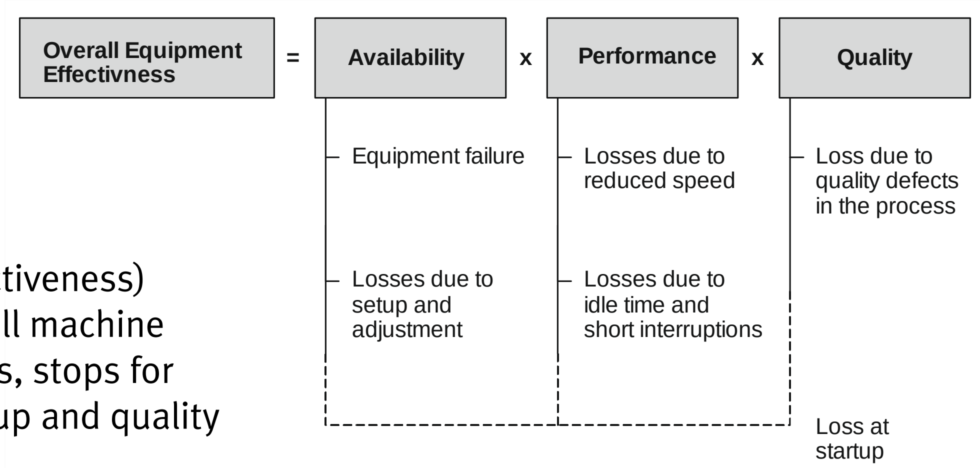
The relation between losses and OEE or TEEP



Core messages of OEE:

- Shows the productivity of a machine.
- Provides indications for the plan-ning of value streams and capacities
- On basis of OEE the maintenance strategy can be defined.

Overall Equipment Effectivness (OEE)



Explanation

The KPI (key performance indicator) OEE (Overall Equipment Effectiveness) gives a complete overview on equipment availability. It captures all machine and equipment downtimes resulting from unscheduled downtimes, stops for setup or adjustment, minor stoppages, reduced speeds and startup and quality losses.

OEE comprises three elements: availability, performance and quality. “Availability” is the ratio of machine runtime (T_{net}) to scheduled utilization time (T_{sched}). “Performance” calculates the ratio between actual processing speed (n_{total} x t_{cycle}) and net processing time (T_{net}). Finally, “Quality” captures the relationship between good parts and total parts.

Formula:

OEE = AR x PR x QR x 100%

$OEE = (T_{Net} / T_{Sched}) \times ((n_{total} \times t_{cycle}) / TL) \times ((n_{total} - n_{rew} - n_{defects}) / n_{total}) \times 100\%$

This formula can be simplified:

$OEE = t_{cycle} \times (n_{total} – n_{rew} – n_{defects}) / T_{sched} \times 100\%$.

Overall Equipment Effectivness (OEE) – Example

Initial situation:
The weekly work time of a turning centre is 10 shifts of 8 hours each. A total of 572 parts were manufactured, of which 2 were rejects and 3 had to be reworked. The cycle time was 6.12 minutes.

$$OEE = \frac{t_{cycle} \cdot \left(n_{total} - n_{rejects} - n_{rework}\right)}{T_{plan}} \cdot 100\%$$

$$OEE = \frac{372\text{ s} \times (572 - 3 - 2)}{288{,}000\text{ s}} \cdot 100\% = 73.24\%$$

The results of the more detailed OEE formula are more interesting, as they identify the key loss areas. Let us assume that the week under review required 8.5 hours for troubleshooting and job changes.

Availability =	$T_{net} / T_{plan} = 0.89375$
Performance =	$(n_{total} \cdot t_{cycle}) / T_{net} = 0.8266$
Quality level =	$(n_{total} - n_{rejects} - n_{rework}) / n_{total} = 0.99126$
OEE =	$NG \cdot LG \cdot QG \cdot 100\% = 73.24\ \%$

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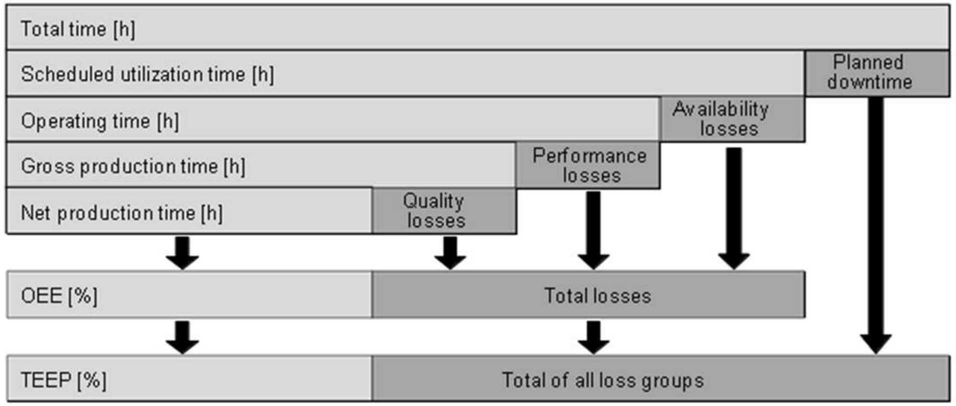
Total Effective Equipment Productivity (TEEP)

Explanation:
TEEP stands for Total Effective Equipment Productivity. TEEP extends the KPI Overall Equipment Effectiveness (OEE) by the scheduled utilization time and, thus, constitutes the ratio between the actual productive time and the theoretically possible productive time for a machine or system.



TEEP is calculated by multiplying the scheduled utilization time by utilization, performance and quality. The scheduled utilization time is calculated as follows:

$$\text{Scheduled time} = \frac{(\text{Total time} - \text{Scheduled downtime})}{\text{Total time}}$$

So, the formula is as follows:

$$\text{TEEP} = \frac{(\text{Total time} - \text{Scheduled downtime})}{\text{Total time}} \cdot \text{OEE}$$

\

Total Effective Equipment Productivity (TEEP) – Example

Initial situation:

A turning centre is used for 10 shifts per week, each of 8 hours. The maximum weekly work time is 24 hours x 7 days. The OEE has been calculated as 73.24%.

$$\text{TEEP} = \frac{(\text{Total time} - \text{Scheduled downtime})}{\text{Total time}} \cdot \text{OEE}$$

$$\text{TEEP} = \frac{7\text{ days} \cdot 24\text{ h} - (7\text{ days} \cdot 24\text{ h} - 10\text{ shifts} \cdot 8\text{ h})}{7\text{ days} \cdot 24\text{ h}} \cdot 73.24\%$$

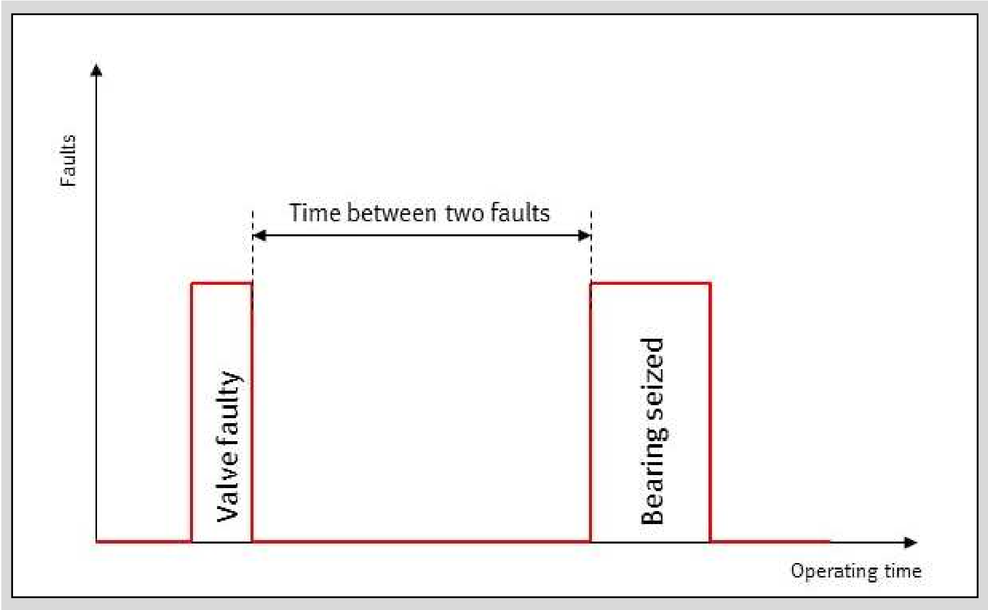
$$\text{TEEP} = \frac{(168\text{ h} - [168 - 80\text{ h}])}{168\text{ h}} \cdot 73.24\% = 34.88\%$$

\

Exercise: Please calculate OEE and TEEP

• Number of shifts:	15 per week
• Production time per shift:	440 min (480 min – 40 min break)
• Cycle time:	0,72 min
• Produced pieces last week:	473 goods
• Reworking:	1 piece
• Quality problems:	4 pieces
• Unplaned stopps:	71 min

Mean Time between Failures (MTBF)



Explanation

The Mean Time Between Failures (MTBF) figure determines the value of fault-free production time of a machine or plant. It thus represents the time between two failures. Using this figure, it is possible to assess the reliability of a machine or plant. The figure can be graphically represented as follows.

Formula:

$$MTBF = \Sigma \left(T_{\text{failure } n} - T_{\text{failure } n\text{-}1}\right) / n$$

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Mean Time between Failures (MTBF) – Example

Example:

Occurred on: Date / time	Fault	Cause	Fault index	Resolved on: Date / time	Resolved by	Downtime in min	Fault-free production time in min
13.10.04 6:00	Welding machine transport	Sensor misaligned	m	13.10.05 6:30	Müller	30	1010
13.10.05 23:20	Roll loader unhinged	Hinge worn	m	13.10.05 23:50	Lustlich	30	864
14.10.05 14:14	Air pressure loss	Valve V17 faulty	P	14.10.05 22:10	Hedwig	476	670
15.10.05 9:20	Rotary table not switching	Relay R34 faulty	e	15.10.05 10:00	Augustin	40	520
15.10.05 18:40	Control crashed	Operator error	b	15.10.05 19:50	Hedwig	70	550
16.10.05 5:00	Band tear	Wear	m	16.10.05 6:50	Lustlich	110	
	Total:					756	3614

$$MTBF = \Sigma\,(T_{Fault\ n} - T_{Fault\ n-1})\ /\ n = (1010 + 864 + 670 + 520 + 550)\ /\ n = 722.8\ min$$

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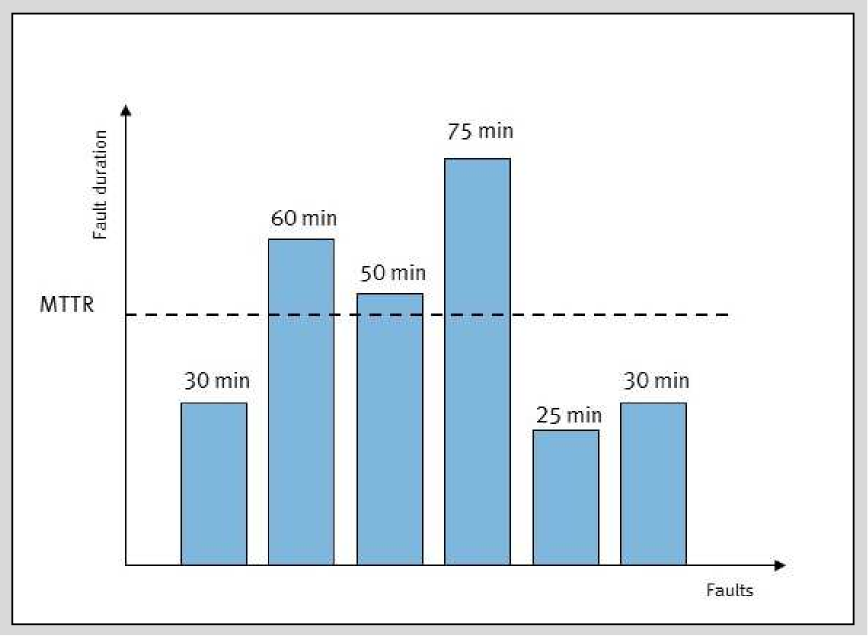
Mean Time to Repair (MTTR)



Explanation:

MTTR is the abbrevation for Mean Time to Repair. The figures shows the avarage time from the moment of fault till the resart of the machine. On basis of this figure, the quality of the repair process can described. On the first hand how fast the information reachs the maintenance operator. On the second hand how fast it is able to repair the machine.

Formula:

MTTR = $(\Sigma_{tr1} + t_{r2} + t_{r3} \ldots + \ldots t_{rn}) / n$

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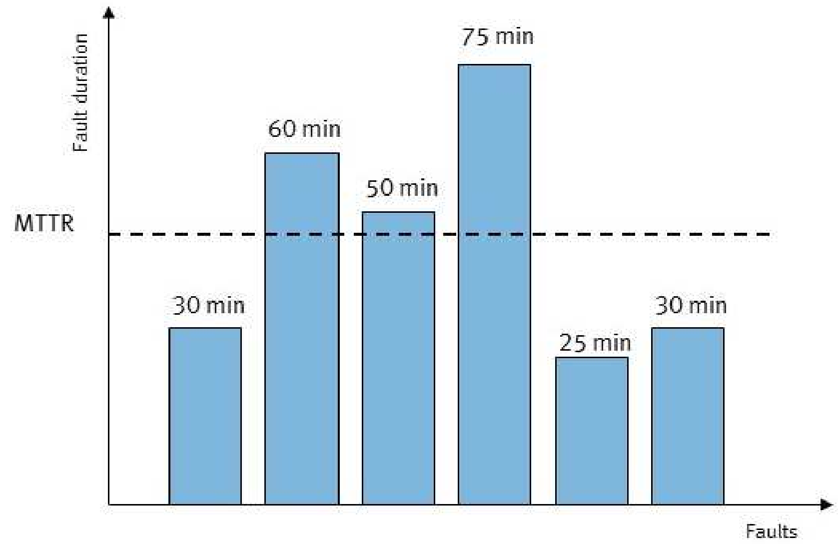
Mean Time to Repair (MTTR) – Example

Mean Time To Repair (MTTR) - Example



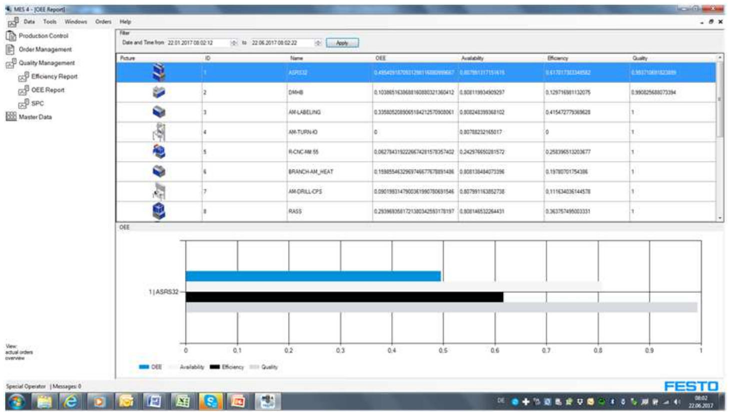
Calculation:

$$MTTR = \Sigma(t_{r1} + t_{r2} + \ldots + t_{rn}) / n_{\text{Number of faults}}$$

$$MTTR = (30 + 60 + 50 + 75 + 25 + 30) / 6$$

$$MTTR = 45 \text{ min}$$

Exercise: Identification of losses with the right maintenance KPI´s

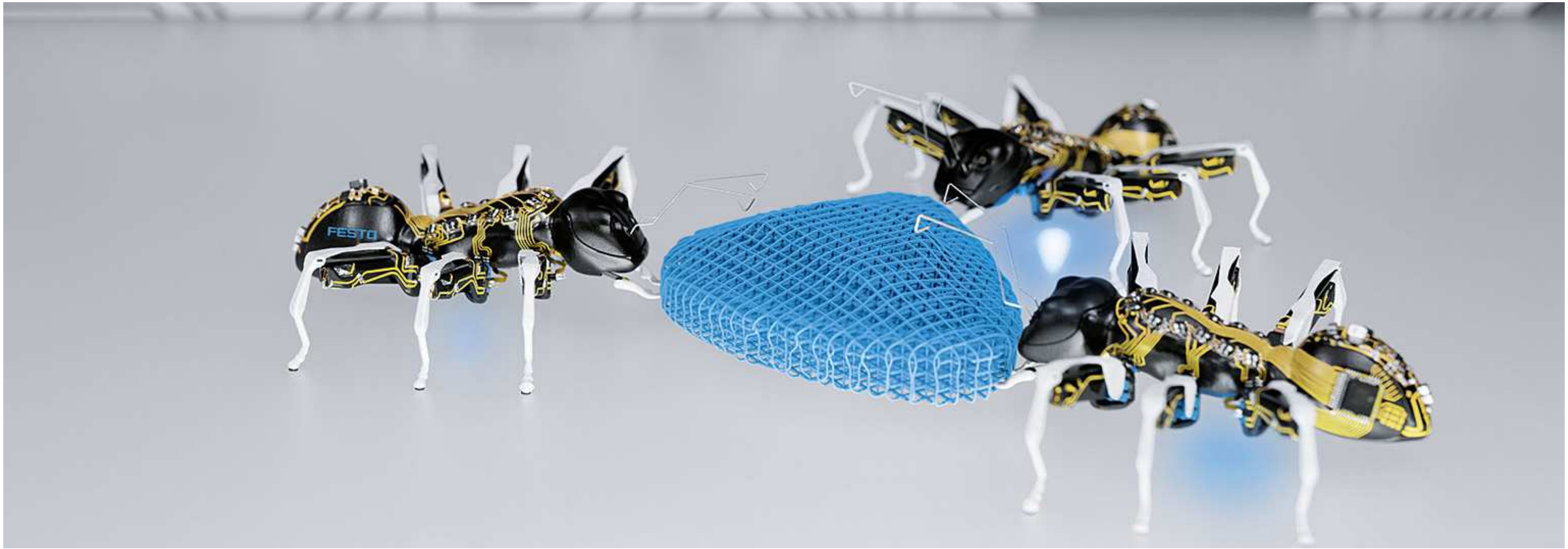


Learning objectives:
Once you have completed this task,
- you know the most important maintenance figures.
- you can determine the values required for this.
- you can calculate them.
- you are able to derive measures to improve the figures.

