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**Automation systems and  
integration — Key performance  
indicators (KPIs) for manufacturing  
operations management —**

**Part 2:  
Definitions and descriptions**

*Systèmes d'automatisation et intégration — Indicateurs de  
la performance clé pour le management des opérations de  
fabrication —*

*Partie 2: Définitions et descriptions*



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## Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see [www.iso.org/directives](http://www.iso.org/directives)).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see [www.iso.org/patents](http://www.iso.org/patents)).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information

The committee responsible for this document is Technical Committee ISO/TC 184, *Automation systems and integration*, Subcommittee SC 5, *Interoperability, integration and architectures of automation systems and applications*.

ISO 22400 consists of the following parts, under the general title *Automation systems and integration — Key performance indicators (KPIs) for manufacturing operations management*

- *Part 1: Overview, concepts and terminology*
- *Part 2: Definitions and descriptions*

The following parts are under preparation:

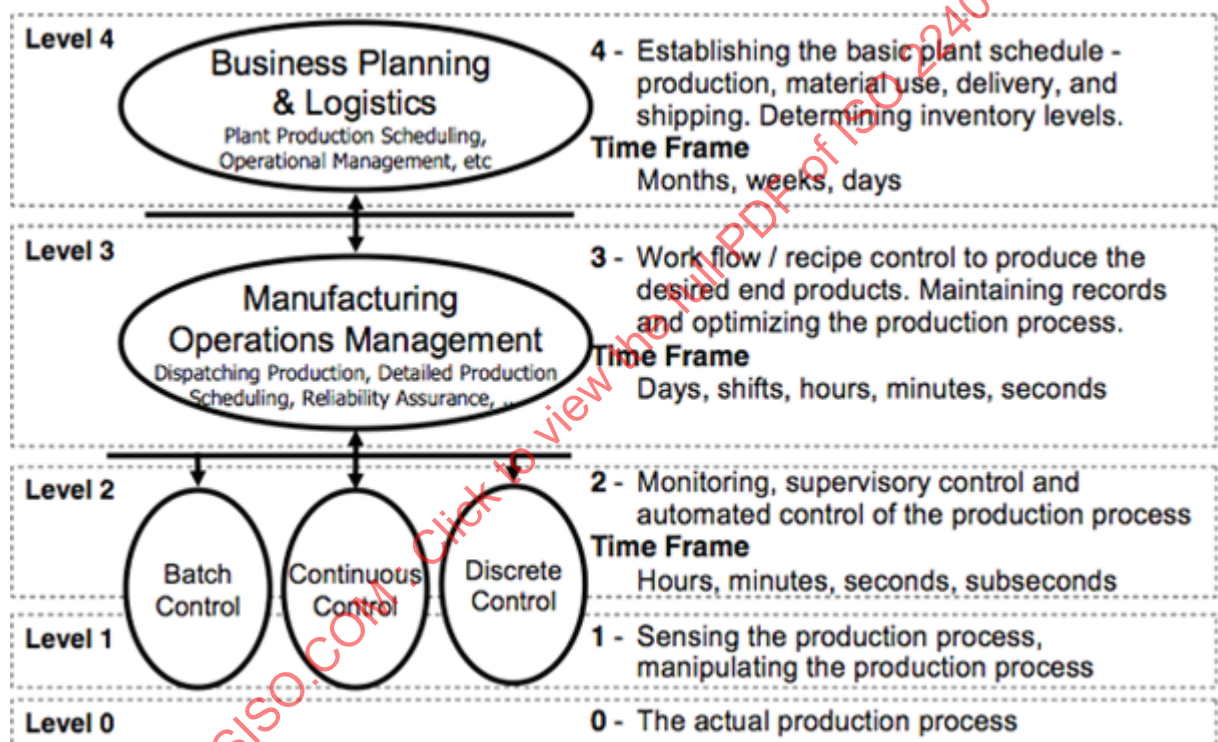
- *Part 3: Exchange and use*
- *Part 4: Relationships and dependencies*

## Introduction

This part of ISO 22400 focuses on key performance indicators (KPIs) for manufacturing operations management.

KPIs are defined as quantifiable and strategic measurements that reflect an enterprise's critical success factors. KPIs are very important for understanding and improving manufacturing performance, both from the lean manufacturing perspective of eliminating waste and from the corporate perspective of achieving strategic goals.

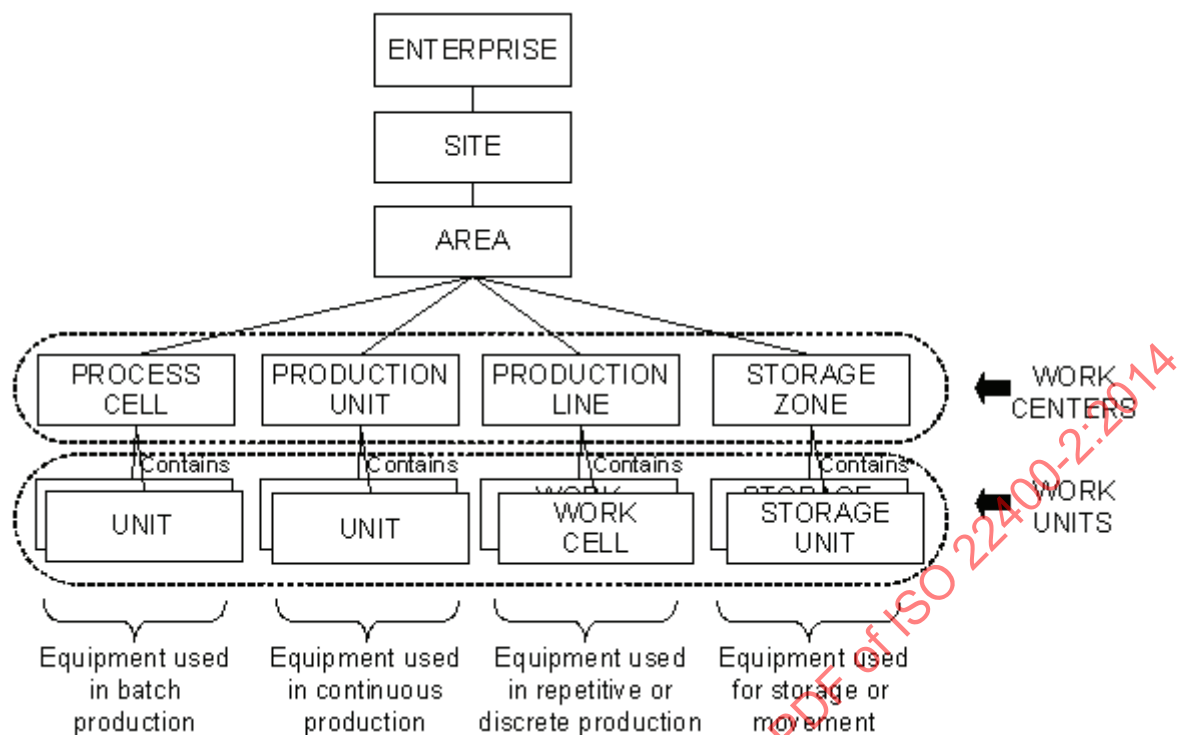
Manufacturing operations management (MOM) is a term used in IEC 62264 to specify a portion of the functional hierarchy model of a manufacturing enterprise. [Figure 1](#) depicts the different levels of the functional hierarchy model: business planning and logistics (Level 4), manufacturing operations and control (Level 3), and batch, continuous, or discrete control (Level 1-2). The levels provide different functions and work in different timeframes.



NOTE Adapted from IEC 62264-3.

**Figure 1 — Functional hierarchy**

IEC 62264 also specifies a hierarchical structure for the physical equipment (see [Figure 2](#)). Enterprise, site and areas are generic terms, whereas there are specific terms for work centres and work units that apply to batch production, continuous production, discrete or repetitive production, and for storage and movement of materials and equipment.



NOTE Adapted from IEC 62264-3.

**Figure 2 — Role based equipment hierarchy**

This part of ISO 22400 specifies the KPIs “residing” at Level 3, i.e. related to MOM. These KPIs are generated/calculated within Level 3. Some of these KPIs are forwarded to Level 4 for further usage. In order to generate these KPIs, parameters from Levels 2 and 1 might be needed.

The KPIs in this part of ISO 22400 use the most generic terms possible (e.g. work centres and work units), instead of industry specific terms.

MOM, sometimes referred to as manufacturing execution systems (MES), models four major categories of operations management:

- production operations management;
- maintenance operations management;
- quality operations management;
- inventory operations management.

An activity model further details each category. Each activity model includes eight activities:

- detailed scheduling;
- dispatching;
- execution management;
- resource management;
- definition management;
- tracking;

- data collection;
- analysis.

These activities apply to production operations, quality operations, inventory operations and maintenance operations.

Analysis is the performance of calculating KPIs using information from other activities. Workflows can be used to illustrate the important events and steps needed in the calculation process for KPIs.

KPIs alone are not sufficient factors to perform the necessary management and execution operations for an enterprise. For many of the indicators, a company specific threshold is defined. When the value of the indicator exceeds or falls below the threshold, actions are initiated (e.g. to improve efficiency or quality). Often it is necessary to define warning and action limits. Warning limits help to detect the trends in process and equipment changes before company-specific thresholds are violated.

To improve the productivity of the manufacturing resources, information provided by industrial automation systems and control devices about process, equipment, operator and material can be useful for providing critical feedback through KPIs.

A standardized schema for the expression of these KPIs is intended to:

- a) facilitate the specification and procurement of integrated systems, in particular, the interoperability requirements among MES applications;
- b) provide a means to categorize productivity tools that can be used across applications.

ISO 22400 provides an overview of the concepts, the terminology and the methods to describe and to exchange KPIs for the purpose of managing manufacturing operations. The audience is factory managers responsible for production performance, software suppliers developing KPIs for factory management, engineers engaged in process planning of products, planners and designers of manufacturing systems, and equipment and device suppliers.

KPIs also reside at Level 4, i.e. KPIs related to business planning and logistics, which are outside the scope of this part of ISO 22400. Level 4 KPIs are often related to economic, business, logistic and financial factors. These KPIs are used to assess the progress or extent of compliance with regard to important objectives or critical success factors within a company. Economic KPIs serve as a basis for decisions (problem identification, presentation, information extraction), for economic control (target/actual comparison), for financial documentation and for coordination (behaviour management) of important facts and relationships within the company.

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# Automation systems and integration — Key performance indicators (KPIs) for manufacturing operations management —

## Part 2: Definitions and descriptions

### 1 Scope

ISO 22400 specifies key performance indicators (KPIs) used in manufacturing operations management (MOM).

This part of ISO 22400 specifies a selected number of KPIs in current practice. The KPIs are presented by means of their formula and corresponding elements, their time behaviour, their unit/dimension and other characteristics. This part of ISO 22400 also indicates the user group where the KPIs are used, and the production methodology to which they correspond.

With reference to equipment, the KPIs in this part of ISO 22400 relate to work units, as specified in IEC 62264.

### 2 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

#### 2.1

##### **reference time**

base timeline used for time models, corresponding to the planned maximum time interval available for production and maintenance tasks

EXAMPLE A calendar day with 24 hours; a week.

#### 2.2

##### **planned time**

planned duration of a specific time period

EXAMPLE The intended duration of an operation or a resource state according to the planning.

#### 2.3

##### **actual time**

realized duration of a specific time period

EXAMPLE The actual duration of an operation or a resource state.

Note 1 to entry: Actual time may be less than, equal to, or greater than corresponding planned time.

#### 2.4

##### **time model**

partition of the reference time

### 3 Symbols and abbreviated terms

ADET actual unit delay time

## ISO 22400-2:2014(E)

|          |                                           |
|----------|-------------------------------------------|
| ADOT     | actual unit downtime                      |
| AOET     | actual order execution time               |
| APAT     | actual personnel attendance time          |
| APT      | actual production time                    |
| APWT     | actual personnel work time                |
| AQT      | actual queuing time                       |
| AUST     | actual unit setup time                    |
| ATT      | actual transport time                     |
| AUBT     | actual unit busy time                     |
| AUPT     | actual unit processing time               |
| CI       | consumables inventory                     |
| $C_m$    | machine capability index                  |
| CM       | consumed material                         |
| $C_{mk}$ | critical machine capability index         |
| CMT      | corrective maintenance time               |
| $C_p$    | process capability index                  |
| $C_{pk}$ | critical process capability index         |
| EPC      | equipment production capacity             |
| FE       | failure event                             |
| FGI      | finished goods inventory                  |
| GP       | good part                                 |
| GQ       | good quantity                             |
| IGQ      | integrated good quantity                  |
| IP       | inspected part                            |
| LSL      | lower specification limit                 |
| LT       | loading time                              |
| MOM      | manufacturing operations management       |
| NEE      | net overall equipment effectiveness index |
| NOT      | net operating time                        |
| OC       | operation cluster                         |
| OEE      | overall equipment effectiveness           |
| OL       | other loss                                |

|                 |                                 |
|-----------------|---------------------------------|
| OPT             | operating time                  |
| PBT             | planned busy time               |
| PL              | production loss                 |
| PMT             | preventive maintenance time     |
| PO              | production order                |
| POET            | planned order execution time    |
| POQ             | planned order quantity          |
| POS             | production order sequence       |
| POT             | planned operation time          |
| PQ              | produced quantity               |
| PRI             | planned run time per item       |
| PSQ             | planned scrap quantity          |
| PUST            | planned unit setup time         |
| RMI             | raw material inventory          |
| RQ              | rework quantity                 |
| $\sigma$        | standard deviation              |
| SQ              | scrap quantity                  |
| STL             | storage and transportation loss |
| TBF             | operating time between failure  |
| TTF             | time to failure                 |
| TTR             | time to repair                  |
| USL             | upper specification limit       |
| WG              | working group                   |
| WIP             | work in process inventory       |
| WOP             | work process                    |
| WP              | work place                      |
| $\bar{x}$       | arithmetic average              |
| $\bar{\bar{x}}$ | average of average values       |
| $\hat{\sigma}$  | estimated deviation             |
| $\sigma^2$      | variance                        |

## 4 Structure of KPI description

KPI specifications are expressed using the structure in [Table 1](#) and are in accordance with ISO 22400-1. The structure in [Table 1](#) identifies KPI descriptive elements in the left column and gives a description of each element in the right column.

**Table 1 — Structure of KPI description**

| <b>KPI description</b> |                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Content:</b>        |                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| Name                   | Name of the KPI                                                                                                                                                                                                                                                                                                                                                                                                                   |
| ID                     | A user defined unique identification of the KPI in the user environment                                                                                                                                                                                                                                                                                                                                                           |
| Description            | A brief description of the KPI                                                                                                                                                                                                                                                                                                                                                                                                    |
| Scope                  | Identification of the element that the KPI is relevant for, which can be a work unit, work centre or production order, product or personnel                                                                                                                                                                                                                                                                                       |
| Formula                | The mathematical formula of the KPI specified in terms of elements                                                                                                                                                                                                                                                                                                                                                                |
| Unit of measure        | The basic unit or dimension in which the KPI is expressed                                                                                                                                                                                                                                                                                                                                                                         |
| Range                  | Specifies the upper and lower logical limits of the KPI                                                                                                                                                                                                                                                                                                                                                                           |
| Trend                  | Is the information about the improvement direction, higher is better or lower is better                                                                                                                                                                                                                                                                                                                                           |
| <b>Context:</b>        |                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| Timing                 | <p>A KPI can be calculated either in</p> <ul style="list-style-type: none"> <li>• real-time - after each new data acquisition event</li> <li>• on demand - after a specific data selection request</li> <li>• periodically - done at a certain interval, e.g. once per day</li> </ul>                                                                                                                                             |
| Audience               | <p>Audience is the user group typically using this KPI. The user groups used in this part of ISO 22400 are</p> <ul style="list-style-type: none"> <li>• Operators – personnel responsible for the direct operation of the equipment</li> <li>• Supervisors – personnel responsible for directing the activities of the operators</li> <li>• Management – personnel responsible for the overall execution of production</li> </ul> |
| Production methodology | <p>Specifies the production methodology that the KPI is generally applicable for</p> <ul style="list-style-type: none"> <li>• Discrete</li> <li>• Batch</li> <li>• Continuous</li> </ul>                                                                                                                                                                                                                                          |
| Effect model diagram   | <p>The effect model diagram is a graphical representation of the dependencies of the KPI elements that can be used to drill down and understand the source of the element values.</p> <p>NOTE This is a quick analysis which supports rapid efficiency improvement by corrective actions, and thus reduces errors</p>                                                                                                             |
| Notes                  | <p>Can contain additional information related to the KPI. Typical examples are</p> <ul style="list-style-type: none"> <li>• Constraints</li> <li>• Usage</li> <li>• Other information</li> </ul>                                                                                                                                                                                                                                  |

## 5 Elements used in KPI description

### 5.1 Time elements

#### 5.1.1 Notations

In the time model of this part of ISO 22400, in order to process and complete a production order, one or more tasks are performed using a set of production resources, e.g. production personnel, equipment and materials.

NOTE 1 Since many continuous operations (e.g. refineries and other petrochemical facilities) define “throughput” using an arbitrary time period (e.g. a day or a shift), rather than a production order based time interval, KPIs derived using this production order time model need to be adjusted for those industries.

NOTE 2 The identifying element name abbreviations indicated in round brackets in this clause are used in KPI calculations in [Clause 6](#).

NOTE 3 Definitions of maintenance elements have been taken from IEC 60050-191.

NOTE 4 The term “time” in the element specifications refers to a duration of time.

#### 5.1.2 Planned times

##### 5.1.2.1 Planned order execution time (POET)

The planned order execution time shall be the planned time for executing an order.

NOTE It is often calculated from the planned run time per item multiplied by the order quantity plus the planned setup time.

##### 5.1.2.2 Planned operation time (POT)

The planned operation time shall be the planned time in which a work unit can be used. The operation time is a scheduled time.

##### 5.1.2.3 Planned unit setup time (PUST)

The planned unit setup time shall be the planned time for the setup of a work unit for an order.

##### 5.1.2.4 Planned busy time (PBT)

The planned busy time shall be the planned operation time minus the planned downtime.

NOTE The planned down time can be used for planned maintenance work. The planned busy period is available for the detailed planning of the work unit for expected production orders.

##### 5.1.2.5 Planned run time per item (PRI)

The planned run time per item shall be the planned time for producing one quantity unit.

#### 5.1.3 Actual times

##### 5.1.3.1 Actual personnel work time (APWT)

The actual personnel work time shall be the time that a worker needs for the execution of a production order.

#### **5.1.3.2 Actual unit processing time (AUPT)**

The actual unit processing time shall be the time needed for setup and for the production.

#### **5.1.3.3 Actual unit busy time (AUBT)**

The actual unit busy time shall be the actual time that a work unit is used for the execution of a production order.

#### **5.1.3.4 Actual order execution time (AOET)**

The actual order execution time shall be the time difference between start time and end time of a production order. It includes the actual busy time, the actual transport and the actual queuing time.

#### **5.1.3.5 Actual personnel attendance time (APAT)**

The actual personnel attendance time shall be the actual time that a worker is available to work on production orders. It does not include actual time for company authorized break periods (e.g. lunch). It shall be the difference between login and logout excluding breaks.

#### **5.1.3.6 Actual production time (APT)**

The actual production time shall be the actual time during which a work unit is producing. It includes only the value-adding functions.

#### **5.1.3.7 Actual queuing time (AQT)**

The actual queuing time shall be the actual time in which the material is either in transport or progressing through a manufacturing process, i.e. the material is waiting for the process to begin.

#### **5.1.3.8 Actual unit down time (ADOT)**

The actual unit down time shall be the actual time when the work unit is not executing order production although it is available.

#### **5.1.3.9 Actual unit delay time (ADET)**

The actual unit delay time shall be the actual time associated with malfunction-caused interruptions, minor stoppages, and other unplanned time intervals that occur while tasks are being completed that lead to unwanted extension of the order processing time.

#### **5.1.3.10 Actual unit setup time (AUST)**

The actual unit setup time shall be the time consumed for the preparation of an order at a work unit.

#### **5.1.3.11 Actual transport time (ATT)**

The actual transport time shall be the actual time required for transport between work units.

#### **5.1.3.12 Actual unit processing time (AUPT)**

The actual unit processing time shall be the actual production time plus the actual unit setup time.

#### **5.1.3.13 Actual unit busy time (AUBT)**

The actual unit busy time shall be the actual unit processing time plus the actual unit delay time.

#### 5.1.3.14 Actual order execution time (AOET)

The actual order execution time shall be the time from the start of the order until the time of the completion of the order.

### 5.1.4 Maintenance times

#### 5.1.4.1 Time between failures (TBF)

The time between failures shall be the actual unit busy time (AUBT) between two consecutive failures of a work unit including setup time, production time and repair time related to the orders being processed and without delay times.

#### 5.1.4.2 Time to repair (TTR)

The time to repair shall be the actual time during which a work unit is unavailable due to a failure.

#### 5.1.4.3 Time to failure (TTF)

The time to failure shall be the time between failures minus the time to repair.

#### 5.1.4.4 Failure event count (FE)

The failure event count shall be the count over a specified time interval of the terminations of the ability for a work unit to perform a required operation.

#### 5.1.4.5 Corrective maintenance time (CMT)

The corrective maintenance time shall be the part of the maintenance time during which corrective maintenance is performed on a work unit, including technical delays and logistic delays inherent in corrective maintenance (see IEC 60050-191).

#### 5.1.4.6 Preventive maintenance time (PMT)

The preventive maintenance time shall be that part of the maintenance time during which preventive maintenance is performed on a work unit, including technical delays and logistic delays inherent in preventive maintenance (see IEC 60050-191).

### 5.2 Time model for work units

This time model applies to time considerations for the use of work units. [Figure 3](#) shows the relationship between specific periods. In [Figure 3](#), the difference between time elements constitutes a loss of operation time.

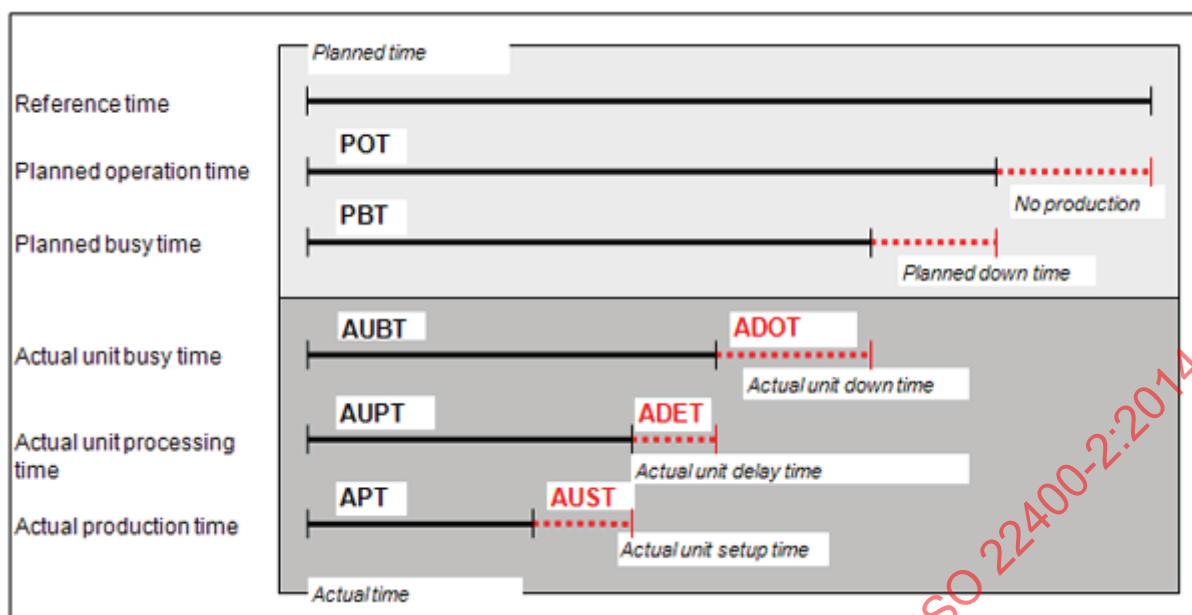


Figure 3 — Time lines for work units

NOTE [Annex B](#) provides a time model for work units with different time element partitions for which KPIs (e.g. OEE) generated using that model are different from those specified in [Clause 6](#).

### 5.3 Time model for production order

This time model is valid for executing the production order. [Figure 4](#) shows the production order processing time line consisting of multiple occurrences of operations equipment time lines (see [Figure 3](#)). The work unit time lines for a production order may be carried out in separate operations at several work units.

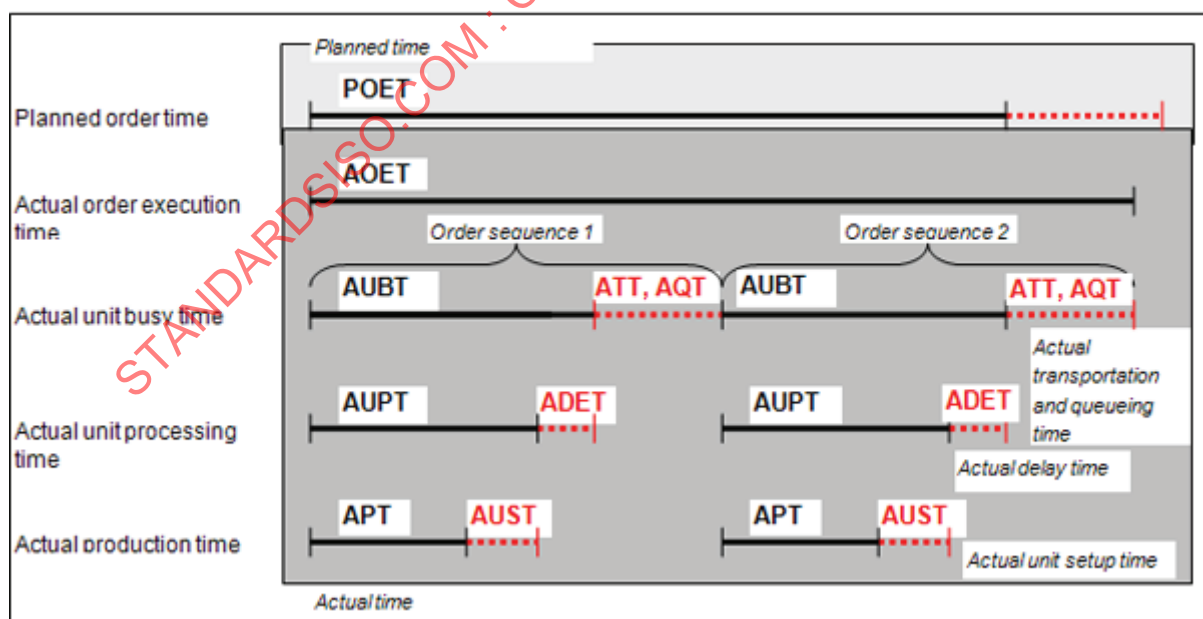


Figure 4 — Time lines for production order processing

## 5.4 Time model for personnel

This time model applies to time considerations for personnel.