Problem:
The respective maintenance figures are to be determined for a CP Lab / CP Factory.

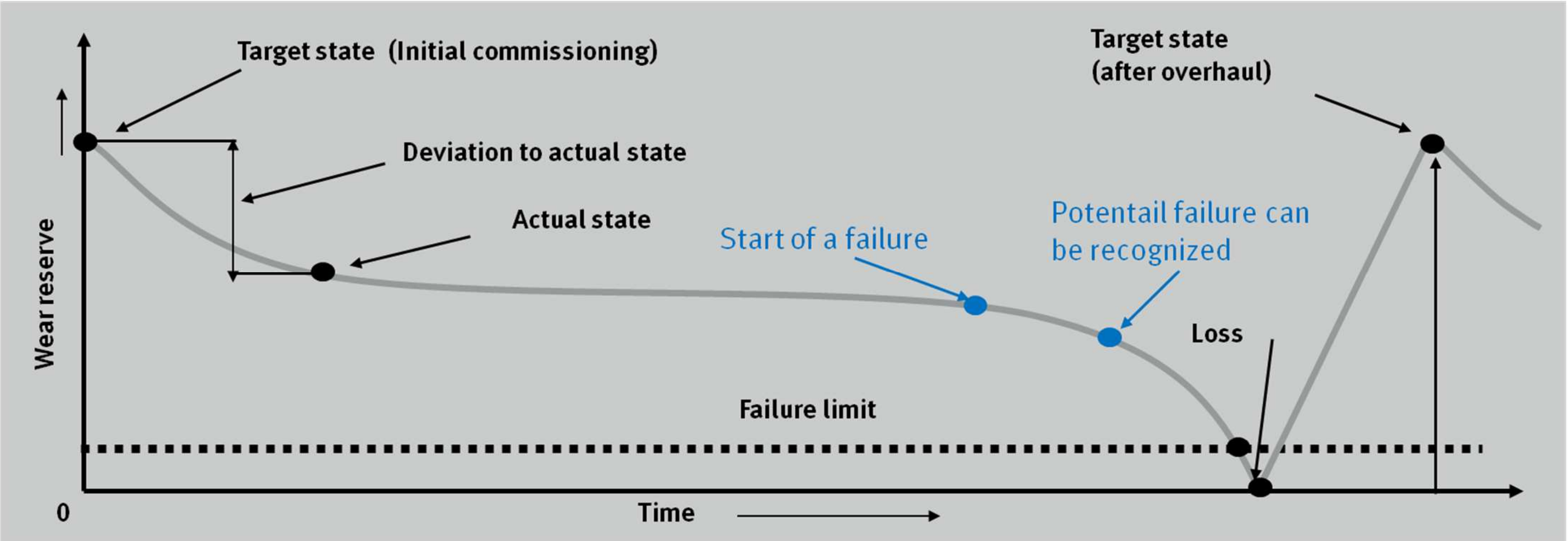
Work orders:
1. Read the OEE report (Overall Equipment Effectiveness) and interpret it.
2. Calculate the TEEP (Total Effective Equipment Productivity).
3. Determine the MTTR (mean time to repair).
4. Determine the MTBF (mean time between failures).

Smart Maintenance: Condition Monitoring



Principle of Condition Monitoring

- Cyclic or permanent collection of data on machine conditions through measuring physical values like vibrations, speed, temperature etc.
- Many fault causes send signals a long time before the machine has a downtime.



Typical approaches of Condition Monitoring

Verfahren	Abkürzung	Dynamik	Prinzip	Interaktionsraum	Grundlage
Bewehrungsortung (induktiv)		statisch	magnetisch	Volumen	DGZfP Merkblatt B02
Bewehrungsortung (kapazitiv)		statisch	elektrisch	Volumen	DGZfP Merkblatt B02
Durchstrahlungsprüfung	RT[2]	dynamisch	elektromagnetisch	Volumen	EN 444[4], EN 13068[5], EN 16016[6]
Feuchtemessung (kapazitiv)		statisch	elektrisch	Oberfläche	EN 13183-3[7]
Feuchtemessung (resistiv)		statisch	elektrisch	Oberfläche	EN 13183-2[8]
Impakt-Echo Verfahren	IE	dynamisch	mechanisch	Volumen	DGZfP Merkblatt B11
Akustische Resonanzanalyse	ART	dynamisch	mechanisch	Volumen	DGZfP Richtlinie US06
Vibrationsprüfung	VA	dynamisch	mechanisch	System	ISO 13373[9], DIN 45669[10]
Potentialfeldmessung		statisch	elektrochemisch	Volumen	DGZfP Merkblatt B03
Bodenradar	GPR	dynamisch	elektromagnetisch	Volumen	DGZfP Merkblatt B10
Rückprallhammer		dynamisch	mechanisch	Oberfläche	EN 12504-2[11]
Schallemissionsanalyse	AT[2]	dynamisch	mechanisch	Volumen	EN 13554[12]
Zeitbereichsreflektometrie	TDR	dynamisch	elektromagnetisch	Volumen	DIN 19745[13]
Infrarotthermografie	TT[3]	dynamisch	thermisch	Oberfläche	DIN 54190[14], DIN 54192[15], EN 13187[16]
Ultraschallprüfung	UT[2]	dynamisch	mechanisch	Volumen	EN 583[17], DGZfP Merkblatt B04
Visuelle Inspektion	VT[2]		optisch	Oberfläche	EN 13018[18], DGZfP Merkblatt B06
Wirbelstromprüfung	ET[2]	statisch	elektrisch	Oberfläche	ISO 15549[19]
Leitfähigkeitsprüfung			elektrisch, thermisch	Volumen	materialabhängig
magnetinduktive Methode		statisch	magnetisch	Oberfläche	ISO 2178[20]
Magnetpulverprüfung	MT[2]	statisch	magnetisch	Oberfläche	ISO 9934[21]
Dichtheitsprüfung	LT[2]		chemisch	System	EN 1779[22], EN 13184[23], EN 13185[24], EN 1593[25]
Eindringprüfung	PT[2]		mechanisch	Oberfläche	EN 571-1[26]
Shearografie	ST[3]	dynamisch	optisch	Oberfläche	
Streufeldmessung		statisch	magnetisch	Volumen	

Planning of Condition Monitoring solutions

Past-oriented

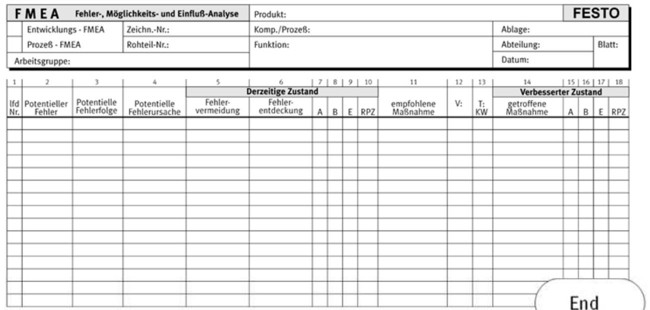
Aufgetreten am: Datum /Uhrzeit	Störung	Ursache	Fehlerindex	Behoben am: Datum, Uhrzeit	Behoben durch	Stillstands-zeit in min	Störungsfreie Produktionszeit in min
13.10.15 6:00	Transport Schweißmaschine	Sensor dejustiert	m	13.10.05 6:30	Müller	30	[illegible]
13.10.15 23:20	Rollladen ausgehängt	Schamiere abgenutzt	m	13.10.05 23:50	Lustlich	30	864
14.10.15 14:14	Druckluftausfall	Ventil V17 defekt	P	14.10.05 22:10	Hedwig	[illegible]	[illegible]
15.10.15 9:20	Rundtisch wird nicht geschaltet	Relais R34 defekt	e	15.10.05 10:00	Augustin	60	520
15.10.15 18:40	Steuerung abgestürzt	Fehlbedienung	b	15.10.05 19:50	Hedwig	[illegible]	550
16.10.15 5:00	Bandriss	Verschleiß	m	16.10.05 6:50	Lustlich	[illegible]	
	Summe:					756	3614

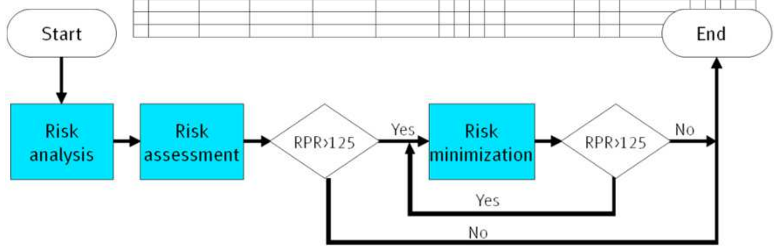
Evaluation of:
- Fault lists
- KPI's like MTBF, MTTR
- Downtime analysis
- Technical availability
- Work sequence analysis

Attention!
Condition Monitoring is a very expensive approach and should be used in an efficient way.

Examples of applications:
- Frequently occurring faults
- Full use of wear margin
- Very expensive spare parts
- Spare part with long delivery time
- Very time-consuming service tasks
- ...

Future-oriented





Evaluation of:
- Frequency
- Impact
- Detectablitiy

Example 2: Condition monitoring in the mining sector

Initial situation:

Hydraulic excavators contain many different pumps. In the case of fault it takes a lot of time to procure the right pump. In the worst case the pump has to be produced after receiving the customer order. So, the down time of excavators was often unacceptably long.

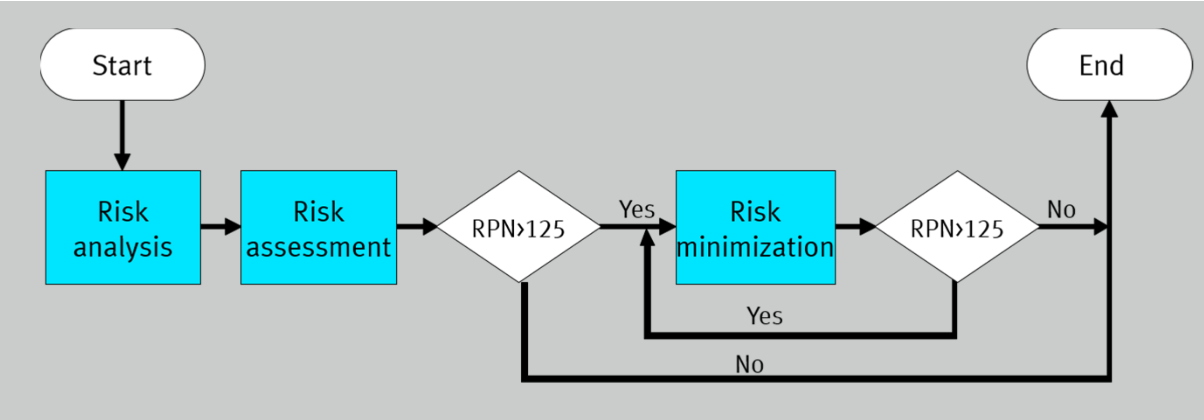
Now:

- Each pump will be equipped as a smart pump.
- Thus, the pump can send operational data to the user or to the producer.
- In the case of deviations (over heating, too high energy consumption, vibrations, …) a new pump can be ordered before the old one fails.
- The downtimes can be reduced significantly.

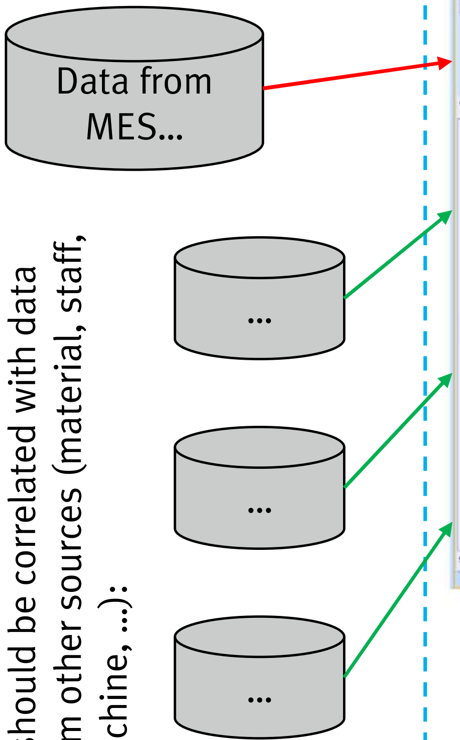
Excursus: FMEA

FMEA Fauilure Mode and Effect Analysis				Product:
	Development FMEA	Drawing:		Process:
	Process FMEA	Raw product:		Function:
	Sheet:	Date:		Team:

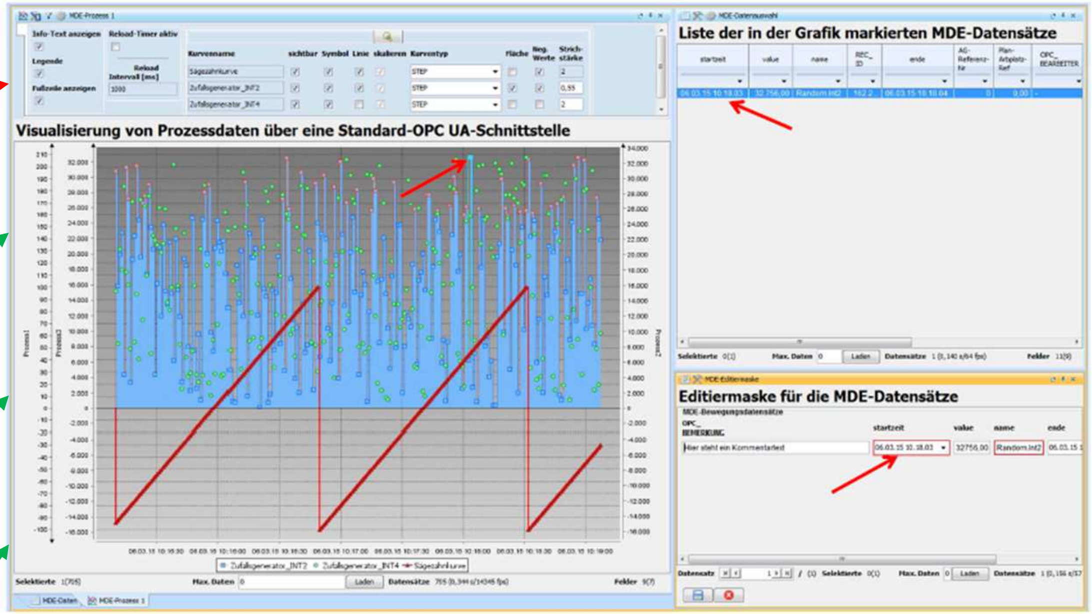
No.	Potential failure	Potential effects	Potential cause	Fault precvention	Fault detection	O	S	D	RPN	Activity	resp.	Date



Data analysis & data correlation



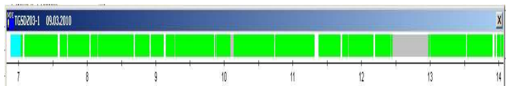
... should be correlated with data from other sources (material, staff, machine, ...):



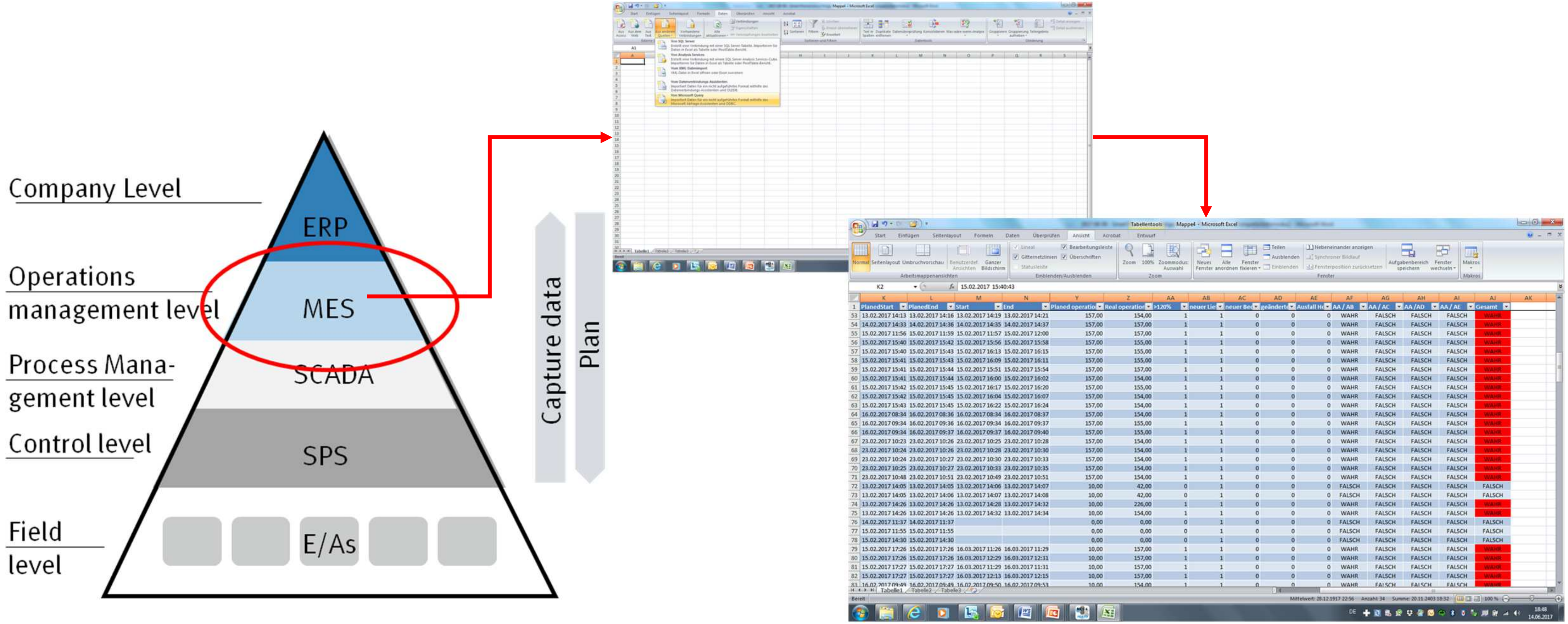
- What is the problem / isn't the problem?
- When did it occur?
- Where did it occur?
- What is the scope?