Figure 5 — Time lines for personnel

## 5.5 Logistical elements

### 5.5.1 Planned order quantity (POQ)

The planned order quantity shall be the planned quantity of products for a production order (lot size, production order quantity).

### 5.5.2 Scrap quantity (SQ)

The scrap quantity shall be the produced quantity that did not meet quality requirements and either has to be scrapped or recycled.

### 5.5.3 Planned scrap quantity (PSQ)

The planned scrap quantity shall be the amount of process-related scrap that is expected when manufacturing the product (e.g. at the start or ramp-up phases of the manufacturing systems).

### 5.5.4 Good quantity (GQ)

The good quantity shall be the produced quantity that meets quality requirements.

### 5.5.5 Rework quantity (RQ)

The rework quantity shall be the quantity that fails to meet the quality requirements, but where these requirements can be met by subsequent work.

### 5.5.6 Produced quantity (PQ)

The produced quantity shall be the quantity that a work unit has produced in relation to a production order.

### 5.5.7 Raw materials (RM)

The raw materials shall be the materials that are changed into finished goods through the production.

### 5.5.8 Raw materials inventory (RMI)

The raw materials inventory shall be the inventory of materials that are changed into intermediates or finished goods through production.

#### 5.5.9 Finished goods inventory (FGI)

The finished goods inventory shall be the amount of acceptable quantity which can be delivered.

#### 5.5.10 Consumable inventory (CI)

The consumable inventory shall be material which is transformed in quantity or quality during the production process and which is no longer available for use in production operations.

EXAMPLE Fuel.

NOTE Consumables are specified in detail in IEC 62264-1.

#### 5.5.11 Consumed material (CM)

The consumed material shall be the summed quantity of materials consumed by a process.

NOTE In the process industry (e.g. oil refining and chemicals), consumed material is usually used in the denominator to calculate the related KPIs. In some industrial processes, input can be less than the output. Many chemical and physical changes occur during production, and product yield has fluctuation and uncertainty. It is therefore difficult to calculate and measure the output.

#### 5.5.12 Integrated good quantity (IGQ)

The integrated good quantity shall be the summed product count or quantity resulting from a multi-product production process used in KPI calculations instead of GQ.

EXAMPLE If the quality of a product has not reached a higher level "A", it can be sold as a product with a lower quality level "B". Then the ratio of products of level "B" raises as the ratio of products of level "A" declines. Therefore, KPIs are calculated from the view of all related products, e.g. the level "A" plus level "B" products.

NOTE Since IGQ represents the quantity of all products during production, all products need to be measured in the same unit of measure, or be converted to the same unit of measure. A list of conversion coefficients can be used to unify the measurement modes of different products.

#### 5.5.13 Production loss (PL)

The production loss shall be the quantity lost during production, calculated as output minus input.

NOTE Used in batch and continuous manufacturing.

#### 5.5.14 Storage and transportation loss (STL)

The storage and transportation loss shall be the quantity lost during storage and transportation, e.g. inventory lost during an inventory calculation or material lost during movement from one place to another.

NOTE Used in batch and continuous manufacturing.

#### 5.5.15 Other loss (OL)

Other loss shall be the quantity lost due to extraordinary incidents, e.g. natural disasters.

NOTE Used in batch and continuous manufacturing.

#### 5.5.16 Equipment production capacity (EPC)

Equipment production capacity is the maximum production quantity of production equipment.

NOTE Used in batch and continuous manufacturing.

## 5.6 Quality elements

### 5.6.1 Good part (GP)

A good part shall be the count of individual identifiable parts, e.g. by serialization, which meets the quality requirements.

NOTE In discrete manufacturing, a part is typically a single produced item. In batch manufacturing, a party refers to a specified material lot.

### 5.6.2 Inspected part (IP)

An inspected part shall be the count of individual identifiable parts, e.g. by serialization, which was tested against the quality requirements.

NOTE In discrete manufacturing, a part is typically a single produced item. In batch manufacturing, a party refers to a specified material lot.

### 5.6.3 Upper specification limit (USL)

An upper specification limit is a value below which performance of a product or process is acceptable. It represents the maximum acceptable value of a variable.

### 5.6.4 Lower specification limit (LSL)

A lower specification limit is a value above which performance of a product or process is acceptable. It represents the minimum acceptable value of a variable.

## 5.7 Quality elements

### 5.7.1 Arithmetic average ( $\bar{x}$ )

If, in a series of  $n$  measurements, each measured value  $x_1, \dots, x_i, \dots, x_n$  was measured independently based on repetition conditions, then  $\bar{x}$  ("x-bar") represents the arithmetic average value from these  $n$  individual values.

### 5.7.2 Average of average values ( $\bar{\bar{x}}$ )

$\bar{\bar{x}}$  is calculated from the average of single sample average values ( $\bar{x}$ ).

### 5.7.3 Estimated deviation ( $\hat{\sigma}$ )

The estimated deviation is calculated by the average value of the standard deviation from a sequence of samples with constant random inspection size, multiplied by a confidence factor depending on the random inspection size of the standard deviations.

### 5.7.4 Standard deviation ( $\sigma$ )

The standard deviation is a measure for the dispersion of measured values around its average value, and is determined from the square root of the variance.

### 5.7.5 Variance ( $\sigma^2$ )

The variance is a measure which describes how strongly a measured variable (characteristic) strews. It is calculated as the distances of the measured values from the average value are squared, summed up and divided by the number of measured values.

## 6 Description of KPIs

Tables 2 to 35 describe the KPIs for MOM. [Annex A](#) specifies the logical relation among the KPI elements. [Annex A](#) is mandatory for any implementation of this part of ISO 22400, although not all elements of [Annex A](#) are required in all implementations.

**Table 2 — Worker efficiency**

| KPI description        |                                                                                                                                                                                              |
|------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Content</b>         |                                                                                                                                                                                              |
| Name                   | Worker efficiency                                                                                                                                                                            |
| ID                     |                                                                                                                                                                                              |
| Description            | The worker efficiency considers the relationship between the actual personnel work time (APWT) related to production orders and the actual personnel attendance time (APAT) of the employee. |
| Scope                  | Worker, workgroup, work unit                                                                                                                                                                 |
| Formula                | Worker efficiency = APWT / APAT                                                                                                                                                              |
| Unit of measure        | %                                                                                                                                                                                            |
| Range                  | Min: 0%<br>Max: 100%                                                                                                                                                                         |
| Trend                  | The higher the better                                                                                                                                                                        |
| <b>Context</b>         |                                                                                                                                                                                              |
| Timing                 | Periodically                                                                                                                                                                                 |
| Audience               | Supervisor, management                                                                                                                                                                       |
| Production methodology | Discrete, batch, continuous                                                                                                                                                                  |
| Effect model diagram   | see <a href="#">Figure A.1</a>                                                                                                                                                               |
| Notes                  | When calculating worker efficiency be careful of possible double counts if the worker is working on several work units or production orders simultaneously                                   |

**Table 3 — Allocation ratio**

| KPI description        |                                                                                                                                                                                                                             |
|------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Content                |                                                                                                                                                                                                                             |
| Name                   | Allocation ratio                                                                                                                                                                                                            |
| ID                     |                                                                                                                                                                                                                             |
| Description            | The allocation ratio is the relationship of the complete actual busy time over all work units (AUBT) involved in a production order to the actual order execution time of a production order (AOET).                        |
| Scope                  | Product, production order, and plant                                                                                                                                                                                        |
| Formula                | Allocation ratio = $\sum \text{AUBT} / \text{AOET}$<br>$\sum \text{AUBT}$ = sum of the AUBT of all work units involved in a production order.                                                                               |
| Unit of measure        | %                                                                                                                                                                                                                           |
| Range                  | Min: 0%<br>Max: 100%<br>>100% is possible in case of overlapping of production operations                                                                                                                                   |
| Trend                  | The higher the better                                                                                                                                                                                                       |
| Context                |                                                                                                                                                                                                                             |
| Timing                 | Periodically                                                                                                                                                                                                                |
| Audience               | Supervisor, management                                                                                                                                                                                                      |
| Production methodology | Discrete, batch, continuous                                                                                                                                                                                                 |
| Effect model diagram   | see <a href="#">Figure A.2</a>                                                                                                                                                                                              |
| Notes                  | The allocation ratio is an index for the wait times and delay times. It shows how much of the throughput time of a production order is caused by actual processing. Too much wait and down time extend the throughput time. |

**Table 4 — Throughput rate**

| KPI description        |                                                                                                                                                                                                                                                                                                               |
|------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Content                |                                                                                                                                                                                                                                                                                                               |
| Name                   | Throughput rate                                                                                                                                                                                                                                                                                               |
| ID                     |                                                                                                                                                                                                                                                                                                               |
| Description            | Process performance in terms of produced quantity of an order (PQ) and the actual execution time of an order (AOET).                                                                                                                                                                                          |
| Scope                  | Product, production order, and plant                                                                                                                                                                                                                                                                          |
| Formula                | Throughput rate = $\text{PQ} / \text{AOET}$                                                                                                                                                                                                                                                                   |
| Unit of measure        | Quantity unit / Time unit                                                                                                                                                                                                                                                                                     |
| Range                  | Min: 0 quantity units / time unit<br>Max: product-specific                                                                                                                                                                                                                                                    |
| Trend                  | The higher the better                                                                                                                                                                                                                                                                                         |
| Context                |                                                                                                                                                                                                                                                                                                               |
| Timing                 | On demand, periodically                                                                                                                                                                                                                                                                                       |
| Audience               | Supervisor, management                                                                                                                                                                                                                                                                                        |
| Production methodology | Discrete, batch                                                                                                                                                                                                                                                                                               |
| Effect model diagram   | see <a href="#">Figure A.3</a>                                                                                                                                                                                                                                                                                |
| Notes                  | The Throughput rate is an index for the performance of a process. This performance indicator is an important index for the efficiency in production<br>The performance indicator is calculated per order after order closing. Hours or days are typical time-units to rate throughput specific for a product. |

Table 5 — Allocation efficiency

| KPI description        |                                                                                                                                                                                                                                                                                                                         |
|------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Content                |                                                                                                                                                                                                                                                                                                                         |
| Name                   | Allocation efficiency                                                                                                                                                                                                                                                                                                   |
| ID                     |                                                                                                                                                                                                                                                                                                                         |
| Description            | The allocation efficiency is the ratio between the actual allocation time of a work unit expressed as the actual unit busy time (AUBT) and the planned time for allocating the work unit expressed as the planned unit busy time (PBT).                                                                                 |
| Scope                  | Product, production order, and work unit                                                                                                                                                                                                                                                                                |
| Formula                | Allocation efficiency = AUBT / PBT                                                                                                                                                                                                                                                                                      |
| Unit of measure        | %                                                                                                                                                                                                                                                                                                                       |
| Range                  | Min: 0%<br>Max: 100%                                                                                                                                                                                                                                                                                                    |
| Trend                  | The higher the better                                                                                                                                                                                                                                                                                                   |
| Context                |                                                                                                                                                                                                                                                                                                                         |
| Timing                 | On-demand                                                                                                                                                                                                                                                                                                               |
| Audience               | Operator, supervisor, management                                                                                                                                                                                                                                                                                        |
| Production methodology | Discrete, batch, continuous                                                                                                                                                                                                                                                                                             |
| Effect model diagram   | see <a href="#">Figure A.4</a>                                                                                                                                                                                                                                                                                          |
| Notes                  | <p>The allocation efficiency indicates how strongly the planned capacity of the work unit is already used and how much planned capacity is still available</p> <p>The allocation efficiency is only affected by the actual unit idle time while the availability KPI takes the actual unit delay time into account.</p> |

Table 6 — Utilization efficiency

| KPI description        |                                                                                                                                                                                                       |
|------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Content                |                                                                                                                                                                                                       |
| Name                   | Utilization efficiency                                                                                                                                                                                |
| ID                     |                                                                                                                                                                                                       |
| Description            | The utilization efficiency is the ratio between the actual production time (APT) and the actual unit busy time (AUBT)                                                                                 |
| Scope                  | Work unit                                                                                                                                                                                             |
| Formula                | Utilization efficiency = APT / AUBT                                                                                                                                                                   |
| Unit of measure        | %                                                                                                                                                                                                     |
| Range                  | Min: 0%<br>Max: 100%                                                                                                                                                                                  |
| Trend                  | The higher the better                                                                                                                                                                                 |
| Context                |                                                                                                                                                                                                       |
| Timing                 | On-demand, periodically, real-time                                                                                                                                                                    |
| Audience               | Operator, supervisor, management                                                                                                                                                                      |
| Production methodology | Discrete, batch, continuous                                                                                                                                                                           |
| Effect model diagram   | See <a href="#">Figure A.5</a>                                                                                                                                                                        |
| Notes                  | This indicator identifies the productivity of work units. Because only the production time affects an added value which will be paid by the market, the goal should be to get a high indicator value. |