Examples

- Hospital: the downtime of an x-ray apparatus was caused by the test of the emergency power system.
- Sheet metal processing: passing forklifts were the cause of the high amount of waste in a laser cutting machine.
- Machine building: the OEE was substantially reduced through idle stops.

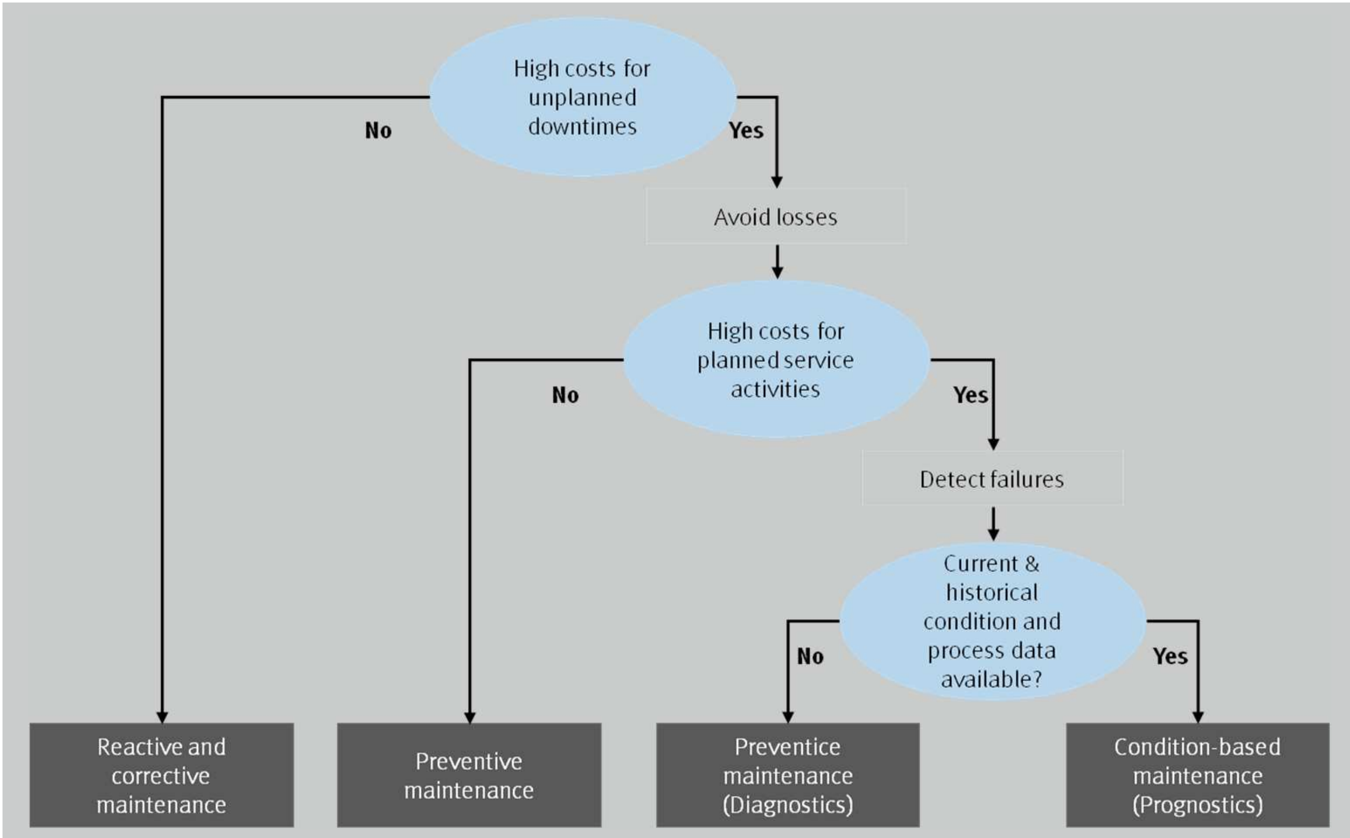


Procedure for data analysis and data correlation

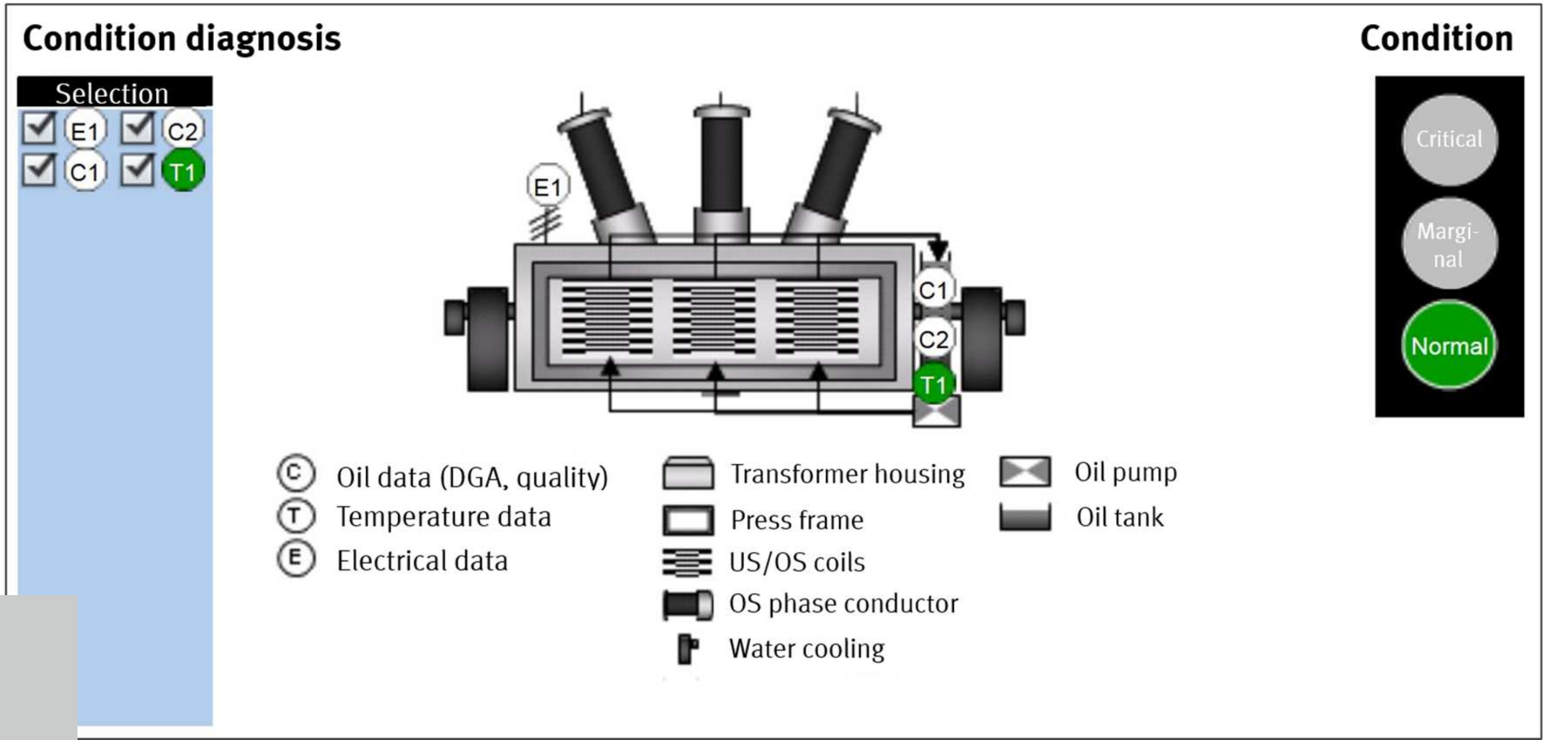


Predictive Maintenance

- Predictive Maintenance connects Condition Monitoring, data analysis and data correlation as well as special computing algorithms
- Target 1: detecting potential faults before they occur
- Target 2: making full use of component remaining service life
- Methods: **diagnostics** und **prognostics**

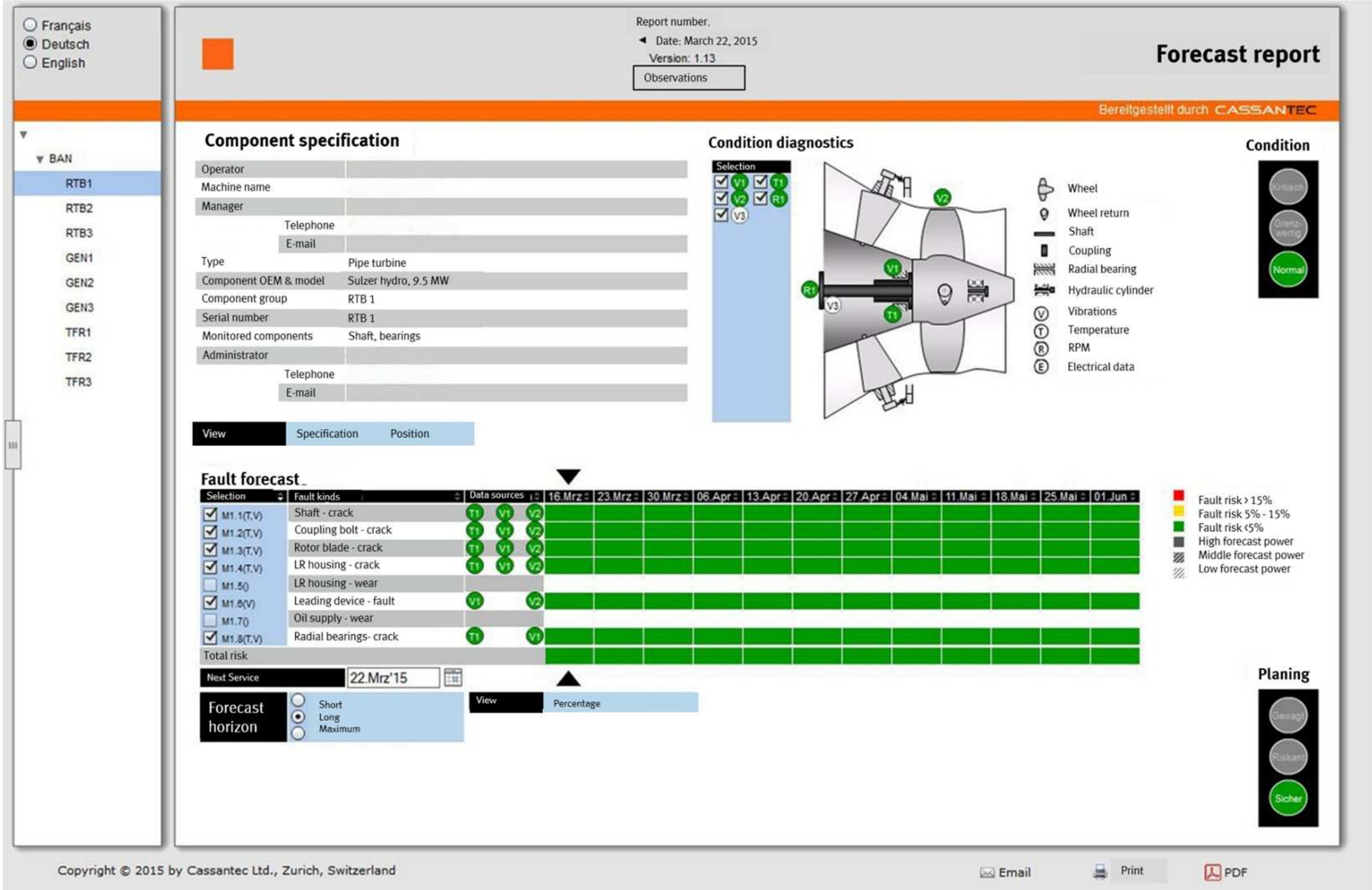


Diagnostics



- Monitoring the condition of critical components
- Detecting causes
- Deriving measures for repair
- Proposing suitable data for fault elimination

Prognostics



Additionally to diagnostics:

- Calculation of condition gradients considering the historical machine data
- Deriving of condition prognoses
- Their enlargement to a fault prognosis
- Consolidation and prioritization of all condition data
- Comparison of prognosis horizon
- Integration of new machine data (machine learning)

Exercise: Smart maintenance for a smart factory

Learning obejectives:
Once you have completed this task,

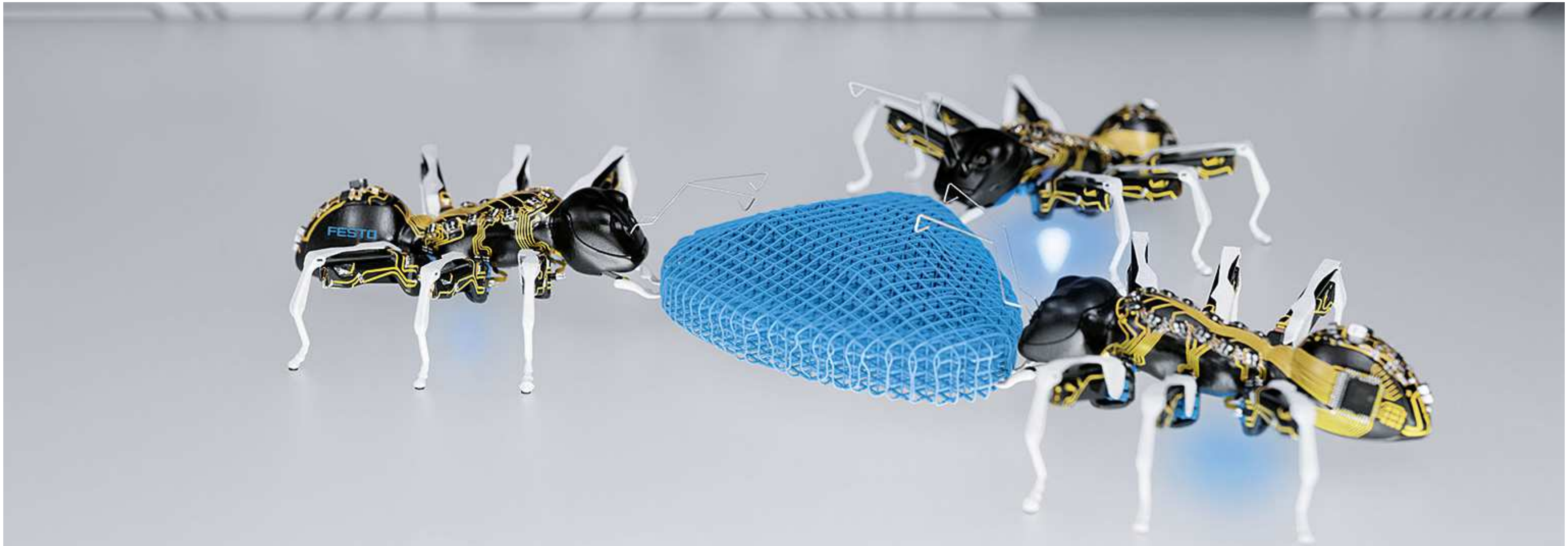
- you are able to plan condition monitoring solutions.
- you can determine the necessary physical quantities.
- you know the procedure for data analysis and data correlation.
- you can use data analysis and data correlation to determine potential causes of faults.

Problem:
The CP Factory should be checked for the possible use of condition monitoring solutions. The possible applications are to be prepared accordingly and can be optionally implemented. Finally, data analysis and data correlation should be used to identify sources of loss and eliminate their causes.

Work orders:

1. Check the CP Lab / CP Factory for possible applications of condition monitoring solutions.
2. Implement a few examples of these.
3. Analyze the data generated and stored by MES4 for possible further sources of loss.
4. Determine its cause and eliminate it.

Smart Maintenance: Preventive Maintenance



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Preventive Maintenance

Short description:
Preventive Maintenance is a kind of periodical maintenance and means to execute the maintenance jobs according to a defined cycle.

Characteristics:
- Checking or changing of components related to the defined cycle.
- The current status of wear remains unconsidered.
- Disadvantages due to high cost will be accepted.

The cycle can be scheduled on the following basis:

- By time interval: After reaching a time limit
- By performance: After reaching a performance limit
- By operation hours: After reaching a defined amount of operation hours
- By operation cases: After reaching a defined amount of operation cases
- from a mix of all

The cycle can be defined in relation to:

- Wear characteristics of the machine
- Periodic initial cleaning and inspection of the machine
- Specification of the producer
- Evaluation of operation conditions
- Evaluation of fault list
- Experience
- Results of FMEA

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Example of a service plan

Company logo

Machine name:

Machine number: **Series:**

G

Service plan for year ....