Table 7 — Overall equipment effectiveness index

| KPI description        |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Content                |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| Name                   | Overall equipment effectiveness index                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| ID                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| Description            | The OEE index represents the availability of a work unit (see <a href="#">Table 9</a> ), the effectiveness of the work unit (see <a href="#">Table 10</a> ), and the quality ratio (see <a href="#">Table 11</a> ) KPIs integrated in a single indicator.                                                                                                                                                                                                                                                                                                                                                                                            |
| Scope                  | Work unit, product, time period, product, defect types                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| Formula                | $OEE\ index = Availability * Effectiveness * Quality\ ratio$                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| Unit of measure        | %                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| Range                  | Min: 0%<br>Max: 100%                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| Trend                  | The higher, the better                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| Context                |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| Timing                 | On-demand, periodically, real-time                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| Audience               | Operator, supervisor, management                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Production methodology | Discrete, batch, continuous                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| Effect model diagram   | See <a href="#">Figure A.6</a>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| Notes                  | <p>Overall equipment effectiveness (OEE) is an indicator for the efficiency of work units, work centres and areas with several work units or an entire work centre. The OEE index forms the basis for improvements by better production information, identification of production losses, and improvement of the product quality by optimized processes.</p> <p>The calculation of OEE based on the hierarchy structure (see <a href="#">Figure 2</a>) is only useful if the characteristic of the work unit processes would be comparable. Before starting a benchmark based on the OEE index the criteria for comparability should be checked.</p> |

Table 8 — Net equipment effectiveness index

| KPI description        |                                                                                                                                                                                                                                                                                                                                                             |
|------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Content                |                                                                                                                                                                                                                                                                                                                                                             |
| Name                   | Net equipment effectiveness index                                                                                                                                                                                                                                                                                                                           |
| ID                     |                                                                                                                                                                                                                                                                                                                                                             |
| Description            | The net equipment effectiveness (NEE) index combines the ratio between actual unit processing time (AUPT) and planned busy time (PBT), the effectiveness KPI (see <a href="#">Table 10</a> ) and the quality ratio KPI (see <a href="#">Table 11</a> ) into a single indicator                                                                              |
| Scope                  | Work unit, product, time period, product, defect types                                                                                                                                                                                                                                                                                                      |
| Formula                | $NEE\ index = AUPT / PBT * Effectiveness * Quality\ ratio$                                                                                                                                                                                                                                                                                                  |
| Unit of measure        | %                                                                                                                                                                                                                                                                                                                                                           |
| Range                  | Min: 0%<br>Max: 100%                                                                                                                                                                                                                                                                                                                                        |
| Trend                  | The higher, the better                                                                                                                                                                                                                                                                                                                                      |
| Context                |                                                                                                                                                                                                                                                                                                                                                             |
| Timing                 | On-demand, periodically                                                                                                                                                                                                                                                                                                                                     |
| Audience               | Supervisor, management                                                                                                                                                                                                                                                                                                                                      |
| Production methodology | Discrete, batch, continuous                                                                                                                                                                                                                                                                                                                                 |
| Effect model diagram   | See <a href="#">Figure A.7</a>                                                                                                                                                                                                                                                                                                                              |
| Notes                  | <p>The net equipment effectiveness (NEE) index is comparable with the OEE index but it includes the setup time within a modified availability KPI that is calculated as the ratio between the actual unit processing time and the planned busy time.</p> <p>The NEE index indicates losses by work unit delays, cycle time losses and losses by rework.</p> |

Table 9 — Availability

| KPI description        |                                                                                                                                                                                                                         |
|------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Content                |                                                                                                                                                                                                                         |
| Name                   | Availability                                                                                                                                                                                                            |
| ID                     |                                                                                                                                                                                                                         |
| Description            | Availability is a ratio that shows the relation between the actual production time (APT) and the planned busy time (PBT) for a work unit.                                                                               |
| Scope                  | Work unit, product, time period, product                                                                                                                                                                                |
| Formula                | $\text{Availability} = \text{APT} / \text{PBT}$                                                                                                                                                                         |
| Unit of measure        | %                                                                                                                                                                                                                       |
| Range                  | Min: 0%<br>Max: 100%                                                                                                                                                                                                    |
| Trend                  | The higher, the better                                                                                                                                                                                                  |
| Context                |                                                                                                                                                                                                                         |
| Timing                 | On-demand, periodically                                                                                                                                                                                                 |
| Audience               | Supervisor, management                                                                                                                                                                                                  |
| Production methodology | Discrete, batch, continuous                                                                                                                                                                                             |
| Effect model diagram   | See <a href="#">Figure A.8</a>                                                                                                                                                                                          |
| Notes                  | Availability indicates how strongly the capacity of a work unit for the production is used in relation to the available capacity.<br><br>The term availability is also called degree of utilization or capacity factor. |

Table 10 — Effectiveness

| KPI description        |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
|------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Content                |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| Name                   | Effectiveness                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| ID                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| Description            | Effectiveness represents the relationship between the planned target cycle and the actual cycle expressed as the planned runtime per item (PRI) multiplied by the produced quantity (PQ) divided by the actual production time (APT).                                                                                                                                                                                                                                                                                                                                                                                                           |
| Scope                  | Work unit, work centre, area, product, time period, product                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Formula                | $\text{Effectiveness} = \text{PRI} * \text{PQ} / \text{APT}$                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| Unit of measure        | %                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| Range                  | Min: 0%<br>Max: 100%                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| Trend                  | The higher, the better                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| Context                |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| Timing                 | On-demand, periodically, real-time                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| Audience               | Operator, supervisor, management                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| Production methodology | Discrete, batch, continuous                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Effect model diagram   | See <a href="#">Figure A.9</a>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Notes                  | The effectiveness can be calculated in short periods and indicates how effective a work unit will be during the production time.<br><br>The specification uses the element planned runtime per item (PRI) also known as cycle time. This specifies how long it takes to produce a fixed quantity of produced material. Batch and continuous production methodologies typically express the expected output per time as the quantity that can be produced in a specified period of time (e.g. HL per hour). This value is reciprocal to the PRI element and can be converted into a PRI by specifying a fixed quantity of the produced material. |

Table 11 — Quality ratio

| KPI description        |                                                                                                      |
|------------------------|------------------------------------------------------------------------------------------------------|
| Content                |                                                                                                      |
| Name                   | Quality ratio                                                                                        |
| ID                     |                                                                                                      |
| Description            | The quality ratio is the relationship between the good quantity (GQ) and the produced quantity (PQ). |
| Scope                  | Work unit, work centre, area, product, time period, product, defect types                            |
| Formula                | Quality ratio = $GQ / PQ$                                                                            |
| Unit of measure        | %                                                                                                    |
| Range                  | Min: 0%<br>Max: 100%                                                                                 |
| Trend                  | The higher, the better                                                                               |
| Context                |                                                                                                      |
| Timing                 | On-demand, periodically, real-time                                                                   |
| Audience               | Operator, supervisor, management                                                                     |
| Production methodology | Discrete, batch, continuous                                                                          |
| Effect model diagram   | See <a href="#">Figure A.10</a>                                                                      |
| Notes                  | This indicator is usable as real-time indicator for the operator level.                              |

Table 12 — Setup ratio

| KPI description        |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
|------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Content                |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| Name                   | Setup ratio                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| ID                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| Description            | The setup ratio is the ratio of actual unit setup time (AUST) to actual unit processing time (AUPT). It specifies the percentage time used for setup compared to the actual time used for processing.                                                                                                                                                                                                                                                                                                                              |
| Scope                  | Work unit, product, production order                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| Formula                | Setup ratio = $AUST / AUPT$                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| Unit of measure        | %                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Range                  | Min: 0%<br>Max: 100%                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| Trend                  | The lower, the better                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| Context                |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| Timing                 | On-demand, periodically                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| Audience               | Supervisor, management                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| Production methodology | Discrete, batch, continuous                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| Effect model diagram   | See <a href="#">Figure A.11</a>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| Notes                  | <p>The setup ratio indicates the relative loss of value adding opportunity for the work unit. The higher the value of the indicator is the higher is the setup time in relation to the processing time of a production order which adds value to the product. For an enterprise a high setup ratio means a consumption of (potential) value added time.</p> <p>The setup ratio has to be considered especially when the order lot size is decreasing which may happen in a response to the demand for a flexible supply chain.</p> |

Table 13 — Technical efficiency

| KPI description        |                                                                                                                                                                                                                                                            |
|------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Content                |                                                                                                                                                                                                                                                            |
| Name                   | Technical efficiency                                                                                                                                                                                                                                       |
| ID                     |                                                                                                                                                                                                                                                            |
| Description            | The technical efficiency of a work unit is the relationship between the actual production time (APT) and the sum of the actual production time (APT) and the actual unit delay time (ADET) which includes the delays and malfunction-caused interruptions. |
| Scope                  | Work unit, product, and production order                                                                                                                                                                                                                   |
| Formula                | Technical efficiency = $APT / (APT + ADET)$                                                                                                                                                                                                                |
| Unit of measure        | %                                                                                                                                                                                                                                                          |
| Range                  | Min: 0%<br>Max: 100%                                                                                                                                                                                                                                       |
| Trend                  | The higher, the better                                                                                                                                                                                                                                     |
| Context                |                                                                                                                                                                                                                                                            |
| Timing                 | On-demand, periodically, real-time                                                                                                                                                                                                                         |
| Audience               | Operator, supervisor, management                                                                                                                                                                                                                           |
| Production methodology | Discrete, batch, continuous                                                                                                                                                                                                                                |
| Effect model diagram   | See <a href="#">Figure A.12</a>                                                                                                                                                                                                                            |
| Notes                  | The technical efficiency does not include setup time in contrast to the utilization efficiency.<br><br>100% corresponds to maximum attainable technical efficiency without malfunction-caused interruptions.                                               |

Table 14 — Production process ratio

| KPI description        |                                                                                                                                                                                                                                                                          |
|------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Content                |                                                                                                                                                                                                                                                                          |
| Name                   | Production process ratio                                                                                                                                                                                                                                                 |
| ID                     |                                                                                                                                                                                                                                                                          |
| Description            | The production process ratio specifies the relationship between the actual production time (APT) over all work units and work centres involved in a production order and the whole throughput time of a production order which is the actual order execution time (AOET) |
| Scope                  | Product, production order, and plant.                                                                                                                                                                                                                                    |
| Formula                | Production process ratio = $\sum APT / AOET$<br>$\sum APT$ = sum of the APT of all work units and work centres involved in a production order.                                                                                                                           |
| Unit of measure        | %                                                                                                                                                                                                                                                                        |
| Range                  | Min: 0%<br>Max: 100%<br><br>>100% is possible in case of overlapping of production operations                                                                                                                                                                            |
| Trend                  | The higher, the better                                                                                                                                                                                                                                                   |
| Context                |                                                                                                                                                                                                                                                                          |
| Timing                 | On-demand, periodically                                                                                                                                                                                                                                                  |
| Audience               | Supervisor, management                                                                                                                                                                                                                                                   |
| Production methodology | Discrete, batch, continuous                                                                                                                                                                                                                                              |
| Effect model diagram   | See <a href="#">Figure A.13</a>                                                                                                                                                                                                                                          |
| Notes                  | The production process ratio is an index for the efficiency of the production.<br><br>A low production process ratio is low indicates that the production orders include a lot of wait-time or idle periods instead of production time.                                  |

Table 15 — Actual to planned scrap ratio

| KPI description        |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Content                |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Name                   | Actual to planned scrap ratio                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| ID                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Description            | The actual to planned scrap ratio calculated as the scrap quantity (SQ) divided by the planned scrap quantity (PSQ) indicated how much scrap was actually produced compared with the expected (planned) value.                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| Scope                  | Work unit, product, defect type                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Formula                | Actual to planned scrap ratio = $SQ / PSQ$                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| Unit of measure        | %                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| Range                  | Min: 0%<br>Max: unlimited                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| Trend                  | The lower, the better                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| Context                |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Timing                 | On-demand, periodically, real-time                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| Audience               | Operator, supervisor, management                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| Production methodology | Discrete, batch, continuous                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| Effect model diagram   | See <a href="#">Figure A.14</a>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Notes                  | <p>The indicator is used as a short term indicator to improve production as well as a tool to control the planning value in the Level 4 applications (ERP).</p> <p>A low value indicates that the less scrap is produced than expected. This is good as a short term goal.</p> <p>On the other hand a constant low value indicates that the planned scrap ratio, which is typically specified in a Level 4 system (ERP), is too high. This might result in unnecessary material allocation.</p> <p>The planned scrap quantity (which can be expected) is typically already specified in the ERP system in order to ensure the necessary material allocation.</p> |

Table 16 — First pass yield

| KPI description        |                                                                                                                                                                                                                                                                                                                           |
|------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Content                |                                                                                                                                                                                                                                                                                                                           |
| Name                   | First pass yield                                                                                                                                                                                                                                                                                                          |
| ID                     |                                                                                                                                                                                                                                                                                                                           |
| Description            | The first pass yield (FPY) designates the percentage of products, which full fill the quality requirements in the first process run without reworks (good parts). It is expressed as the ratio between good parts (GP) and inspected parts (IP).                                                                          |
| Scope                  | Work unit, product, production order, and defect types                                                                                                                                                                                                                                                                    |
| Formula                | $FPY = GP / IP$                                                                                                                                                                                                                                                                                                           |
| Unit of measure        | %                                                                                                                                                                                                                                                                                                                         |
| Range                  | Min: 0%<br>Max: 100%                                                                                                                                                                                                                                                                                                      |
| Trend                  | The higher, the better                                                                                                                                                                                                                                                                                                    |
| Context                |                                                                                                                                                                                                                                                                                                                           |
| Timing                 | On-demand, periodically, real-time                                                                                                                                                                                                                                                                                        |
| Audience               | Operator, supervisor, management                                                                                                                                                                                                                                                                                          |
| Production methodology | Discrete, batch                                                                                                                                                                                                                                                                                                           |
| Effect model diagram   | See <a href="#">Figure A.15</a>                                                                                                                                                                                                                                                                                           |
| Notes                  | For identifying the first pass it is necessary to label each part with an identification number (serial number). See <a href="#">5.6.1</a> for the explanation how the concept of a part is used in discrete and batch manufacturing methodologies.<br><br>The FPY stands in reciprocal relationship to the defect costs. |

Table 17 — Scrap ratio

| KPI description        |                                                                                             |
|------------------------|---------------------------------------------------------------------------------------------|
| Content                |                                                                                             |
| Name                   | Scrap ratio                                                                                 |
| ID                     |                                                                                             |
| Description            | The scrap ratio is the relationship between scrap quantity (SQ) and produced quantity (PQ). |
| Scope                  | Work unit, product, production order, and defect type.                                      |
| Formula                | $Scrap\ ratio = SQ / PQ$                                                                    |
| Unit of measure        | %                                                                                           |
| Range                  | Min: 0%<br>Max: 100%                                                                        |
| Trend                  | The lower, the better                                                                       |
| Context                |                                                                                             |
| Timing                 | On-demand, periodically, real-time                                                          |
| Audience               | Operator, supervisor, management                                                            |
| Production methodology | Discrete, batch, continuous                                                                 |
| Effect model diagram   | See <a href="#">Figure A.16</a>                                                             |
| Notes                  | The scrap ratio will be also used for the commercial rating.                                |

Table 18 — Rework ratio

| KPI description        |                                                                                               |
|------------------------|-----------------------------------------------------------------------------------------------|
| Content                |                                                                                               |
| Name                   | Rework ratio                                                                                  |
| ID                     |                                                                                               |
| Description            | The rework ratio is the relationship between rework quantity (RQ) and produced quantity (PQ). |
| Scope                  | Work unit, product, production order, and defect type.                                        |
| Formula                | $\text{Rework ratio} = \text{RQ} / \text{PQ}$                                                 |
| Unit of measure        | %                                                                                             |
| Range                  | Min: 0%<br>Max: 100%                                                                          |
| Trend                  | The lower, the better                                                                         |
| Context                |                                                                                               |
| Timing                 | On-demand, periodically, real-time                                                            |
| Audience               | Operator, supervisor, management                                                              |
| Production methodology | Discrete, batch, continuous                                                                   |
| Effect model diagram   | See <a href="#">Figure A.17</a>                                                               |
| Notes                  | The rework ratio will be also used for the commercial rating.                                 |

Table 19 — Fall off ratio

| KPI description        |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Content                |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| Name                   | Fall off ratio                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| ID                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| Description            | The fall off ratio considers the fall off quantity for a specific production operation in relation to the produced quantity in the first operation (PQ). The fall off quantity is calculated as the produced quantity (PQ) on the first production order sequence minus the good quantity (GQ) on the current production order sequence                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| Scope                  | Production order sequence, product                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| Formula                | Fall off ratio of the current production order sequence =<br>$\frac{(PQ \text{ of first production order sequence} - GQ \text{ of current production order sequence})}{PQ \text{ of first production order sequence}}$                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| Unit of measure        | %                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| Range                  | Min: 0%<br>Max: 100%                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| Trend                  | The lower, the better                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| Context                |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| Timing                 | On-demand                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| Audience               | Operator, supervisor, management                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| Production methodology | Discrete, batch                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| Effect model diagram   | See <a href="#">Figure A.18</a>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| Notes                  | <p>The KPI is typically used in a concatenated processes, where a product (e.g. mother-board) is produced in the first manufacturing step and but may have scrap in the further operations.</p> <p>The fall of ratio is usable as indicator after the order sequence will be finished.</p> <p>The mother products can be serialized in the first manufacturing step.</p> <p>The indicator has an influence on the planning quality (planned scrap) and on the production quality per manufacturing step as well as the material wastage.</p> <p>In process industry, e.g. oil refining and chemical industry usually use “consumed material” as denominator to calculate the related KPIs. The “finished goods ratio” (see <a href="#">Table 26</a>) can be used to calculate the quality.</p> |

Table 20 — Machine capability index

| KPI description        |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Content                |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| Name                   | Machine capability index ( $C_m$ )                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| ID                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| Description            | The machine capability index ( $C_m$ ) is the relationship between the dispersion of a process and the specification limits. The method compares the range between the specification limits (USL, LSL) and the $6\sigma$ dispersion of a series of measurements for a specific characteristic.                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| Scope                  | Product, work unit, characteristic, and series of measurements                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| Formula                | $C_m = (USL - LSL) / (6 * \sigma)$                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| Unit of measure        | N/A                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| Range                  | Min: $>0$ , $C_m$ approaches 0 if $\sigma$ approaches infinite.<br>Max: infinite                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| Trend                  | The higher, the better                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| Context                |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| Timing                 | On-demand, periodically                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| Audience               | Operator, supervisor, management                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| Production methodology | Discrete, batch, continuous                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| Effect model diagram   | See <a href="#">Figure A.19</a>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| Notes                  | <p>The machine capability index (<math>C_m</math>) indicates the ability of a machine or a work mechanism to produce the specified quality for a specific characteristic. The evaluation should be executed if possible by exclusion of other process influences. The method is used mainly for the approval of machines in combination with products</p> <p><math>C_m</math> is a characteristic value of a short time capability investigation. Usually the normal distribution will be the statistical method.</p> <p>The machine capability value is usually specified by customer requirements. Typical value is <math>C_m &gt; 1,67</math>.</p> <p>The value can be used for characteristic with upper and lower specification limits only.</p> |

Table 21 — Critical machine capability index

| KPI description        |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Content                |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| Name                   | Critical machine capability index ( $C_{mk}$ )                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| ID                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| Description            | The critical machine capability index ( $C_{mk}$ ) is the relationship between the dispersion of a process and the upper or lower specification limit (USL, LSL) and its averages ( $\bar{x}$ ). The method compares the range between the upper or lower specification limit and its averages and the $3\sigma$ dispersion of the series of measurements for a specific characteristic.                                                                                                                                                                                                                                                                                          |
| Scope                  | Product, work unit, characteristic, and series of measurements                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| Formula                | $C_{mku} = (USL - \bar{x}) / (3 * \sigma) ; C_{mkl} = (\bar{x} - LSL) / (3 * \sigma)$ $C_{mk} = \text{Min} (C_{mku}, C_{mkl})$                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| Unit of measure        | N/A                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| Range                  | Min: $>0$ , $C_{mk}$ approaches 0 if $\sigma$ approaches infinite.<br>Max: infinite                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| Trend                  | The higher, the better                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| Context                |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| Timing                 | On-demand, periodically                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| Audience               | Operator, supervisor, management                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Production methodology | Discrete, batch, continuous                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| Effect model diagram   | See <a href="#">Figure A.19</a>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| Notes                  | <p>The critical machine capability index (<math>C_{mk}</math>) indicates the ability of a machine or a work mechanism to produce the specified quality for a specific characteristic. The evaluation should be executed if possible by exclusion of other process influences. The method is used mainly for the approval of machines in combination with products</p> <p><math>C_{mk}</math> is a characteristic value of a short time capability investigation. Usually the normal distribution will be the statistical method.</p> <p>The critical machine capability target is usually specified by customer requirements. Typical value is <math>C_{mk} &gt; 1,67</math>.</p> |

Table 22 — Process capability index

| KPI description        |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
|------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Content                |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| Name                   | Process capability index ( $C_p$ )                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| ID                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| Description            | The process capability index ( $C_p$ ) is the relationship between the dispersion of a process and the specification limits. The method compares the range between the specification limits (USL, LSL) and the $6\sigma$ process dispersion for a specific characteristic.                                                                                                                                                                                                                                                                                                 |
| Scope                  | Product, work unit, characteristic, and series of measurements                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| Formula                | $C_p = (USL - LSL) / (6 * \hat{\sigma})$                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| Unit of measure        | N/A                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| Range                  | Min: $>0$ , $C_p$ approaches 0 if $\hat{\sigma}$ approaches infinite.<br>Max: infinite                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Trend                  | The higher, the better                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Context                |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| Timing                 | On-demand, periodically, real-time                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| Audience               | Operator, supervisor, management                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| Production methodology | Discrete, batch, continuous                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| Effect model diagram   | See <a href="#">Figure A.20</a>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| Notes                  | <p>The process capability index should indicate based on statistic methods as soon as possible if the production process will produce the product according to the committed quality specifications.</p> <p>The measurement has to be done in regular time steps or after specified quantity intervals with small samples (1-25).</p> <p>A process is usually called capable if the <math>C_p &gt; 1,33</math>.</p> <p><math>\hat{\sigma}</math> will be calculated based on a confidence factor from the standard deviation, depending on the inspection sample size.</p> |

Table 23 — Critical process capability index

| KPI description        |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
|------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Content                |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| Name                   | Critical process capability index ( $C_{pk}$ )                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| ID                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| Description            | The critical process capability index ( $C_{pk}$ ) is the relationship between the dispersion of a process and the upper or lower specification limit (USL, LSL) and its average of averages ( $\bar{x}$ ). The method compares the range between the upper or lower specification limit and its averages and the $3\sigma$ process dispersion.                                                                                                                                                                                                                                    |
| Scope                  | Product, work unit, characteristic, and series of measurements                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Formula                | $C_{pku} = (USL - \bar{x}) / (3 * \hat{\sigma})$ ; $C_{pkl} = (\bar{x} - LSL) / (3 * \hat{\sigma})$<br>$C_{pk} = \text{Min} (C_{pku}, C_{pkl})$                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| Unit of measure        | N/A                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| Range                  | Min: $>0$ , $C_{pk}$ approaches 0 if $\hat{\sigma}$ approaches infinite.<br>Max: infinite                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| Trend                  | The higher, the better                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| Context                |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| Timing                 | On-demand, periodically, real-time                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| Audience               | Operator, supervisor, management                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| Production methodology | Discrete, batch, continuous                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| Effect model diagram   | See <a href="#">Figure A.20</a>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| Notes                  | <p>The critical process capability index should indicate based on statistic methods as soon as possible if the production process will produce the product according to the committed quality specifications.</p> <p>The measurement has to be done in regular time steps or after specified quantity intervals with small samples (1-25).</p> <p>A process is usually called capable if <math>C_{pk} &gt; 1,33</math>.</p> <p><math>\hat{\sigma}</math> will be calculated based on a confidence factor from the standard deviation, depending on the inspection sample size.</p> |

Table 24 — Comprehensive energy consumption

| KPI description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Content                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| Name                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | Comprehensive energy consumption                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| ID                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | Comprehensive energy consumption is the ratio between all the energy consumed in a production cycle and the produced quantity (PQ)                                                                                                                                                                                                                                                                                                                                                                                          |
| Scope                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | Product, equipment                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| Formula                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | $e = E/PQ = (\sum Mi \cdot Ri + Q) / PQ$ <p>where</p> <p>e: unit energy consumption of an equipment,</p> <p>E: comprehensive energy consumption,</p> <p>Mi: actual consumption of certain kind of energy (kilowatt hour)</p> <p>Ri<sup>a</sup>: conversion coefficient of certain kind of energy</p> <p>Q: algebraic sum of effective energy exchanges with the environment</p>                                                                                                                                             |
| Unit of measure                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | Joule / (number of units) or amount                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| Range                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | <p>Min: 0 Joule / (number of units) or amount</p> <p>Max: product specific</p>                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| Trend                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | The lower, the better                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| Context                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| Timing                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | On-demand, periodically                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Audience                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | Operator, supervisor, management                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| Production methodology                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | Discrete, batch, continuous                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| Effect model diagram                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | See <a href="#">Figure A.21</a>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| Notes                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | <p>Indicators to measure the consumption of energy are used by enterprises for energy savings, environmental protection, and cost reduction. Even though energy can be considered as a form of raw material, it helps to evaluate the consumption of energy using distinct indicators.</p> <p>Energy consumption is an important factor impacting the production costs and company profits.</p> <p>National laws and regulation have to be considered and may require additional KPI calculation on energy consumption.</p> |
| <p><sup>a</sup> The conversion coefficient Ri is used to unify the measurement modes of different energy types, by which a certain kind of energy can be changed into standard quantity, e.g. the unit of Ri for water is standard quantity per ton of refrigeration; for electricity the unit of Ri is standard quantity per kilowatt-hour. The comprehensive energy consumption indicator is used with a collection of standard quantity conversion tables, which are unique for different industries</p> |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |

Table 25 — Inventory turns

| KPI description                                                                                                                                                                                                |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Content                                                                                                                                                                                                        |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Name                                                                                                                                                                                                           | Inventory turns                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| ID                                                                                                                                                                                                             |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Description                                                                                                                                                                                                    | Inventory turns is specified as the ratio of the throughput (TH) to average inventory. It is commonly used to measure the efficiency of inventory, and represents the average number of times the inventory stock is replenished or turned over.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| Scope                                                                                                                                                                                                          | Stock                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| Formula                                                                                                                                                                                                        | Inventory turns = TH / average inventory                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| Unit of measure                                                                                                                                                                                                | Time unit                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| Range                                                                                                                                                                                                          | Min: 0 time unit<br>Max: product specific                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| Trend                                                                                                                                                                                                          | The higher, the better                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| Context                                                                                                                                                                                                        |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Timing                                                                                                                                                                                                         | On-demand, periodically                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| Audience                                                                                                                                                                                                       | Operator, supervisor, management                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| Production methodology                                                                                                                                                                                         | Continuous<br>(Inventory turns is typically a Level 4 KPI in discrete and batch manufacturing)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| Effect model diagram                                                                                                                                                                                           | See <a href="#">Figure A.22</a>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Notes                                                                                                                                                                                                          | <p>The specification of indicators for inventory is quite important in the process industry where production is organized based on inventory. How long the product is stored may affect the quality and cost.</p> <p>The four types of inventory are described below.</p> <p>1) Raw materials (RM): The materials that are changed into finished goods through the production.</p> <p>2) Consumables (CI): The materials of which the quantity or quality is changed during the production, e.g. a catalyst. (Consumables are specified in detail in IEC 62264-1.)</p> <p>3) Crib and finished goods inventory (FGI): The stock point at the end of a routing is either a crib inventory location or finished goods inventory. Crib inventories are used to gather different parts within the plant before further processing or assembly. For instance, a routing to produce gear assemblies may be fed by several crib inventories containing gears, housings, crankshafts and so on. Finished goods inventory is where end items are held prior to shipping to the customer.</p> <p>4) Work in process inventory (WIP)<sup>a</sup>: The inventory between the start and end points of a product routing is called Work in process (WIP). Since routing begin and end at stock points, WIP is the entire product between, but not including, the ending stock points. Although in colloquial use WIP often includes crib inventories, a distinction is made between crib inventory and WIP for clarification.</p> |
| <p><sup>a</sup> WIP inventory as specified in VDMA 66412-1 is that material which is assigned to the production order and is not for the stock. This inventory is normally located in the production area.</p> |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |

Table 26 — Finished goods ratio

| KPI description        |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Content                |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Name                   | Finished goods ratio                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| ID                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Description            | The finished goods ratio is the ratio of the good quantity produced (GQ) to the consumed material (CM).                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| Scope                  | work unit, product, defect types                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| Formula                | Finished goods ratio = GQ / CM                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| Unit of measure        | %                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| Range                  | Min: 0%<br>Max: 100%                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| Trend                  | The higher, the better                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| Context                |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Timing                 | On-demand, periodically, real-time                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| Audience               | Operator, supervisor, management                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| Production methodology | Batch, continuous                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| Effect model diagram   | See <a href="#">Figure A.23</a>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Notes                  | In the process industry, e.g. oil refining and chemicals, “consumed material” is usually used in the denominator to calculate the related KPIs. In some industrial processes, input can be less than the output because of losses during processing (i.e. the sum of losses and product equals the sum of consumed material on a mass basis). However, some processes measure consumed material and/or produced product on some basis other than mass, such that the numerical value of produced product may be greater than the numerical value of consumed material. This KPI range value assumes a mass basis for quantities. Many chemical and physical changes occur during production, and product yield has fluctuation and uncertainty. It is therefore difficult to calculate and measure the output as required for the quality ratio (see <a href="#">Table 11</a> ). |

Table 27 — Integrated goods ratio

| KPI description        |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Content                |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| Name                   | Integrated goods ratio                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| ID                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| Description            | The integrated goods ratio is the relationship of the produced quantity of integrated goods (IGQ) to the consumed material (CM).                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| Scope                  | Work unit, defect type                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| Formula                | Integrated goods ratio = IGQ / CM                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| Unit of measure        | %                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| Range                  | Min: 0%<br>Max: 100%                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| Trend                  | The higher, the better                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| Context                |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| Timing                 | On-demand, periodically, real-time                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| Audience               | Operator, supervisor, management                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| Production methodology | Batch, continuous                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| Effect model diagram   | See <a href="#">Figure A.24</a>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| Notes                  | <p>Products in the process industry are closely related to each other since partial amounts of a specific quantity of finished goods at a particular grade or quality can be converted to another product with a different grade or quality. For example, if the quality of a product has not reached a higher level "A," it can be sold as a product with a lower quality level "B." Then the ratio of products of level "B" increases as the ratio of products of level "A" declines. Therefore, KPIs are calculated from the view of all related products, e.g. the level "A" and level "B" products mentioned above. In this case, the KPI "integrated goods ratio" is used instead of "finished goods ratio".</p> <p>Since "integrated goods" represents the quantity of all products during production, it is important to make sure that all products are measured in the same unit, or can be converted to the same unit. A list of conversion coefficients can be used to unify the measurement modes of different products.</p> |

Table 28 — Production loss ratio

| KPI description        |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
|------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Content                |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| Name                   | Production loss ratio                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| ID                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| Description            | The production loss ratio is the relationship of quantity lost during production (PL) to the consumed material (QM).                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| Scope                  | Work unit, defect type                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Formula                | Production loss ratio = $PL / CM$                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| Unit of measure        | %                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| Range                  | Min: 0%<br>Max: 100%                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| Trend                  | The higher, the better                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Context                |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| Timing                 | On-demand, periodically, real-time                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| Audience               | Supervisor, management                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Production methodology | Batch, continuous                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| Effect model diagram   | See <a href="#">Figure A.25</a>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| Notes                  | <p>Typically scrap and reworking are not measured in the process industries. Instead, the focus is on loss, where:</p> <ul style="list-style-type: none"> <li>Integrated goods ratio + Loss ratio = 1</li> <li>Loss ratio = Production loss ratio + Storage and</li> <li>Transportation loss ratio + Other loss ratio</li> </ul> <p>For these calculations the following apply.</p> <ul style="list-style-type: none"> <li>Production loss: for quantity lost during production, calculate as output minus input.</li> <li>Storage and transportation loss: the quantity lost during storage and transportation, e.g. inventory lost during an inventory calculation or material lost during movement from one place to another.</li> <li>Other loss: the quantity lost due to extraordinary incidents, e.g. natural disasters.</li> </ul> |

Table 29 — Storage and transportation loss ratio

| KPI description        |                                                                                                                                                              |
|------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Content                |                                                                                                                                                              |
| Name                   | Storage and transportation loss ratio                                                                                                                        |
| ID                     |                                                                                                                                                              |
| Description            | The storage and transportation loss ratio is the relationship of the quantity of loss during storage and transportation (STL) to the consumed material (CM). |
| Scope                  | Work unit, defect type                                                                                                                                       |
| Formula                | Storage and transportation loss ratio = STL / CM                                                                                                             |
| Unit of measure        | %                                                                                                                                                            |
| Range                  | Min: 0%<br>Max: 100%                                                                                                                                         |
| Trend                  | The higher, the better                                                                                                                                       |
| Context                |                                                                                                                                                              |
| Timing                 | On-demand, periodically, real-time                                                                                                                           |
| Audience               | Operator, supervisor, management                                                                                                                             |
| Production methodology | Batch, continuous                                                                                                                                            |
| Effect model diagram   | See <a href="#">Figure A.26</a>                                                                                                                              |
| Notes                  | See also production loss ratio (see <a href="#">Table 28</a> )                                                                                               |

Table 30 — Other loss ratio

| KPI description        |                                                                                                                                                                        |
|------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Content                |                                                                                                                                                                        |
| Name                   | Other loss ratio                                                                                                                                                       |
| ID                     |                                                                                                                                                                        |
| Description            | The other loss ratio is the relationship of the quantity of loss not related to production, storage or transportation (OL) to the consumed material (CM).              |
| Scope                  | Work unit, defect type                                                                                                                                                 |
| Formula                | Other loss ratio = OL / CM                                                                                                                                             |
| Unit of measure        | %                                                                                                                                                                      |
| Range                  | Min: 0%<br>Max: 100%                                                                                                                                                   |
| Trend                  | The higher, the better                                                                                                                                                 |
| Context                |                                                                                                                                                                        |
| Timing                 | On-demand, periodically, real-time                                                                                                                                     |
| Audience               | Operator, supervisor, management                                                                                                                                       |
| Production methodology | Batch, continuous                                                                                                                                                      |
| Effect model diagram   | See <a href="#">Figure A.27</a>                                                                                                                                        |
| Notes                  | The other loss ratio evaluates loss that is not occurred during production, storage, or transportation. See also production loss ratio (see <a href="#">Table 28</a> ) |

Table 31 — Equipment load ratio

| KPI description        |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
|------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Content                |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| Name                   | Equipment load ratio                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| ID                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| Description            | <p>The equipment loss ratio considers the produced quantity (PQ) in relation to the equipment production capacity (EPC).</p> <p>Equipment production capacity is either “rated” or “maximum:”</p> <ul style="list-style-type: none"> <li>Maximum equipment production capacity: the upper limit value of production demarcated before the equipment delivery.</li> <li>Rated equipment production capacity: the upper limit value of production promised the stable operation of the equipment.</li> </ul>                                                                                                                                                                                                                                                                  |
| Scope                  | Work unit                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| Formula                | Equipment load ratio = $PQ / EPC$ .                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| Unit of measure        | %                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| Range                  | <p>Min: 0%</p> <p>Max: 100%, &gt; 100% if more is produced than specified as the rated equipment production capacity.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| Trend                  | <p>The higher, the better.</p> <p>A value &gt; 100% may indicate a quality issue (see notes)</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| Context                |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| Timing                 | On-demand, periodically                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Audience               | Supervisor, management                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| Production methodology | Batch, continuous                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| Effect model diagram   | See <a href="#">Figure A.28</a>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| Notes                  | <p>Production capacity and the load rate of equipment are important indicators in a manufacturing enterprise.</p> <p>The equipment load ratio is an indicator to reflect the production state of equipment and production efficiency. It helps to reflect the technical performance and utilization of equipment and by researching the usage of equipment. The value of equipment load rate impacts the production costs and ultimately the profit level.</p> <p>A value &gt; 100% may indicate an issue as is possible to impact the security and reliability of equipment when the produced quantity is above the rated equipment production capacity. There is also a lower limit of equipment load rate for some equipment, below which it cannot produce anymore.</p> |

Table 32 — Mean operating time between failures

| KPI description        |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Content                |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| Name                   | Mean operating time between failures (MTBF)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| ID                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| Description            | The mean operation time between failures is calculated as the mean of all time between failure measures (TBF) for a work unit for all failure instances (FE).                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| Scope                  | Work unit                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| Formula                | $MTBF = \frac{\sum_{i=1}^{FE} TBF_i}{FE + 1}$                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| Unit of measure        | Time unit                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| Range                  | Min: 0<br>Max: infinite                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| Trend                  | The higher, the better                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Context                |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| Timing                 | On-demand, periodically                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| Audience               | Supervisor, management                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Production methodology | Discrete, batch, continuous                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| Effect model diagram   | See <a href="#">Figure A.29</a>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| Notes                  | <p>Mean operating time between failures (MTBF) is an indicator of expected system reliability calculated on a statistical basis from the known failure rates of various components of the work unit.</p> <p>It represents the expectation of the operating time between failures (see IEC 60050-191). It is a statistical approximation of how long a work unit should last before failure.</p> <p>MTBF numbers are usually stated in terms of hours.</p> <p>The indicator is calculated in each work unit. Every time a failure happens, a new TBF is obtained to calculate the MTBF.</p> <p>The MTBF is the sum of MTTR and MTTF.</p> |

Table 33 — Mean time to failure

| KPI description        |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Content                |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| Name                   | Mean time to failure (MTTF)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| ID                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| Description            | The mean time to failure is calculated as the mean of all time to failure measures (TTF) for a work unit for all failure instances (FE).                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| Scope                  | Work unit                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| Formula                | $MTTF = \frac{\sum_{i=1}^{FE} TTF_i}{FE + 1}$                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Unit of measure        | Time unit                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| Range                  | Min: 0<br>Max: infinite                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| Trend                  | The higher, the better                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| Context                |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| Timing                 | On-demand, periodically                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| Audience               | Supervisor, management                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| Production methodology | Discrete, batch, continuous                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| Effect model diagram   | See <a href="#">Figure A.30</a>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| Notes                  | <p>Mean time to failure (MTTF) is an indicator of expected system reliability calculated on a statistical basis from the known failure rates of various components of the work unit.</p> <p>It represents the expectation of the time to failure (see IEC 60050-191).</p> <p>MTTF is used for both non repaired items and repairable items.</p> <p>It is equivalent to MTBF in case of a non-repairable work unit.</p> <p>MTTF numbers are usually stated in terms of hours.</p> <p>The indicator is calculated in each work unit. Every time a failure happens, a new TTF is obtained to calculate the MTTF.</p> |

**Table 34 — Mean time to repair**

| KPI description        |                                                                                                                                                                                                                                                                                                                                                                                                         |
|------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Content                |                                                                                                                                                                                                                                                                                                                                                                                                         |
| Name                   | Mean time to repair (MTTR)                                                                                                                                                                                                                                                                                                                                                                              |
| ID                     |                                                                                                                                                                                                                                                                                                                                                                                                         |
| Description            | <p>Mean time to repair (MTTR) is the average time that an item required to restore a failed component in a work unit.</p> <p>The mean time to repair is calculated as the mean of all time to repair measures (TTR) for a work unit for all failure events (FE).</p>                                                                                                                                    |
| Scope                  | Work unit                                                                                                                                                                                                                                                                                                                                                                                               |
| Formula                | $MTTR = \frac{\sum_{i=1}^{FE} TTR_i}{FE + 1}$                                                                                                                                                                                                                                                                                                                                                           |
| Unit of measure        | Time unit                                                                                                                                                                                                                                                                                                                                                                                               |
| Range                  | <p>Min: 0</p> <p>Max: infinite</p>                                                                                                                                                                                                                                                                                                                                                                      |
| Trend                  | The higher, the better                                                                                                                                                                                                                                                                                                                                                                                  |
| Context                |                                                                                                                                                                                                                                                                                                                                                                                                         |
| Timing                 | On-demand, periodically                                                                                                                                                                                                                                                                                                                                                                                 |
| Audience               | Supervisor, management                                                                                                                                                                                                                                                                                                                                                                                  |
| Production methodology | Discrete, batch, continuous                                                                                                                                                                                                                                                                                                                                                                             |
| Effect model diagram   | See <a href="#">Figure A.31</a>                                                                                                                                                                                                                                                                                                                                                                         |
| Notes                  | <p>Mean time to repair (MTTR) is the average time that an item required to restore a failed component in a work unit. It represents the expectation of the time to repair (see IEC 60050-191).</p> <p>MTTR numbers are usually stated in terms of hours.</p> <p>The indicator is calculated in each work unit. Every time a failure has been restored, a new TTR is obtained to calculate the MTTR.</p> |

Table 35 — Corrective maintenance ratio

| KPI description        |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Content                |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| Name                   | Corrective maintenance ratio                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| ID                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| Description            | The corrective maintenance ratio considers the corrective maintenance time (CMT) in relation to the total maintenance expressed as the sum of corrective maintenance time (CMT) and planned maintenance time (PMT).                                                                                                                                                                                                                                                                                                                                     |
| Scope                  | Work unit                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| Formula                | $\text{Corrective maintenance ratio} = \text{CMT} / (\text{CMT} + \text{PMT})$                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| Unit of measure        | %                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| Range                  | Min: 0%<br>Max: 100%                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| Trend                  | The lower, the better                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| Context                |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| Timing                 | On-demand, periodically                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| Audience               | Supervisor, management                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Production methodology | Discrete, batch, continuous                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| Effect model diagram   | See <a href="#">Figure A.32</a>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| Notes                  | <p>The corrective maintenance ratio reveals the magnitude of corrective tasks within all maintenance activities performed in a work unit. This ratio shows the lack of system reliability and should be minimized.</p> <p>This ratio gives the idea of the time spent in corrective tasks on work units compared with the whole maintenance time.</p> <p>The lower the ratio the better.</p> <p>It should be remarked that excessive preventive maintenance would have the same effect on the ratio by increasing the overall maintenance function.</p> |

## 7 Conformance

To be compliant with the requirements of this part of ISO 22400, the KPI elements of a KPI shall conform to the relevant specification in [Clause 5](#) and the KPI shall conform to the description in [Clause 6](#).