No.:	Code	Description	Resources	Duration approx.	Observations	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
						1st Quarter			2nd Quarter			3rd Quarter			4th Quarter		
					an man												

Legend for codes:

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Service plan with layout information

Komm zu Spät(h)
- Präsentationen
- Seminare
- Vorträge
- Ausbildung

Machine name:	Punch unit		
Machine number:	A-3001	Series:	2001

G

2007 Cleaning and maintenance plan

No.	Code	Cleaning	Duration approx	Resources	Observations	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
						1st Quarter			2nd Quarter			3rd Quarter			4th Quarter		
1	PO	Clean bending mechanism, wire feed and guides	20	Sponge and broom	Chips cleared												
2	PO	Clean entire machine	120		Dust and grease clea												
3	PO	Clean motor ventilation	5	Vacuum cleaner, spo	Ventilation slots clean												
4	ME	Clean hydraulic slides	15	Hydraulic gripper	No dark residues												

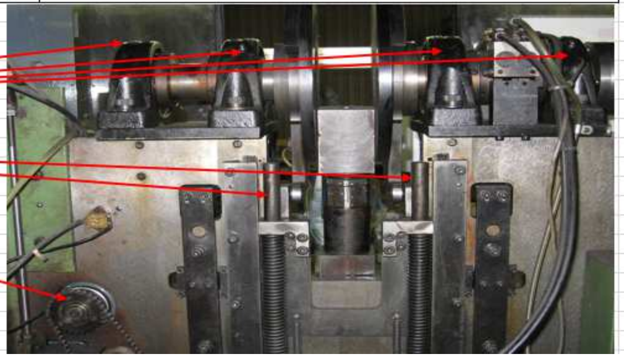
No.	Code	Service	Duration approx	Resources	Observations	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
						1st Quarter			2nd Quarter			3rd Quarter			4th Quarter		
1	PA	Check pneumatic oil and filters															
2	PA	Oil moving parts	10	Oil can													
3	PA	Check pneumatics for air leaks		Production down	No leaks												
4	ME	Inspect bar feed and bending mechanism															
5	PA	Check transport chain for tension															
6	PO	Lubricate grease nipples 4X	30	Grease gun													
7	ME	Check safety equipment	5	Emergency stop, prot	Functionality test												

PA = Plant Adjuster
PO = Plant Operator
ME = Maintenance Engineer

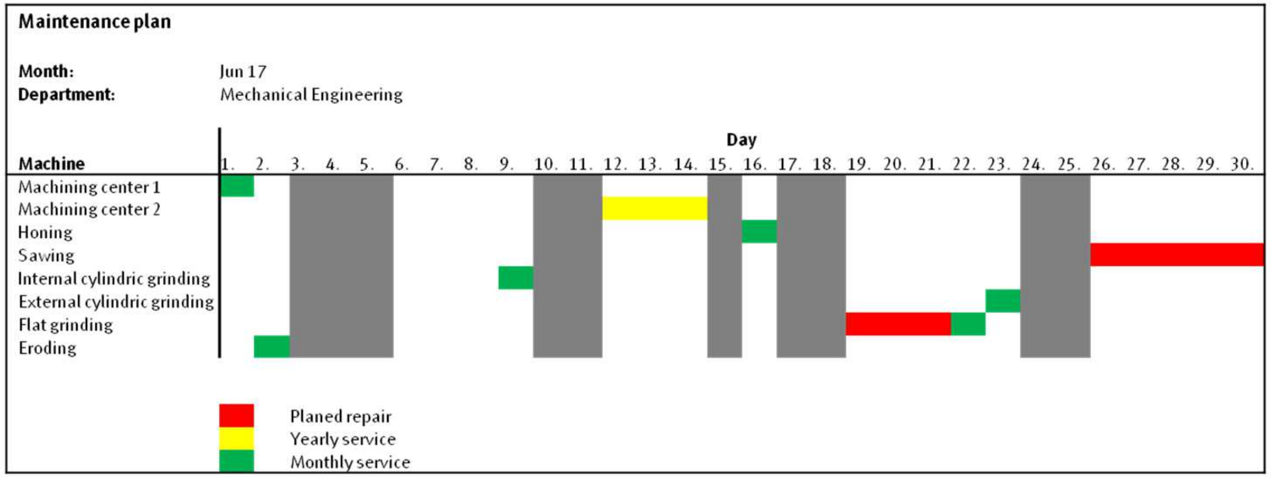
Lubricate grease nipples

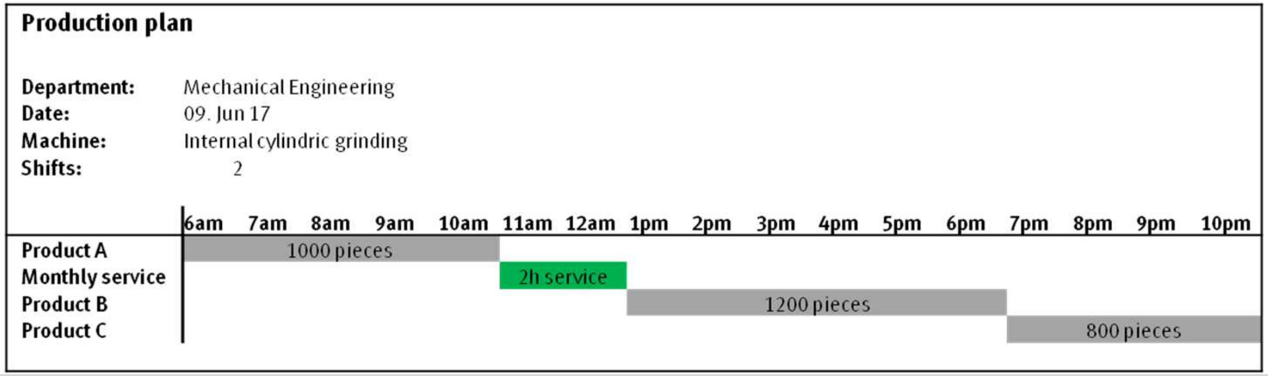
Grease guides

Grease chain



Integration of service into a production plan





Industry 4.0: a new production concept

The process flow matrix

Process flow matrix

Product	Pieces	Ressource 1	2	3	4	5	6	7	8	9	10	11
A	5	x	x		x		x		x	x	x	
B	6	x		x	x				x		x	x
C	1	x	x	x	x							x
D	7					x		x	x			x
E	15	x		x	x		x	x		x		x
F	2		x			x		x			x	
G	1	x	x	x	x	x	x	x	x	x	x	x

Process flow matric: example

	M1: Putting subshell onto the carrier	M2: Position detection	M3: Drilling	M4: Putting top shell onto the carrier	M5: Pressing	M6: Drying	M7: Storing
Variants	No	No	Left / right / both	No	Pressing time available	Heating time and temperature available	Good part / Scrap
							
Drilling subshell double sided	X	X	X				X
Housing	X	X	X	X	X	X	X
...							

Exercise: Preventive maintenance – Service and inspection for a higher availability of machines 1

Learning outcomes:
Once you have completed this task,

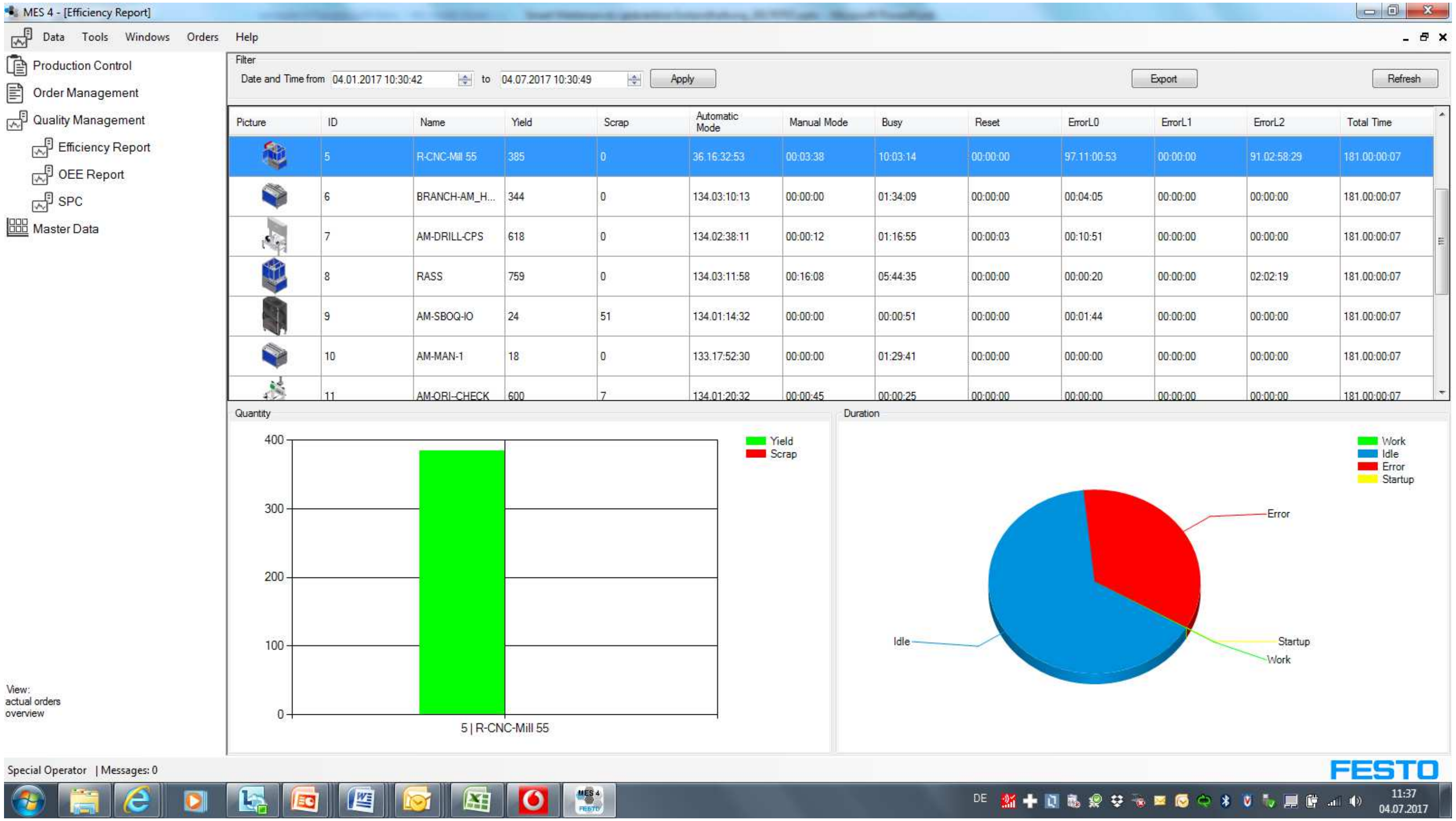
- you know the importance of preventive maintenance.
- you can implement a service and inspection plan.
- you are able to develop smaller service and maintenance plans independently.
- you can optimize service and inspection plans using fault documentation.
- you are familiar with the various criteria according to which service priorities can be determined.
- you can determine service priorities based on the actual load of the respective applications.
- you are able to define service priorities based on machine parameters.
- you can define appropriate warnings and alerts.

Exercise: Preventive maintenance – Service and inspection for a higher availability of machines 2

Problem:
The service and inspection spots of a CP Lab / CP Factory are to be determined and transferred to a service plan. In a next step, the current loads are to be determined and the service priorities accordingly adapted. Warning and alert messages which will be displayed on mobile devices in the following task should also be generated for this purpose.

Work orders:
1. Develop the structure of a service and inspection plan.
2. Create a service and inspection plan for an application on your CP Lab / CP Factory.
3. Optimize the service and inspection plan.
4. Create a process flow matrix for various products in your CP Lab / CP Factory.
5. Supplement these with typical loading values such as operating times, cases of use and energy consumption values.
6. Prepare proposals for selecting service and inspection intervals.
7. Expand your CP Lab / CP Factory to include dynamic service planning.
8. Define warning and alert messages for selected parameters.

MES Screenshot



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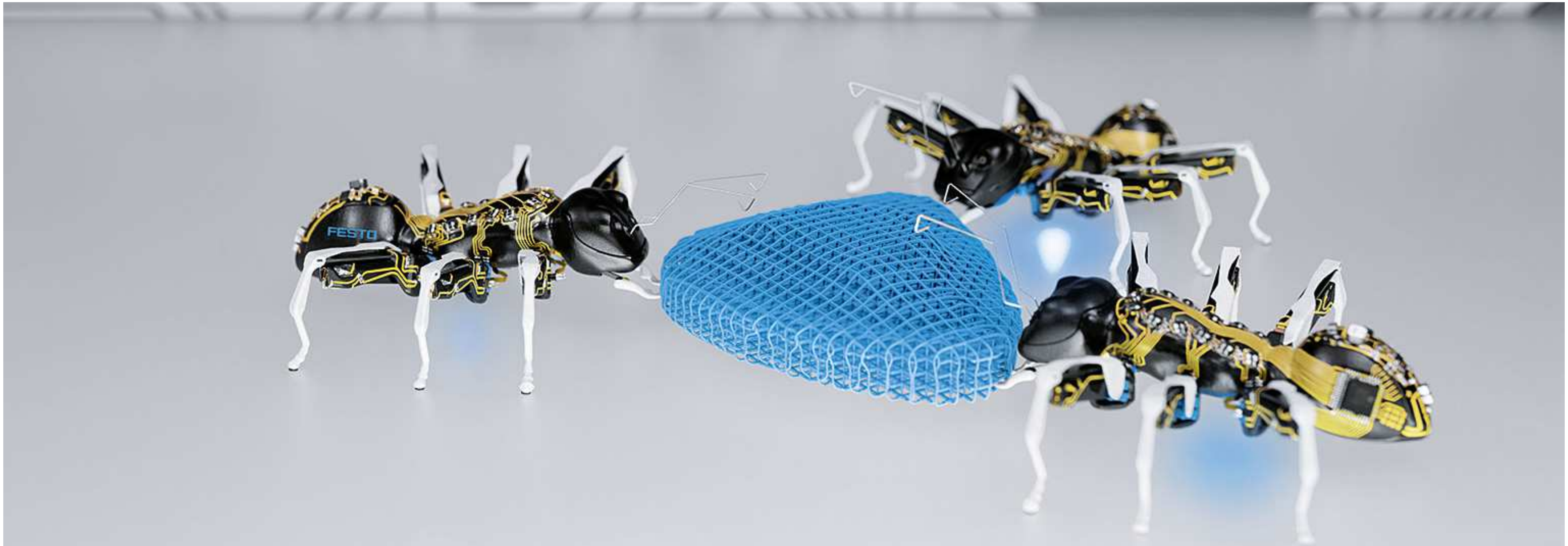
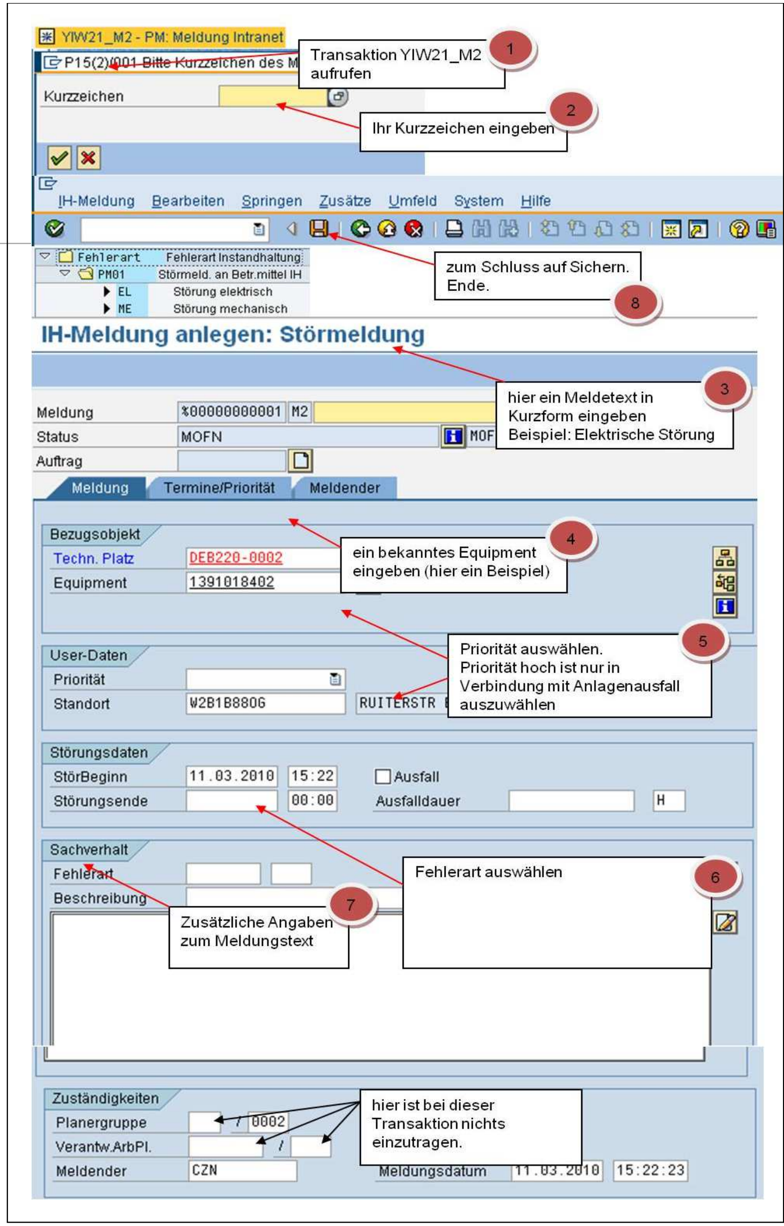
Smart Maintenance: Reactive Maintenance



The process of fault analysis and elimination

1st step: Loss report	2nd step: Start of fault elimination	3rd step: Fault analysis and preparation of repair	4th step: Fault elimination	5th step: Completing fault elimination task
▪ Operator ▪ Team leader	▪ Maintenance supervisor ▪ Maintenance technician	▪ Operator ▪ Maintenance technician	▪ Maintenance technician	▪ Operator ▪ Maintenance technician ▪ Maintenance supervisor
▪ Comprehensive information about the loss	▪ Priorities ▪ Planning of maintenance staff	▪ Analysis of differences ▪ Using Condition Monitoring ▪ Using technical documentation ▪ Preparation of fault elimination	▪ Work safety ▪ Technical fault elimination ▪ Consider producer specifications	▪ Function test ▪ Safety test ▪ Report of fault elimination ▪ Weakness and safety analyses

SAP fault notification



Needed information

- Plant description
- Effect of the fault (plant completely at standstill or production still possible)
- Fault description
- Fault ID or text, if available
- Date
- Time
- Notifying employee

Initiate fault clearance: determining priorities (example)