## **Annex A** (normative)

### **Effect models**

#### **A.1 Parameter-indicator matrix**

[Table A.1](#) provides a parameter-indicator matrix.

**Table A.1 — Parameter-indicator matrix**

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|                        |                                                       | Key Performance Indicators |                  |                 |                       |                        |           |           |              |               |               |             |                      |                          |                               |                  |             |              |               |                          |                                   |
|------------------------|-------------------------------------------------------|----------------------------|------------------|-----------------|-----------------------|------------------------|-----------|-----------|--------------|---------------|---------------|-------------|----------------------|--------------------------|-------------------------------|------------------|-------------|--------------|---------------|--------------------------|-----------------------------------|
| Planned time           | Planned busy time (PBT)                               | Worker efficiency          | Allocation ratio | Throughput rate | Allocation efficiency | Utilisation efficiency | OEE-Index | NEE-Index | Availability | Effectiveness | Quality ratio | Set up rate | Technical efficiency | Production process ratio | Actual to planned scrap ratio | First pass yield | Scrap ratio | Rework ratio | Fail-off rate | Machine capability index | Critical machine capability index |
|                        |                                                       |                            |                  |                 |                       |                        |           |           |              |               |               |             |                      |                          |                               |                  |             |              |               |                          |                                   |
| Real time              | Planned run time per unit (PRTU)                      |                            |                  |                 |                       |                        |           |           |              |               |               |             |                      |                          |                               |                  |             |              |               |                          |                                   |
|                        | Actual personnel work time (APWT)                     |                            |                  |                 |                       |                        |           |           |              |               |               |             |                      |                          |                               |                  |             |              |               |                          |                                   |
|                        | Actual unit processing time (AUP)                     |                            |                  |                 |                       |                        |           |           |              |               |               |             |                      |                          |                               |                  |             |              |               |                          |                                   |
|                        | Actual unit busy time (AUBT)                          |                            |                  |                 |                       |                        |           |           |              |               |               |             |                      |                          |                               |                  |             |              |               |                          |                                   |
|                        | Actual order execution time (AOET)                    |                            |                  |                 |                       |                        |           |           |              |               |               |             |                      |                          |                               |                  |             |              |               |                          |                                   |
|                        | Actual personnel attendance time (APAT)               |                            |                  |                 |                       |                        |           |           |              |               |               |             |                      |                          |                               |                  |             |              |               |                          |                                   |
|                        | Actual production time (PT)                           |                            |                  |                 |                       |                        |           |           |              |               |               |             |                      |                          |                               |                  |             |              |               |                          |                                   |
|                        | Actual unit delay time (DET)                          |                            |                  |                 |                       |                        |           |           |              |               |               |             |                      |                          |                               |                  |             |              |               |                          |                                   |
|                        | Actual unit setup time (AUST)                         |                            |                  |                 |                       |                        |           |           |              |               |               |             |                      |                          |                               |                  |             |              |               |                          |                                   |
|                        | Scrap quantity (SQ)                                   |                            |                  |                 |                       |                        |           |           |              |               |               |             |                      |                          |                               |                  |             |              |               |                          |                                   |
| Logistical quantities  | Planned scrap quantity (PSQ)                          |                            |                  |                 |                       |                        |           |           |              |               |               |             |                      |                          |                               |                  |             |              |               |                          |                                   |
|                        | Good quantity (GQ)                                    |                            |                  |                 |                       |                        |           |           |              |               |               |             |                      |                          |                               |                  |             |              |               |                          |                                   |
|                        | Rework quantity (RQ)                                  |                            |                  |                 |                       |                        |           |           |              |               |               |             |                      |                          |                               |                  |             |              |               |                          |                                   |
|                        | Produced quantity (PQ)                                |                            |                  |                 |                       |                        |           |           |              |               |               |             |                      |                          |                               |                  |             |              |               |                          |                                   |
|                        | Produced quantity (PQ) in the first operation process |                            |                  |                 |                       |                        |           |           |              |               |               |             |                      |                          |                               |                  |             |              |               |                          |                                   |
|                        | Good part (GP)                                        |                            |                  |                 |                       |                        |           |           |              |               |               |             |                      |                          |                               |                  |             |              |               |                          |                                   |
| Quality numbers        | Inspected part (IP)                                   |                            |                  |                 |                       |                        |           |           |              |               |               |             |                      |                          |                               |                  |             |              |               |                          |                                   |
|                        | Average of averages                                   |                            |                  |                 |                       |                        |           |           |              |               |               |             |                      |                          |                               |                  |             |              |               |                          |                                   |
|                        | Upper specification limit (USL)                       |                            |                  |                 |                       |                        |           |           |              |               |               |             |                      |                          |                               |                  |             |              |               |                          |                                   |
|                        | Standard deviation ( $\sigma$ )                       |                            |                  |                 |                       |                        |           |           |              |               |               |             |                      |                          |                               |                  |             |              |               |                          |                                   |
|                        | Lower specification limit (LSL)                       |                            |                  |                 |                       |                        |           |           |              |               |               |             |                      |                          |                               |                  |             |              |               |                          |                                   |
|                        | Estimated deviation                                   |                            |                  |                 |                       |                        |           |           |              |               |               |             |                      |                          |                               |                  |             |              |               |                          |                                   |
| Performance indicators | Availability                                          |                            |                  |                 |                       |                        |           |           |              |               |               |             |                      |                          |                               |                  |             |              |               |                          |                                   |
|                        | Effectiveness                                         |                            |                  |                 |                       |                        |           |           |              |               |               |             |                      |                          |                               |                  |             |              |               |                          |                                   |
|                        | Quality rate                                          |                            |                  |                 |                       |                        |           |           |              |               |               |             |                      |                          |                               |                  |             |              |               |                          |                                   |
| Maintenance terms      | Time to failure                                       |                            |                  |                 |                       |                        |           |           |              |               |               |             |                      |                          |                               |                  |             |              |               |                          |                                   |
|                        | Operating time between failures                       |                            |                  |                 |                       |                        |           |           |              |               |               |             |                      |                          |                               |                  |             |              |               |                          |                                   |
|                        | Time to repair                                        |                            |                  |                 |                       |                        |           |           |              |               |               |             |                      |                          |                               |                  |             |              |               |                          |                                   |
|                        | Failure event                                         |                            |                  |                 |                       |                        |           |           |              |               |               |             |                      |                          |                               |                  |             |              |               |                          |                                   |
|                        | Corrective maintenance time                           |                            |                  |                 |                       |                        |           |           |              |               |               |             |                      |                          |                               |                  |             |              |               |                          |                                   |
|                        | Preventive maintenance time                           |                            |                  |                 |                       |                        |           |           |              |               |               |             |                      |                          |                               |                  |             |              |               |                          |                                   |
|                        |                                                       |                            |                  |                 |                       |                        |           |           |              |               |               |             |                      |                          |                               |                  |             |              |               |                          |                                   |

## A.2 Organizational terms

### A.2.1 Production order sequence (POS)

The order sequence (production order position) specifies the successive manufacturing steps within a production order.

NOTE These are usually numbered subsequently (usually in steps of ten).

### A.2.2 Work process (WOP)

The work process specifies a method of manufacturing (e.g. drilling, turning, hardening). Each production order sequence is assigned to a work process.

### A.2.3 Working group (WG)

The working group serves to organize responsibility and authority in the production area. Every employee in production can be assigned to one working group.

### A.2.4 Workplace (WP)

The workplace is a logical unit of production, which may be manual, semi-automatic or fully automatic.

### A.2.5 Production order (PO)

The production order includes the necessary production order sequences and the order quantity for the manufacturing of a product.

### A.2.6 Operation cluster (OC)

An operation cluster can be a work unit, a workstation or a group of it, or a work centre or a site. The operation clusters are specified hierarchically. An operation cluster is within a hierarchical level a configuration of one or more work centres up to a site.

## A.3 Effect model diagrams

Figures A.1 to A.32 provide effect model diagrams.

The arrows defined in Table A.2 are used in all the figures in this annex.

**Table A.2 — Effect model diagram key**

| Arrow                                                                               | Definition                                  |
|-------------------------------------------------------------------------------------|---------------------------------------------|
|  | results, through use of a formula, in a KPI |
|  | includes (a 1:1 relationship)               |
|  | has (i.e. is booked or entered)             |
|  | consists of (a 1:n relationship)            |