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Priority	Status	Note
1	Occupational or environmental safety hazard	Maintenance staff discretion
2	Fault at central supply unit or energy supply, many production units affected	Maintenance staff discretion
3	Production down at primary linked production plant	Maintenance staff discretion
4	Maintenance fault notifications (production down) are processed before maintenance requests (plant still capable of limited production)	General rule
5	Extent of consequential downtime costs caused by customer's parts being out of stock	Clarify with supervisor
6	Extent of resulting downtime costs or damage to the plant	Clarify with supervisor
7	Time and effort required for repair measures	Faults which can be eliminated quickly are prioritised over faults that need long repair times
8	Sequence of notifications	If the priority is the same, work proceeds according to the order in which notifications were received
9	Ask supervisor if priority unclear	It may be necessary to specify priorities across several departments
10	General routine work	General rule

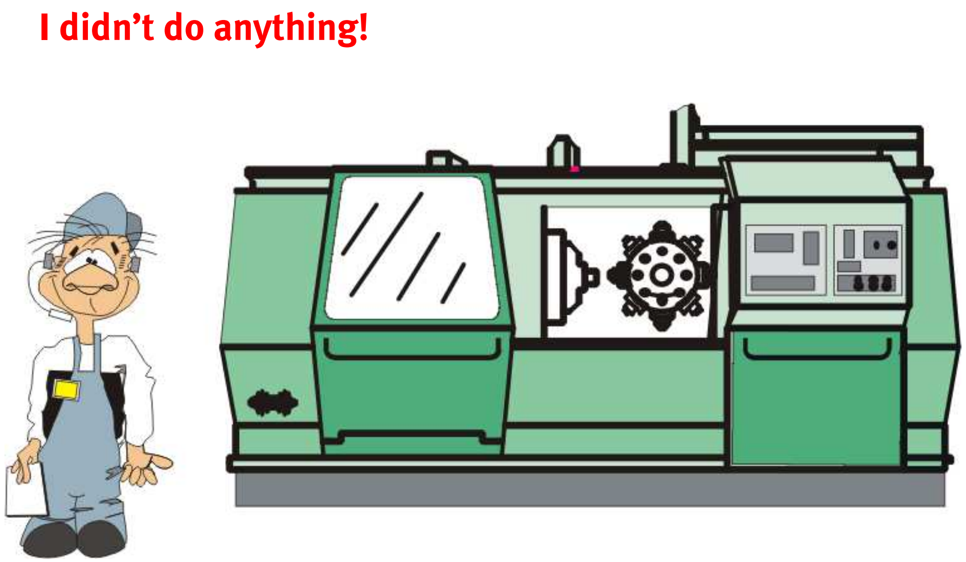
Initial appraisal and preparation of repair

Initial appraisal

- Is there a new or unqualified machine operator at the plant?
- How well is the fault qualified?
- Is the fault unusual, in terms of the plant's history of technical faults?

Typical questions to the machine operator

- Is this the first piece, or are you working with a new setup?
- Has a new processing program been prepared?
- Has the program been modified?
- Has the fault occurred during automatic continuous production?
- Have you noticed anything unusual just before the fault? (sound, smell, vibrations, visible damage, power or air pressure loss, ...)



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Using fault lists

Date	Time	Fault	Cause	Repair	Fault index*	Stop time	Name
1/10	7:30 am	Message 7041	Slack pushbutton	Pushbutton fixed	M	20 min	McGregor
1/13	5:30 pm	Collet doesn't fix the part	No pneumatic pressure	Connector changed	P	60 min	Walter
1/25	11:30 pm	Under load strong drop in speed	Slack fixing bolts for V-belt	V-belt tightened and fixed	M	30 min	Hyder
2/2	3:30 am	Fault message "door switch damaged"	Micro switch broken	Micro switch changed	E	70 min	Hyder
...							

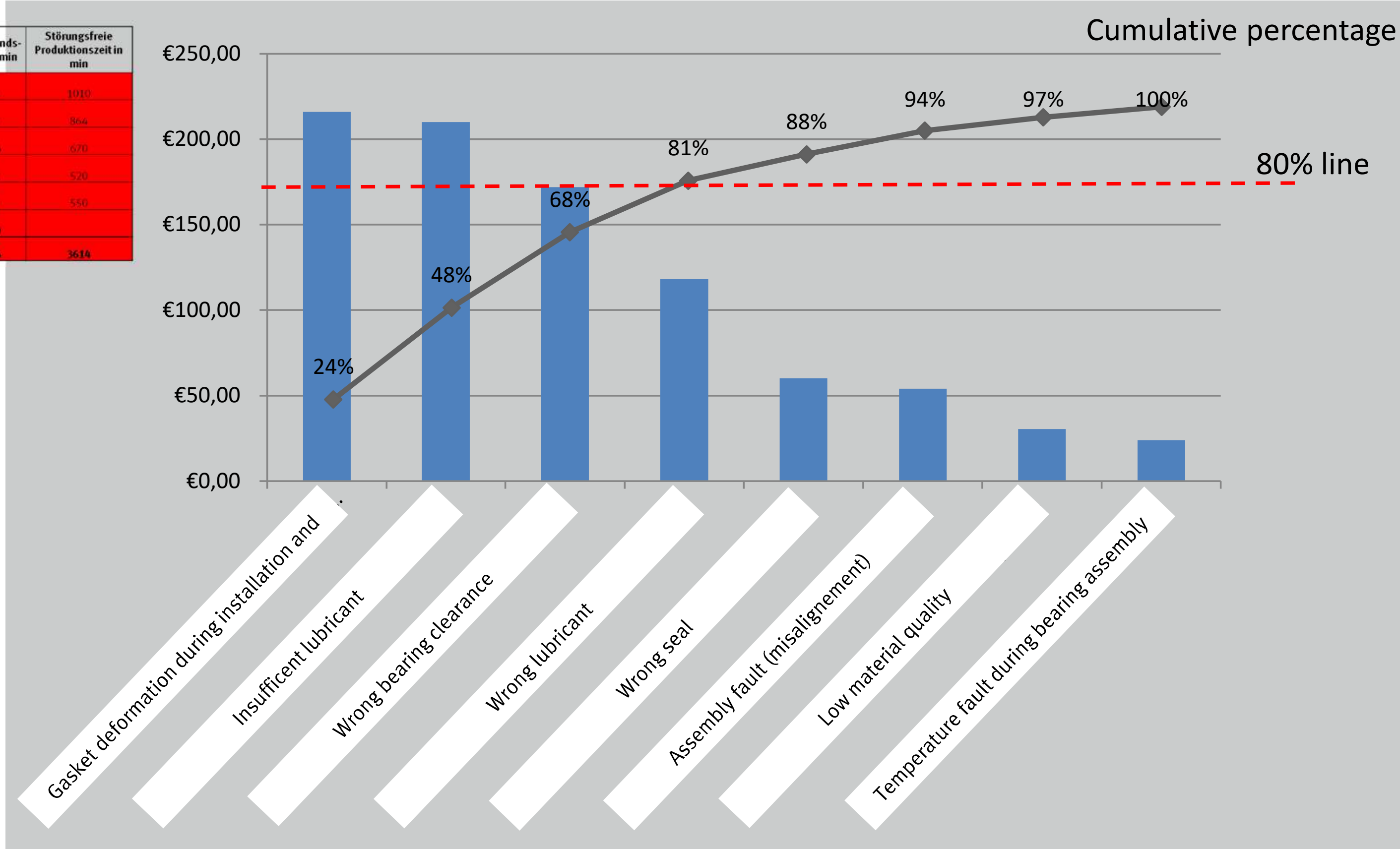
* Fault index: M = Mechanical fault / P = Pneumatic fault / H = Hydraulic fault / E = Electrical fault
O = Operator error / Ma = Maintenance error

Structure of evaluations with fault list

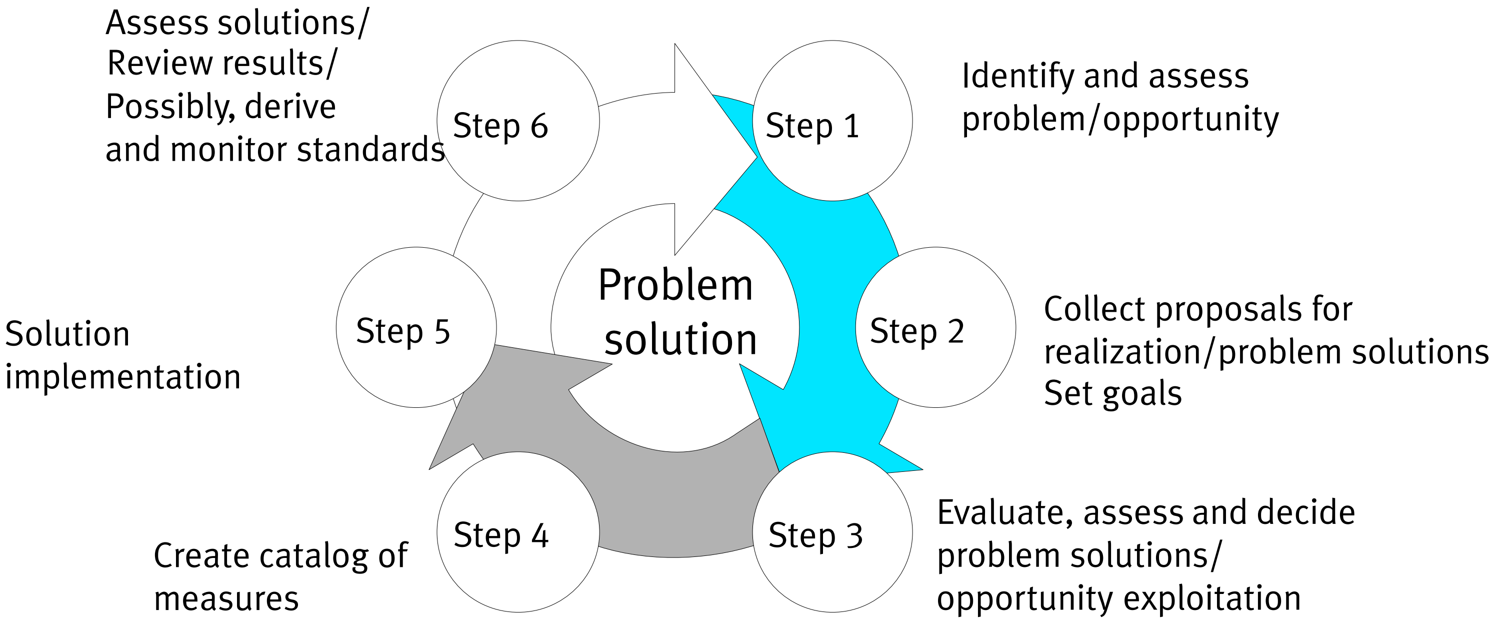
Aufgetreten am: Datum /Uhrzeit	Störung	Ursache	Fehlerindex	Behoben am: Datum, Uhrzeit	Behoben durch	Stillstands-zeit in min	Störungsfreie Produktionszeit in min
13.10.15 6:00	Transport Schweißmaschine	Sensor dejustiert	m	13.10.05 6:30	Müller	30	1010
13.10.15 23:20	Rollladen ausgehängt	Scharniere abgenutzt	m	13.10.05 23:50	Lustlich	30	864
14.10.15 14:14	Druckluftausfall	Ventil V17 defekt	P	14.10.05 22:10	Hedwig	476	670
15.10.15 9:20	Rundtisch wird nicht geschaltet	Relais R34 defekt	e	15.10.05 10:00	Augustin	40	520
15.10.15 18:40	Steuerung abgestürzt	Fehlbedienung	b	15.10.05 19:50	Hedwig	70	550
16.10.15 5:00	Bandriss	Verschleiß	m	16.10.05 6:50	Lustlich	110	
	Summe:					756	3614

Pareto evaluations of fault lists are possible for:

Failure reasons
Relevance of failures
Failure index
Frequency
Operators
...



The problem solving process



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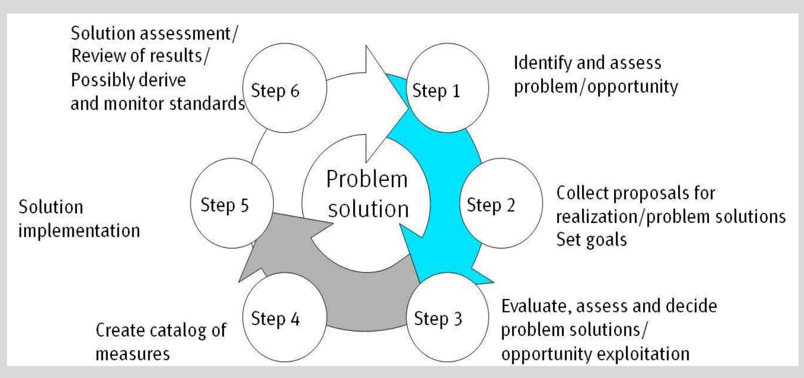
The problem solving process in detail

6th step
- Controlling of implementation
- Measuring of success
- If necessary corrections
- Start managing the next problem

5th step
- Realization of actions in short time
- Preliminary evaluation

4th step
- Develop an implementation plan
- Define measures, deadlines and responsibilities
- Start of implementation



1st step
- Analyzis of problems
- Impact of problems
- Create basis to identify the causes

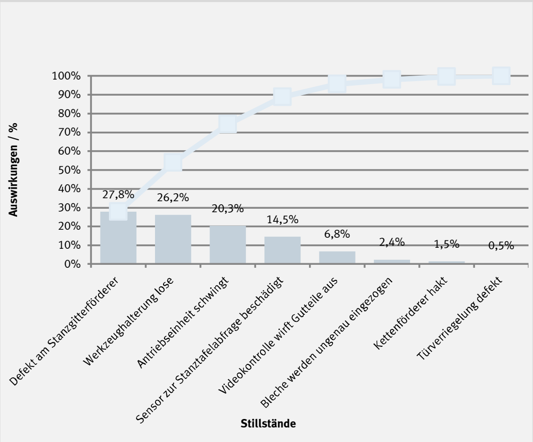
2nd step
- Identify causes
- Collect first ideas for problem-solving
- Define potential solution packages

3rd step
- Define final solution packages
- Evaluate solution packages regarding time consumption and benefit
- Take a decision

The Pareto analysis at a glance

Short description:

According to the Pareto principle, named after the Italian Vilfredo Pareto, 80% of effects result from a relatively small number of causes (approx. 20%). When related to quality, this means that 80% improvement can be achieved with 20% effort. Achieving the remaining 20% would require a comparatively large effort. The Pareto principle is also known as 80/20 rule.



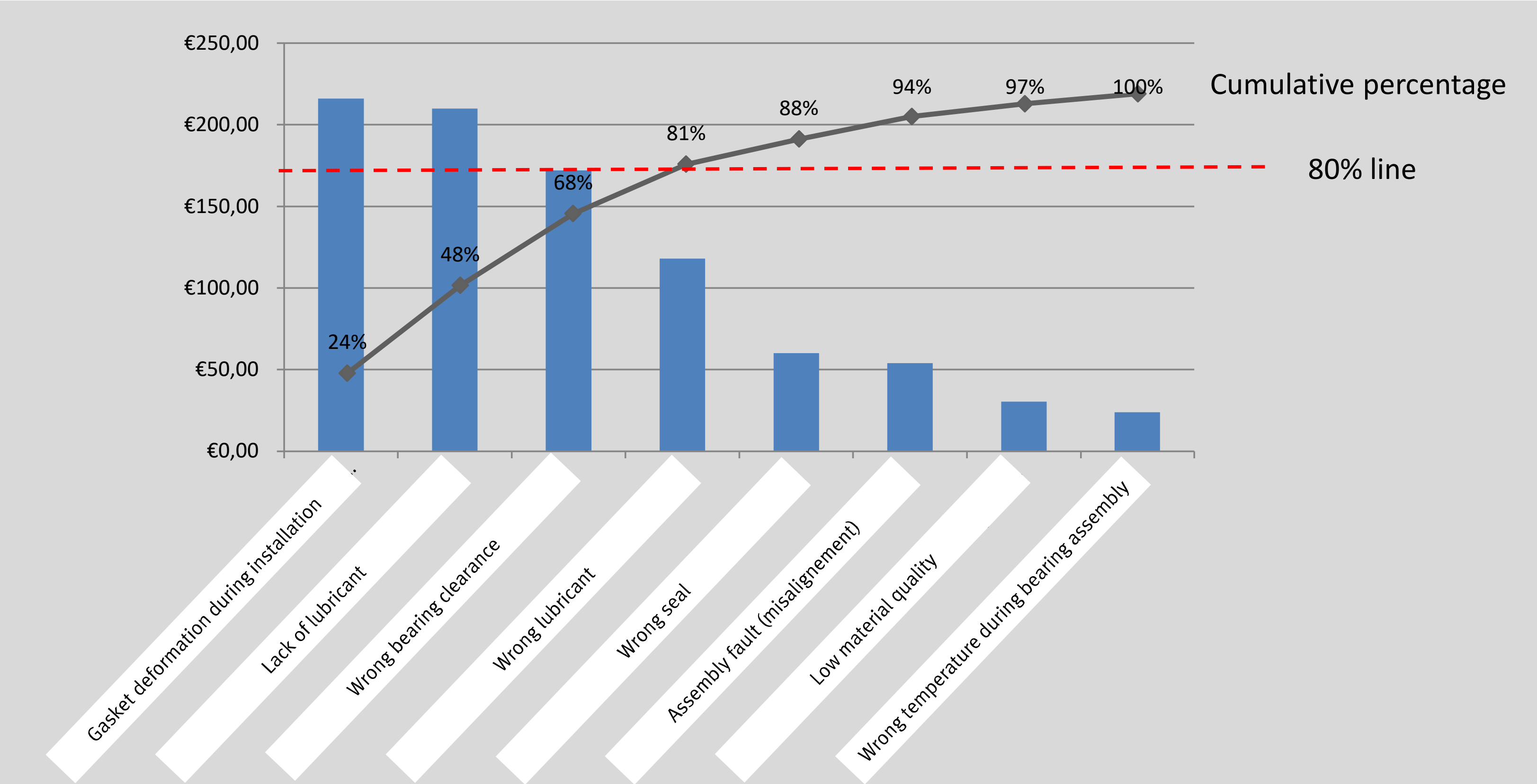
Application:

The Pareto analysis is used for balancing failure groups to facilitate efficient processing. The goal is to identify the causes or groups of causes that have the greatest influence on failure effects. The result is a frequency distribution of the problem causes, usually displayed as a bar graph.

Benefit:

- Identification of key problems
- Impact, frequency and detectability is noted
- A ranking of problem to be solved can be defined

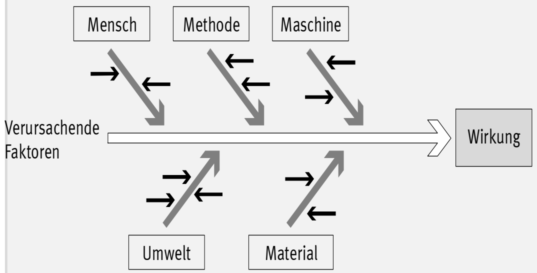
The Pareto analysis: example



The Ishikawa diagram at a glance

Short description:

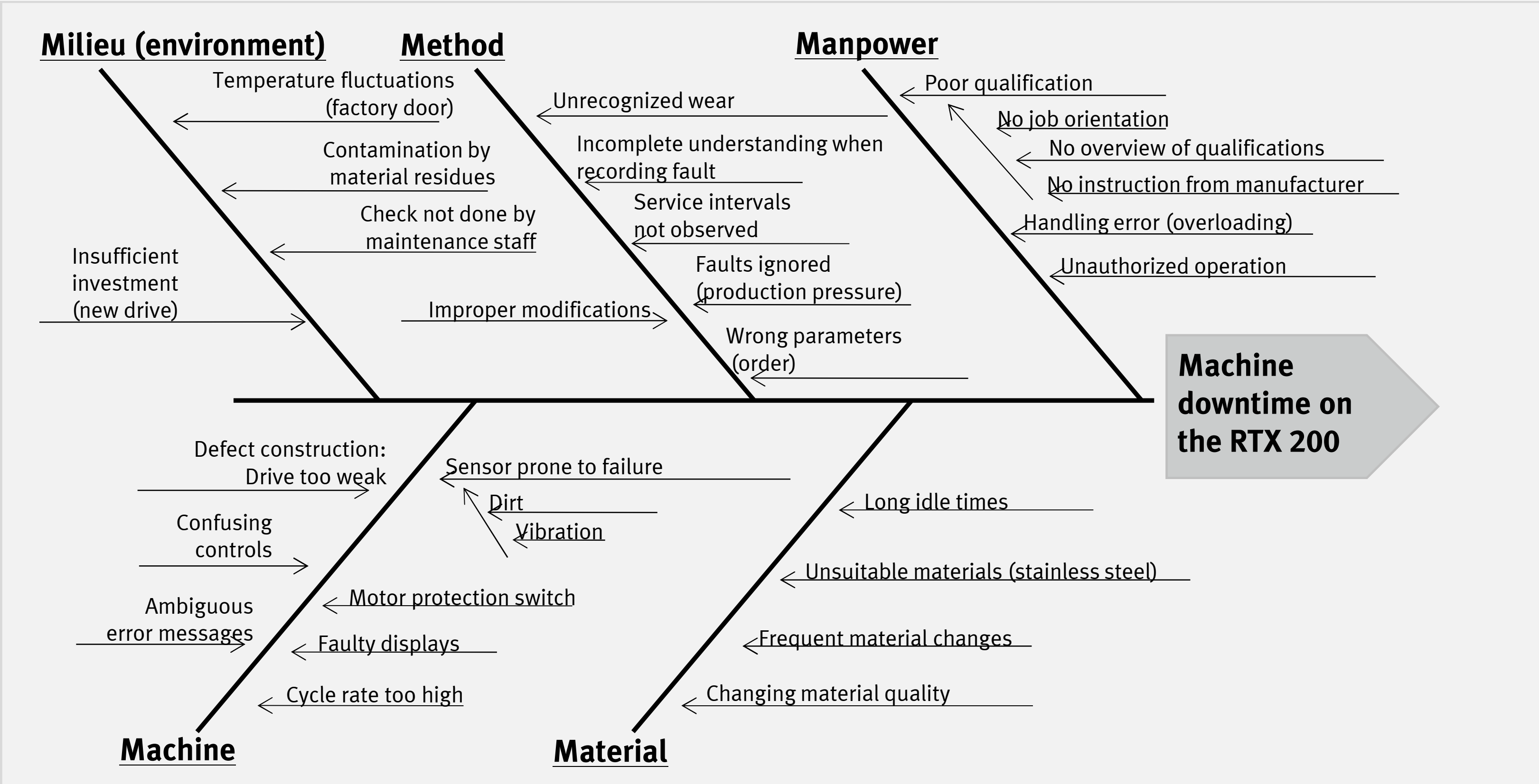
Named after its inventor, the Japanese Kaoru Ishikawa, the Ishikawa diagram is a simple tool for visualization of possible causal relationships and is similar in appearance to a fishbone. For this reason, it is also known as a fishbone, herringbone or cause-and-effect diagram.
It analyses causes of failure based on the 5 M criteria (man, machine, method, material and milieu (environment). Alternatively, other categories can be defined, such as the 4 Ps (Policies, Procedures, People, Plant).



Application:

The goal of the Ishikawa diagram is the detection and systematically structured visualization of problems. The Ishikawa diagram can be used for actual or potential problems within a defined area. It can be applied as a group technique and delivers an overview of the cause and effect relationships of a specific problem within a short time.

The Ishikawa diagram: example



5x Why questioning method at a glance

Short description:

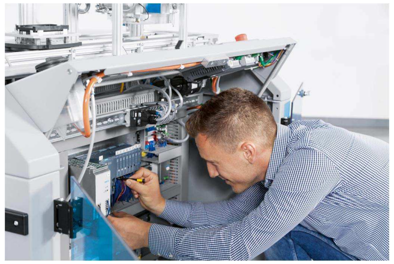
When processing and resolving problems, thinking often begins on the level at which the problem was first noticed. But in reality, the cause of a problem may be somewhere entirely different. The “5 Whys” questioning method (abbreviation: 5W) is a simple method to detect the actual cause of a problem. The principle of the method is that the question “why?” is asked by affected/involved staff five times with regard to the initially spotted cause. The goal is to systematically analyze the source of the problem instead of being content with a superficial or simple response.

Question 1: Why has the machine stopped?
Answer: The turning tool has broken.
Question 2: Why has the turning tool broken?
Answer: The cutting speed was too high.
Question 3: Why was the cutting speed too high?
Answer: The cutting data were wrongly entered.
Question 4: Why were the cutting data wrongly entered?
Answer: ...

Application:

Since this approach can be performed in a very short time, it can be used practically without any preparation. Still, the staff involved should be informed of how the method works and when it will be used, since repeatedly asking “why?” can otherwise be quite irritating. Through this style of questioning, the causes of causes (if linear causation chains are present) can be revealed, i.e. why someone who did something wrong could do something wrong, and provides indications on how the rise of the fault can be avoided by changing the procedure, components, suppliers or work organization. Solutions are only examined after the questioning method has been applied.

5x Why questioning method: example (Co. Heineken)



Exercise: Reactive maintenance – eliminating failures in a target-oriented way

Learning objectives:

Once you have completed this task,

- you know the importance of fault documentation for the continuous improvement of machines.
- you can create fault documentation.
- you are able to document faults in a clear and comprehensible way.
- you know how fault documentation is evaluated in order to identify problem focus points and to eliminate their causes in a targeted way.

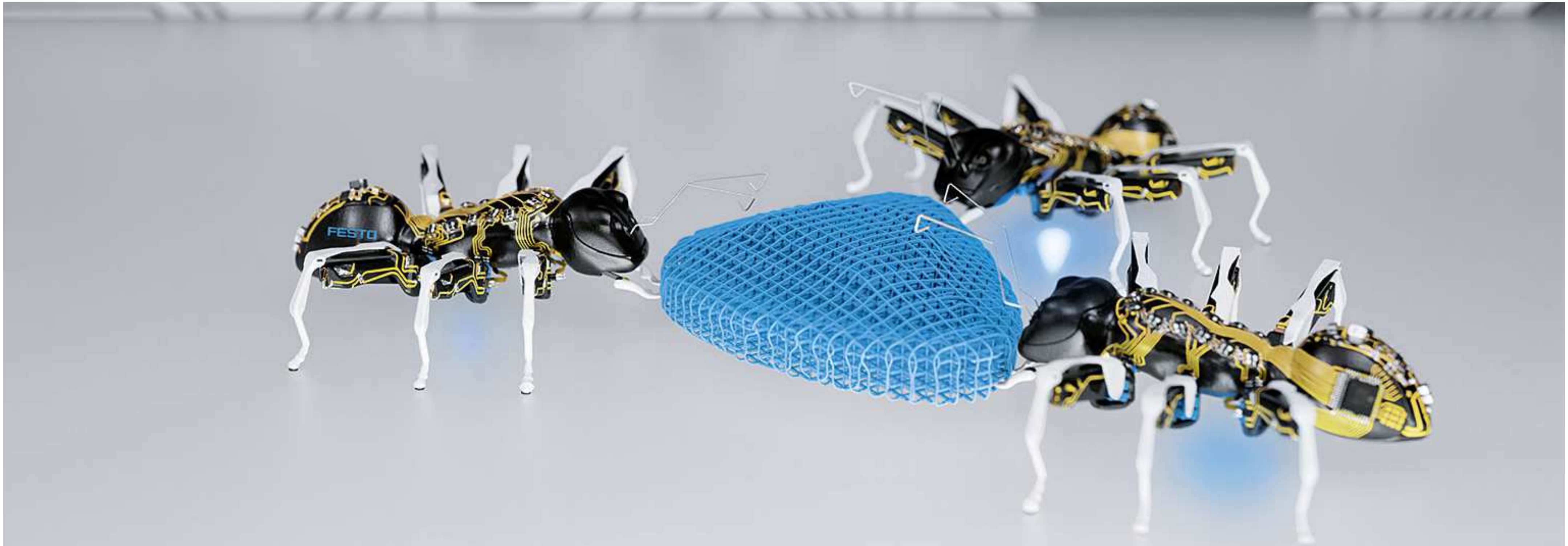
Problem:

Fault documentation needs to be developed and implemented consistently for a CP Lab / CP Factory. This fault documentation must be evaluated in a targeted manner in order to identify problem focus points and permanently eliminate their cause.

Work orders:

1. Prepare a fault documentation.
2. In this documentation, enter any faults that occur.
3. Use a Pareto analysis to evaluate various aspects of existing fault documentation. Determine the problem focus points and develop measures to permanently eliminate their cause.

Smart Maintenance: remote service



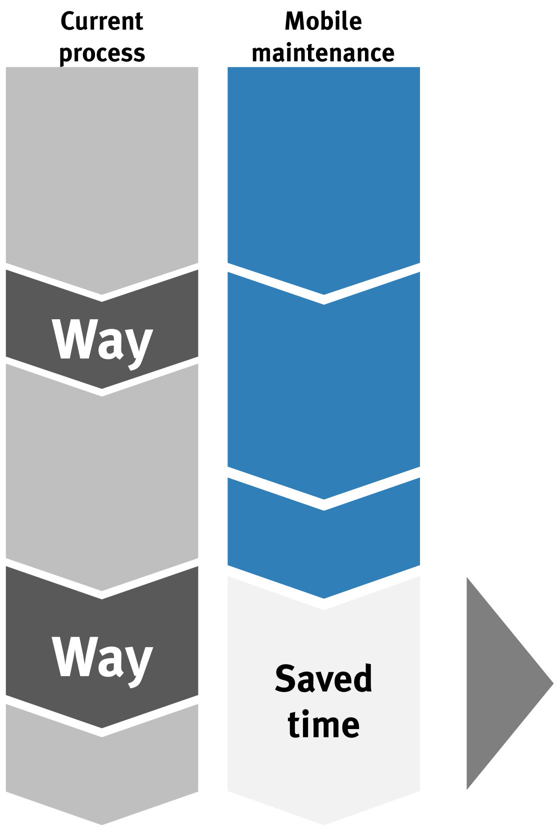
Mobile maintenance

- Use of smart phones or tablet PC for service and repair purposes
- The maintenance specialist receives all needed data digitally on his/her mobile device.

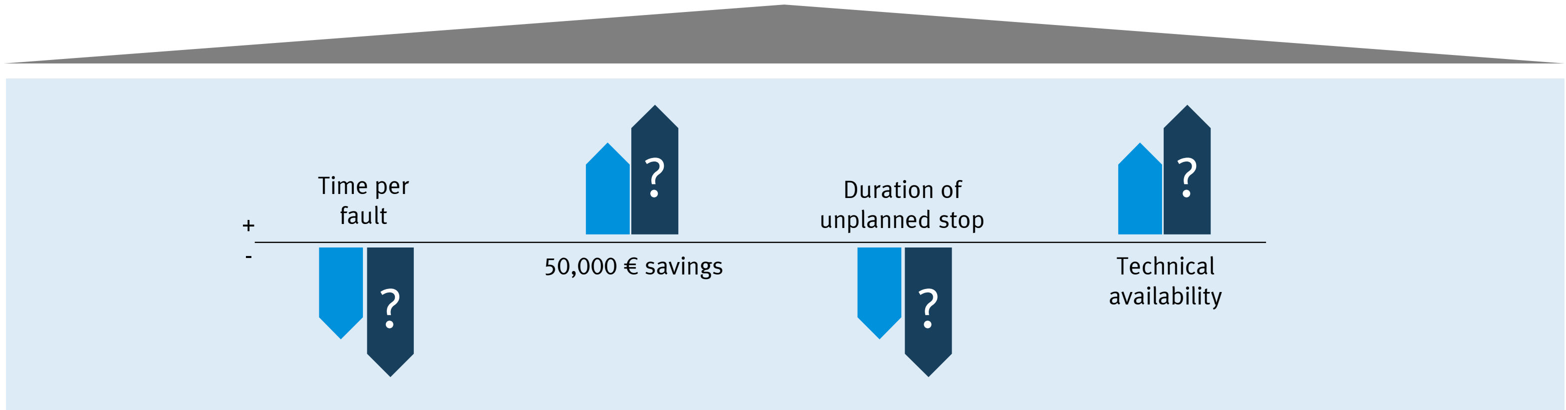
Media disruptions:

	Waste
Machine operator: fault message	
Maitenance disposition: Planning and printing of the maintenance order	
Mainenance operator: damage assessment	
Maintenance operator: compilation of all needed documen-tations	• Search effort • Distances • Up to date of data
Maintenance operator: fault analysis	
Maintenance operator: getting or ordering spare parts	• Dictances • Coordination effort
Maintenance operator: fault elimination	
Maintenance operator: fault documen-tation	• Accuracy of data
Maintenance operator: fault confirmation	• Distances

Mobile maintenance

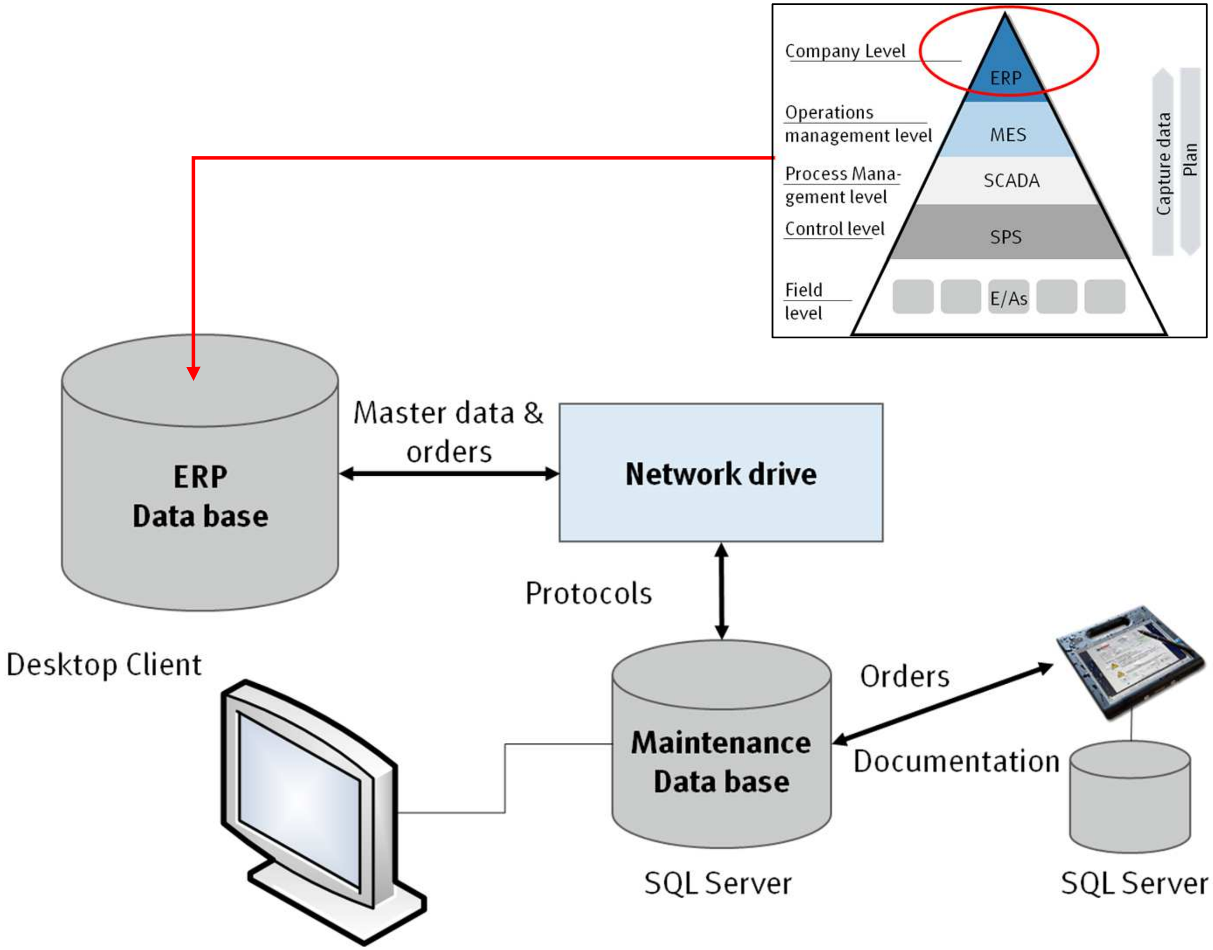


Increase delivery rate



Saved time:	up to 10 minutes per fault message
Berkheim/Scharnhausen:	15-20 faults daily
Rohrbach:	40-60 faults daily

Data process of mobile maintenance



Advantages:

- Comprehensive collection of maintenance data
- Complete documentation of machine history
- Full digital documentation of fault data
- A high data relevance is ensured
- Detailed allocation of maintenance cost to the machines
- Simplified data base for optimization of machines
- Simplified communication with machine producer

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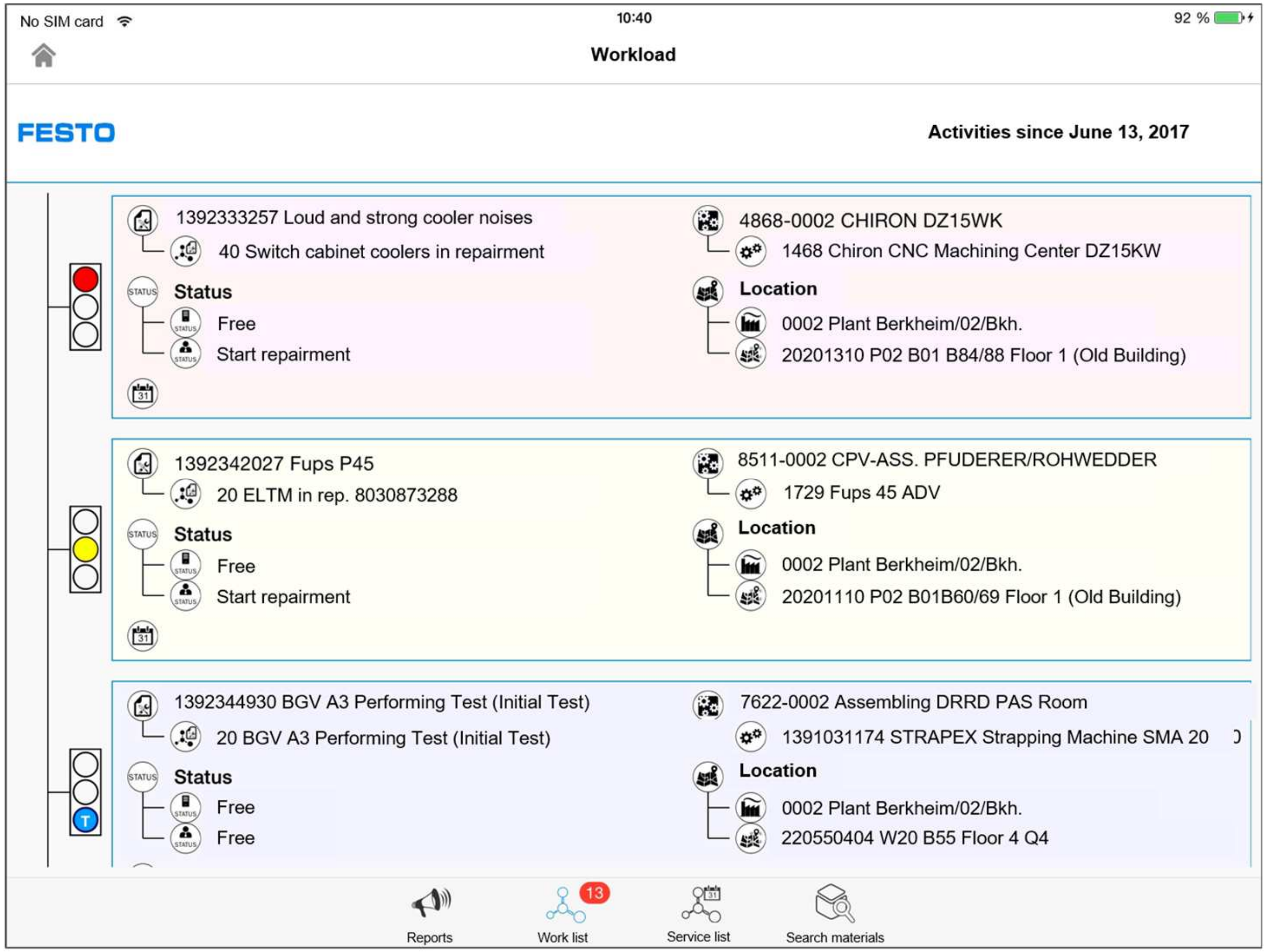
Screenshot: workload



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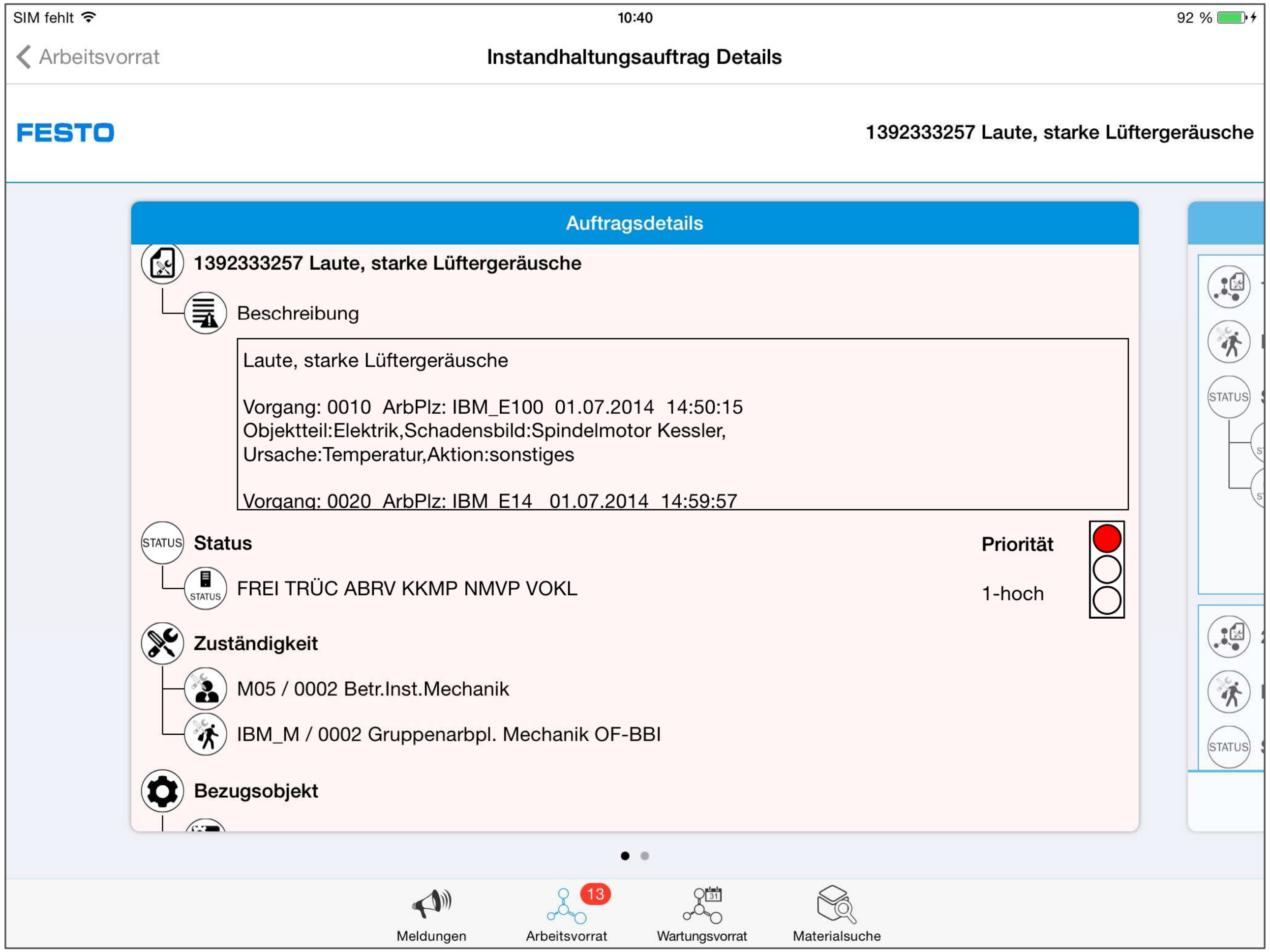
Screenshot: order details



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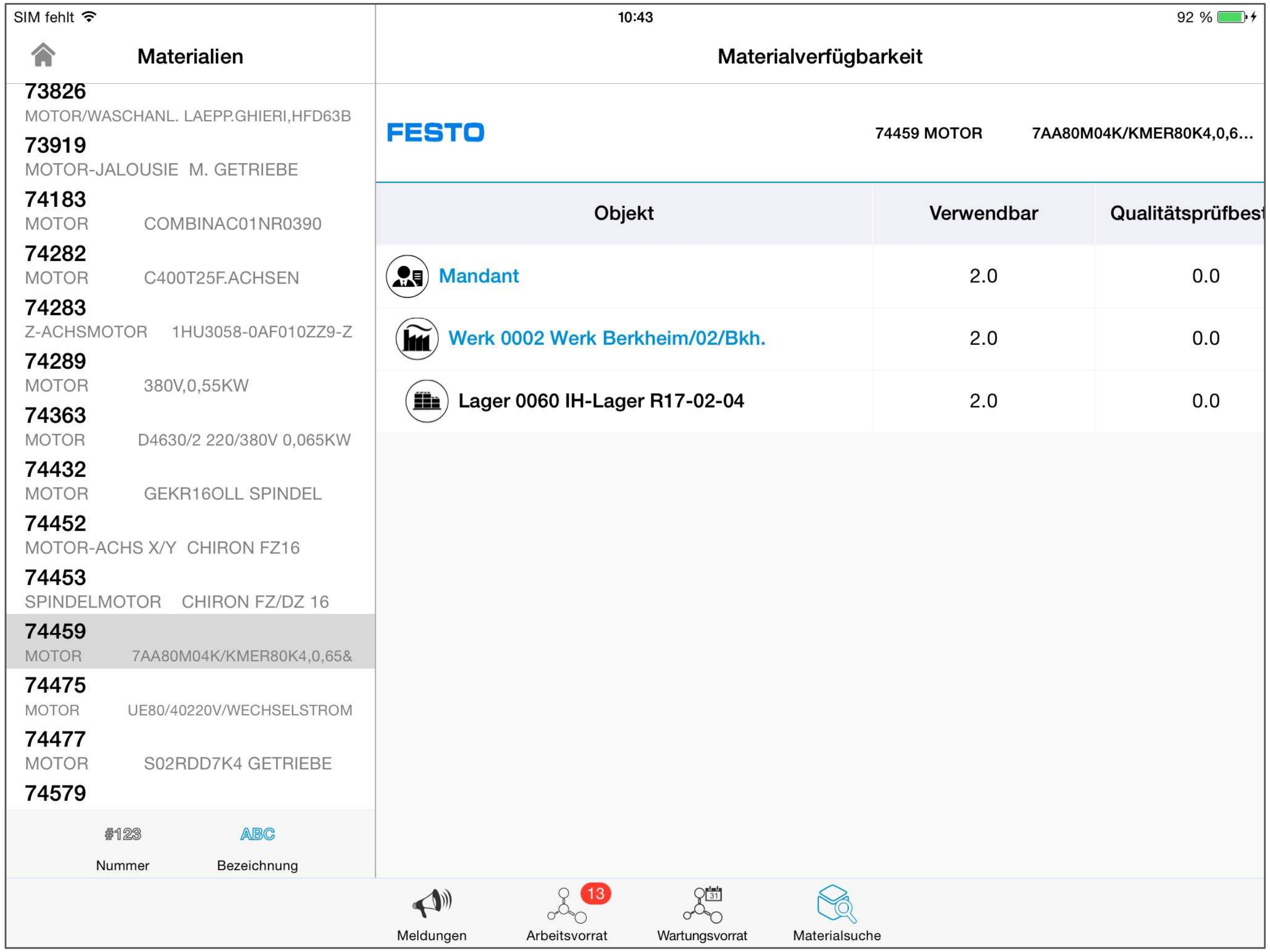
Screenshot: material availability



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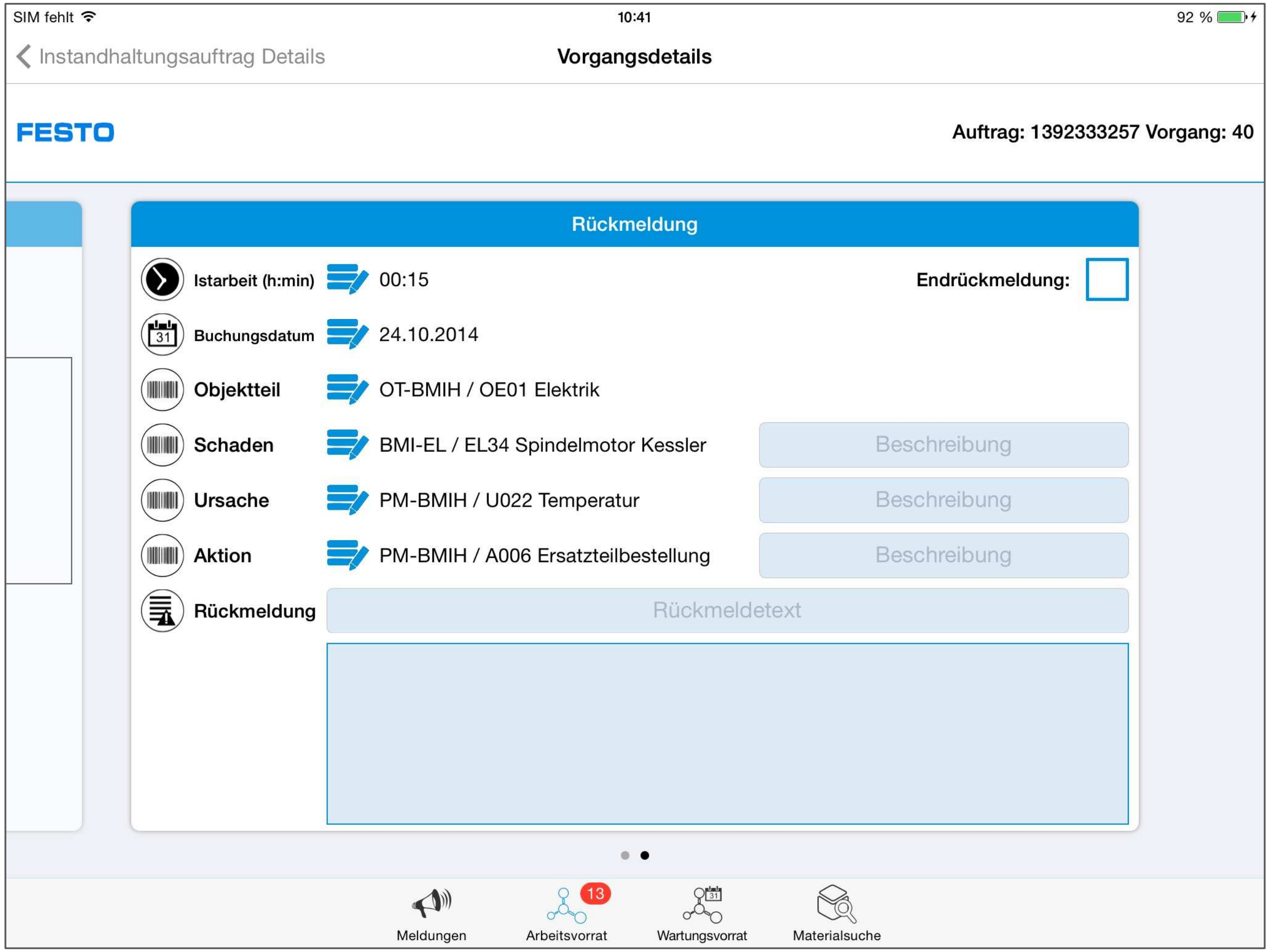
Screenshot: closing the fault elimination process



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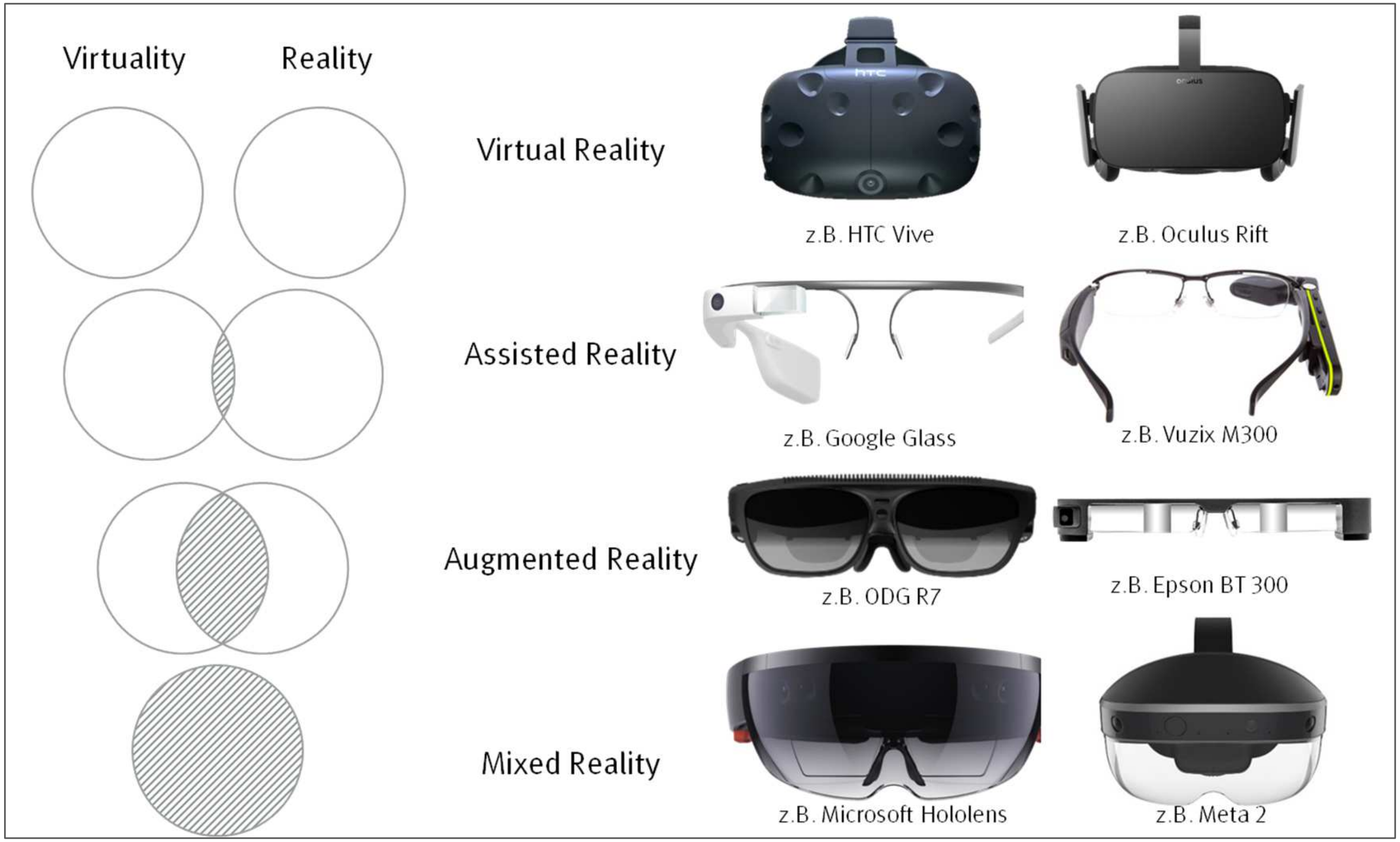
Augmented Reality

Augmented Reality is a kind of melting of virtual and real world.



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Augmented Reality: potential applications

Remote service through experts: two heads are better then one.

Reduction of downtimes*
6 days

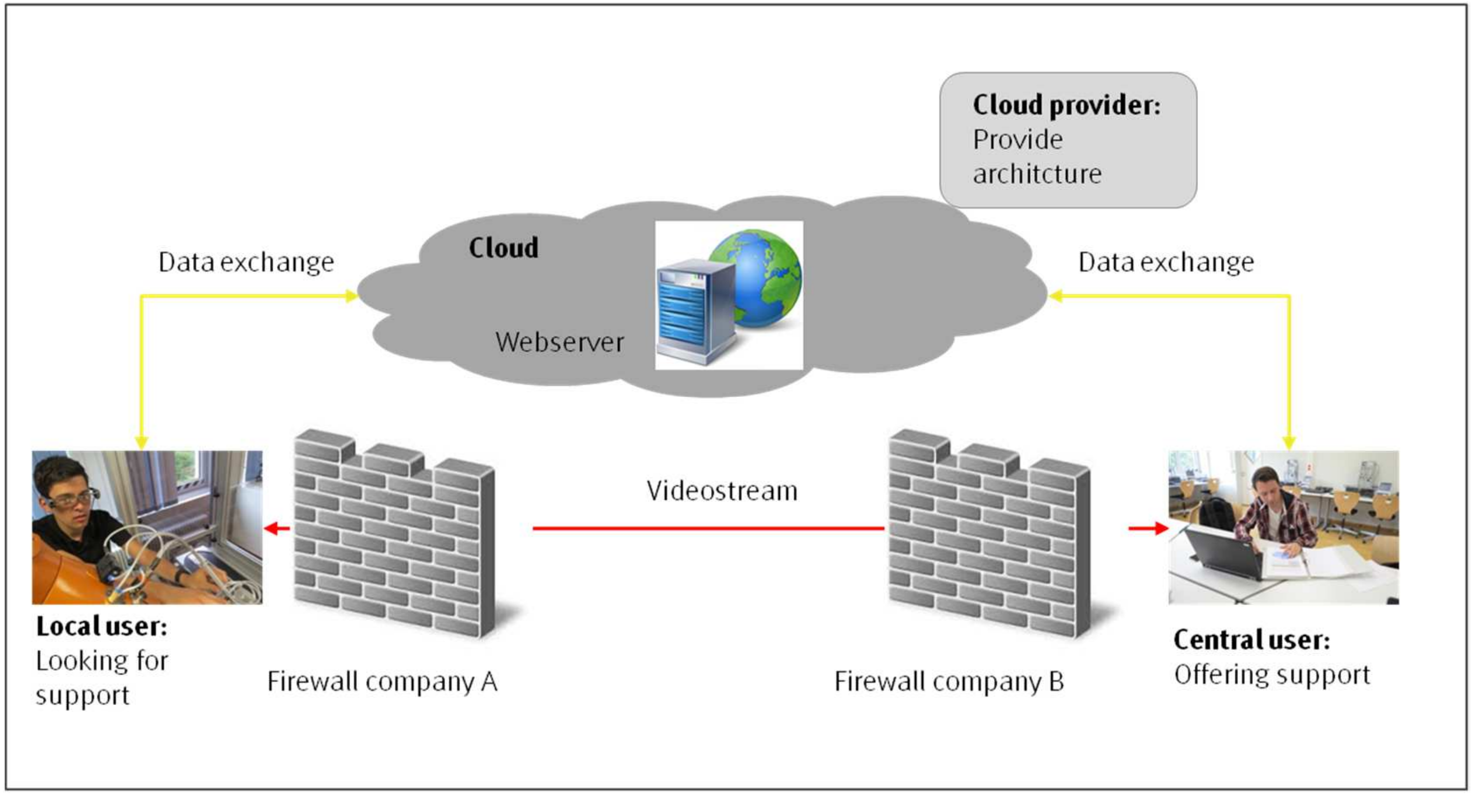
Reduction of travel costs up to
60%

Step by step: assembly instructions for complex tasks and new operators

Reduction of process times up to*
30%

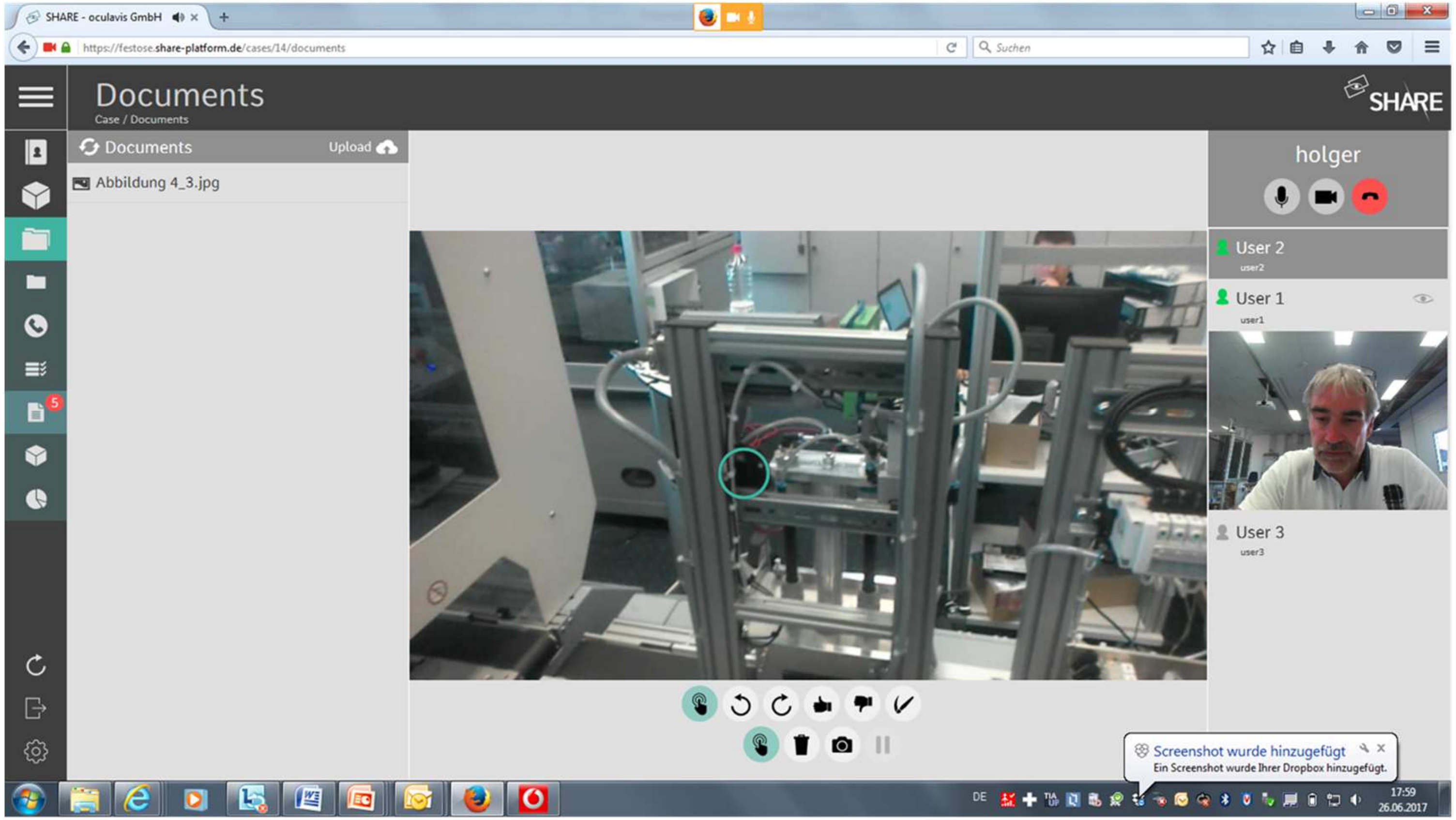
Reduction of failure rates up to*
94%

Process of augmented reality

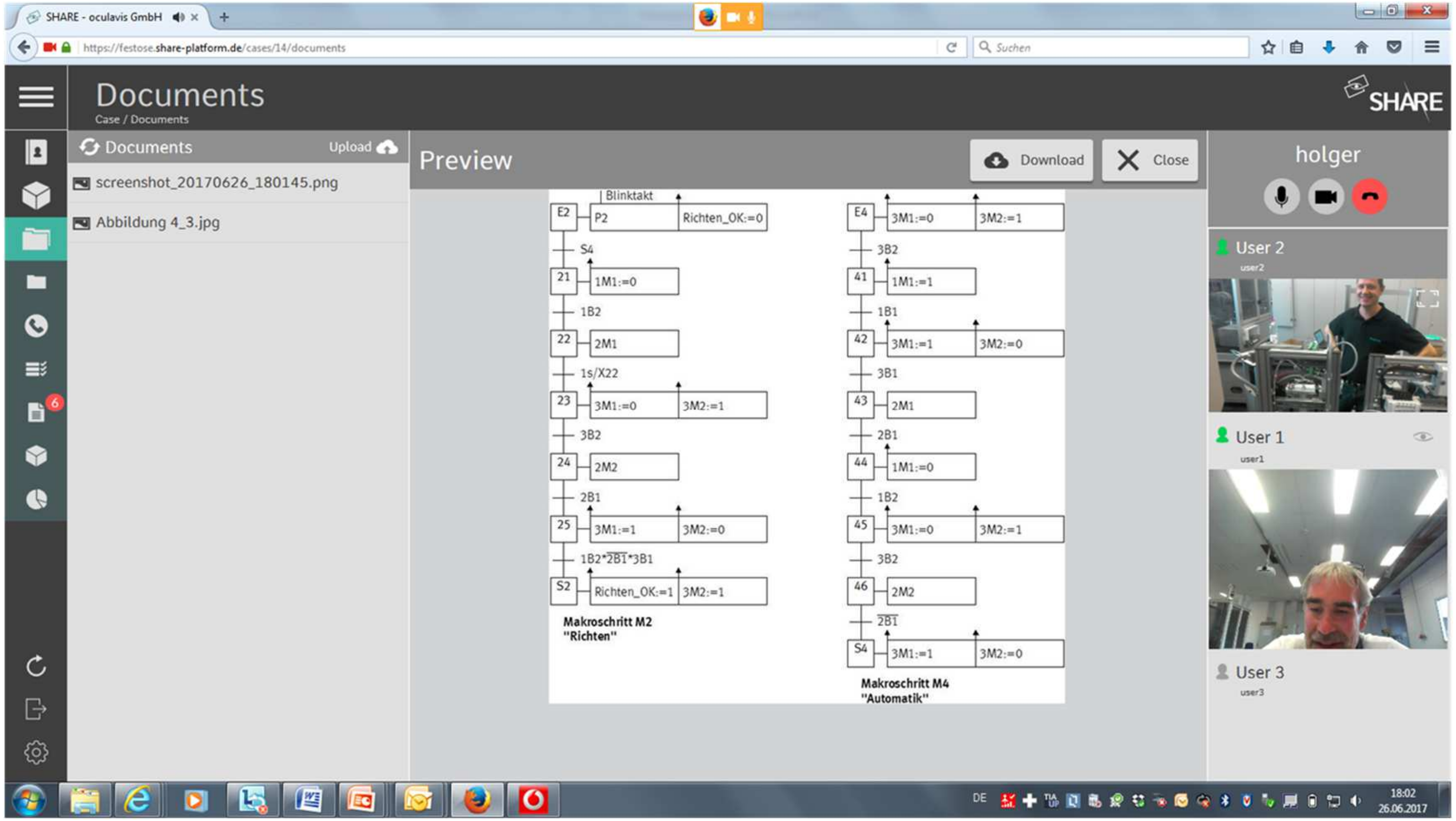


FESTO

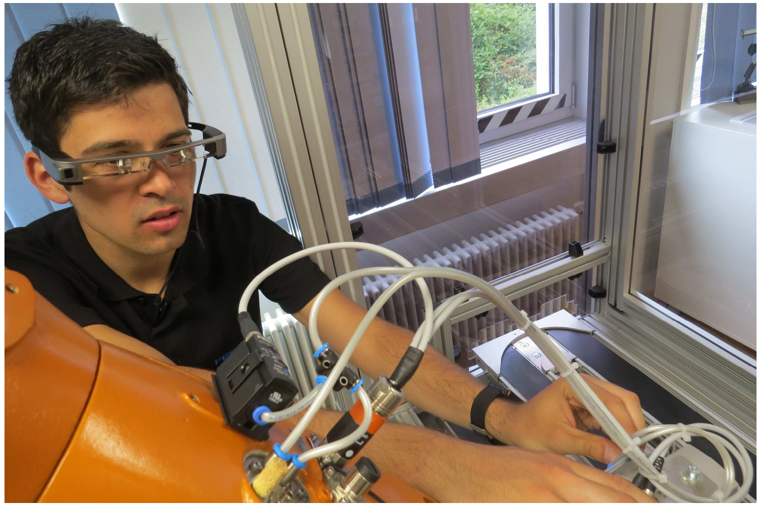
Communication via the platform “Share”



Data exchange via “Share”



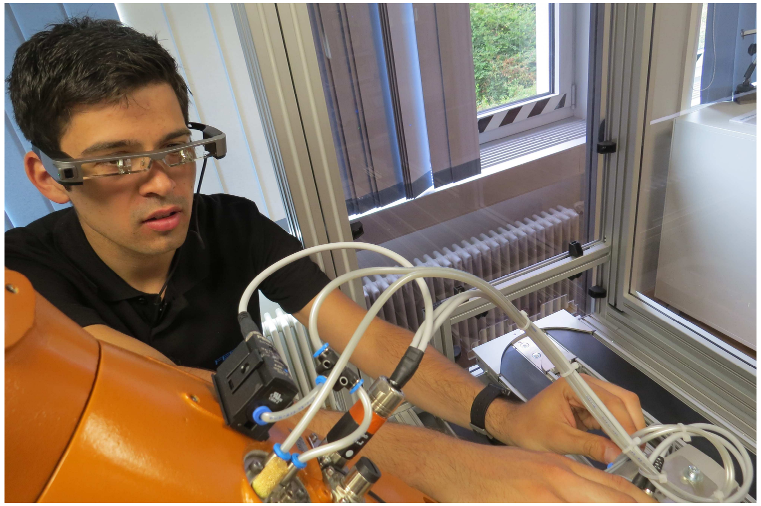
Exercise: remote service for machines 1



Learning objectives:
Once you have completed this task,
- you are able to understand warnings and alerts on mobile devices.
- you are familiar with the possibilities offered by augmented reality in the context of troubleshooting and fault elimination.
- you can use them for practical application scenarios.
- you, as a local expert, are able to describe faults that have occurred and effectively apply the assistance of a central service center.
- you are able, as an employee of a central service center, to assist local experts in troubleshooting and fault elimination.

Exercise: remote service for machines 2

Problem:
Warning and alert messages are to be generated for a CP Lab / CP Factory and are intended to be displayed on mobile devices. Furthermore, current faults are to be analyzed and eliminated with the help of smart glasses and remote services.



Work orders:
1. Design an information process that displays warning and alert messages on mobile devices.
2. Connect your data glasses to the central platform.
3. As a local expert of a central service center, describe any faults that occur during the data communication.
4. As an employee at a central service center, provide your know-how to the local experts during the analysis and elimination of the faults.
5. Share documents such as screenshots, circuit diagrams or operating instructions.
6. Work together to document the errors in the fault documentation.