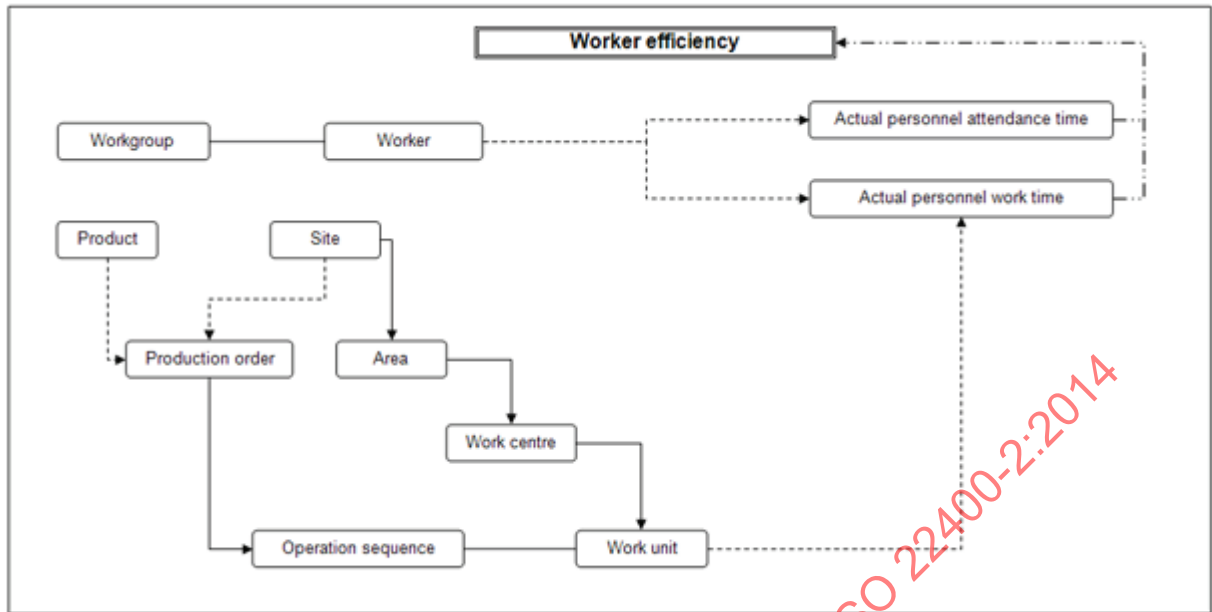


Figure A.1 — Worker efficiency

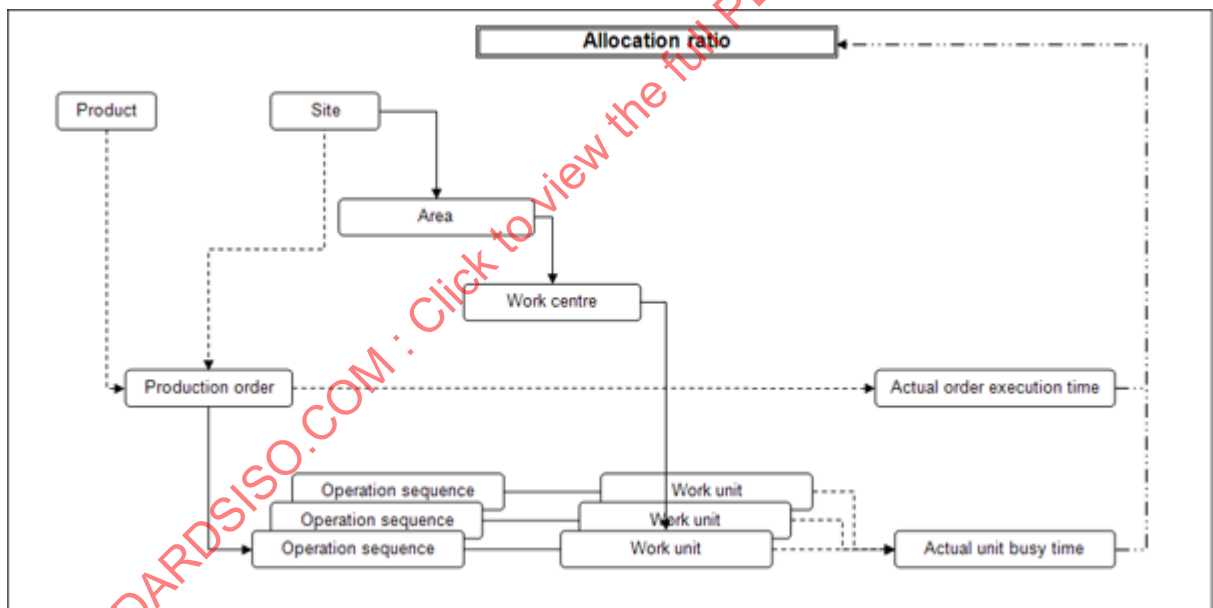


Figure A.2 — Allocation ratio

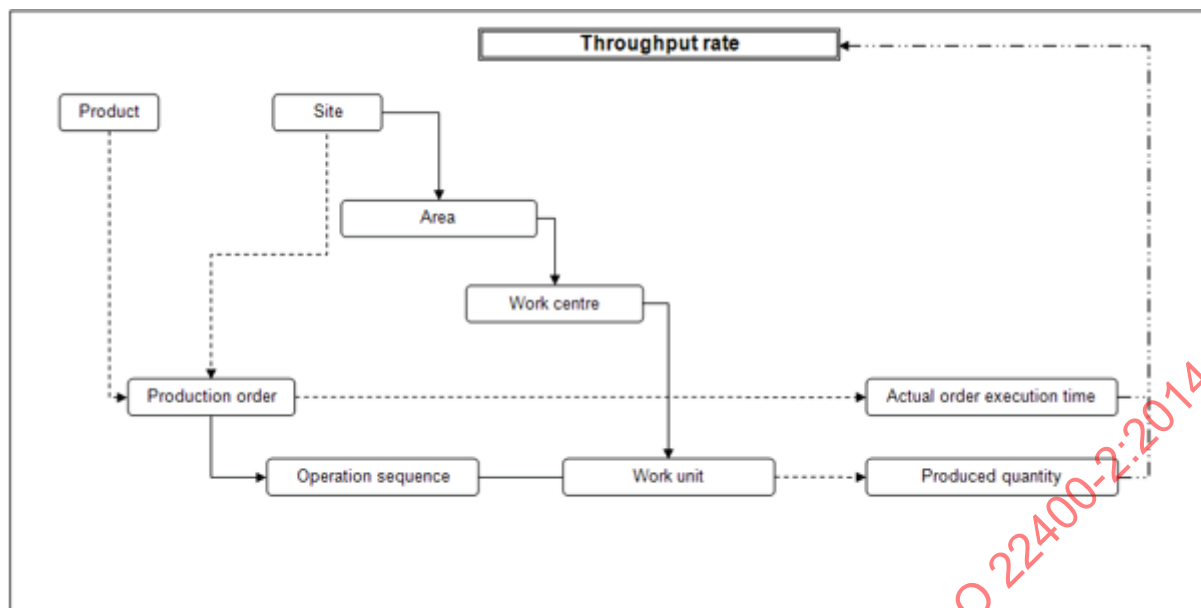


Figure A.3 — Throughput rate

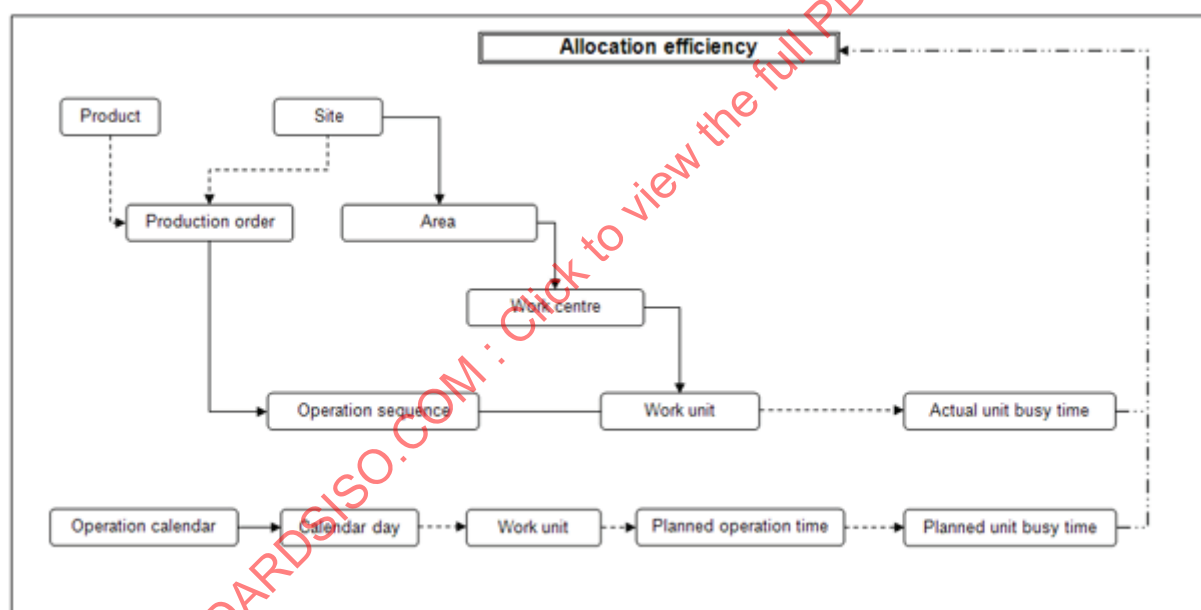


Figure A.4 — Allocation efficiency

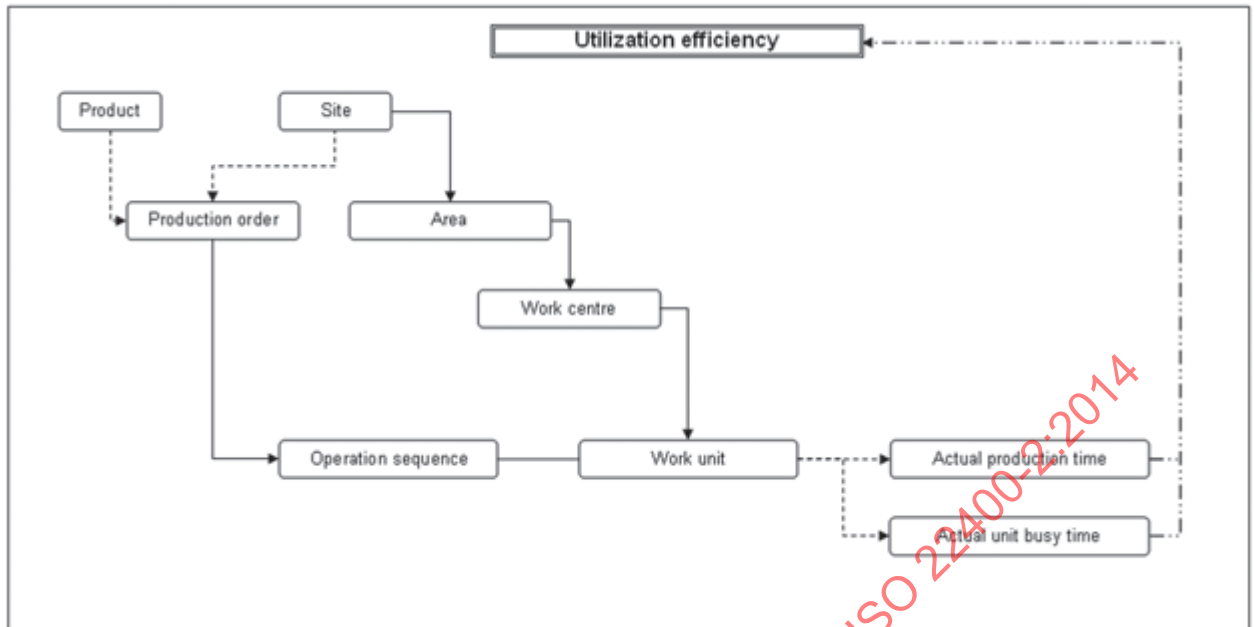


Figure A.5 — Utilization efficiency

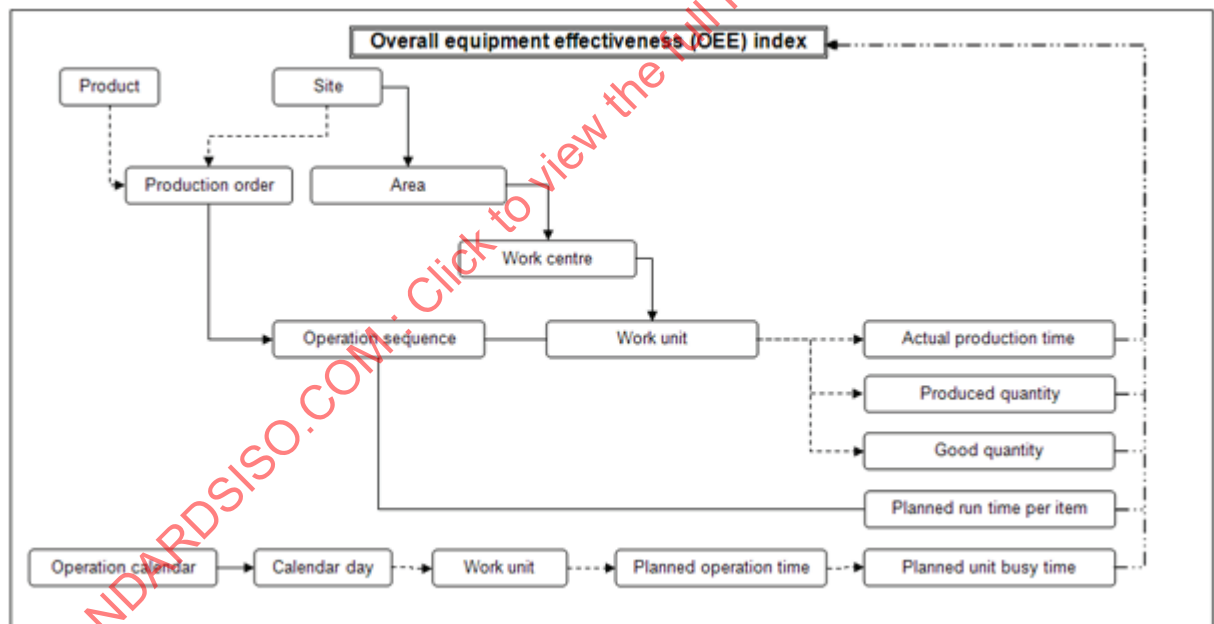


Figure A.6 — Overall equipment effectiveness index

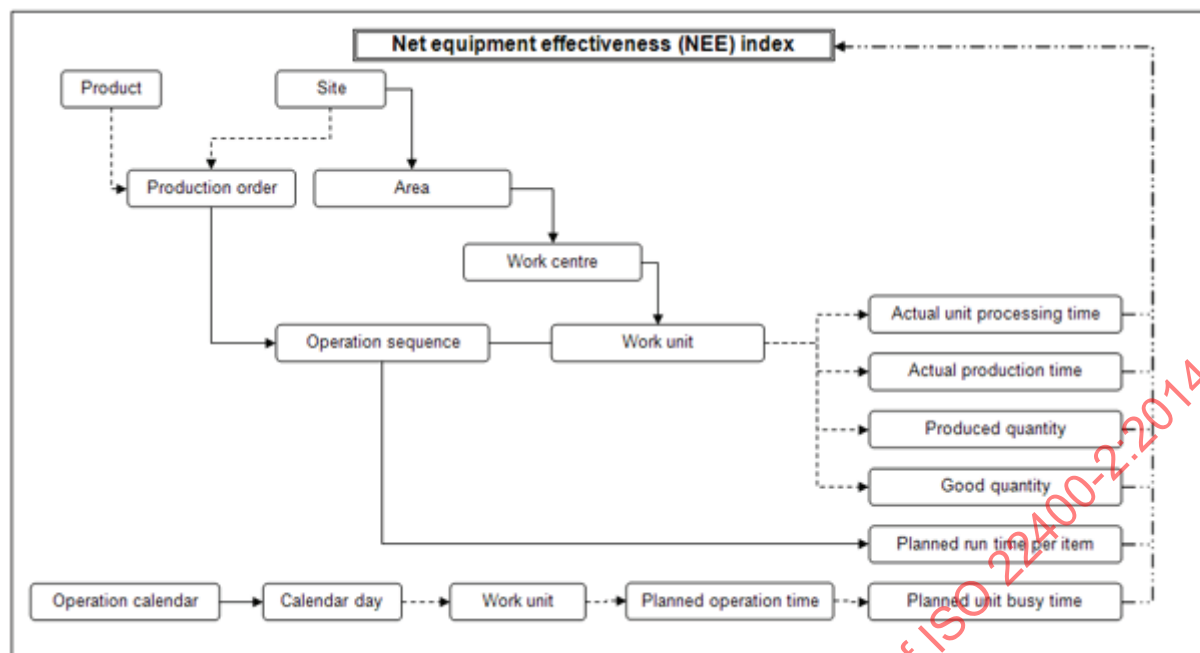


Figure A.7 — Net equipment effectiveness index

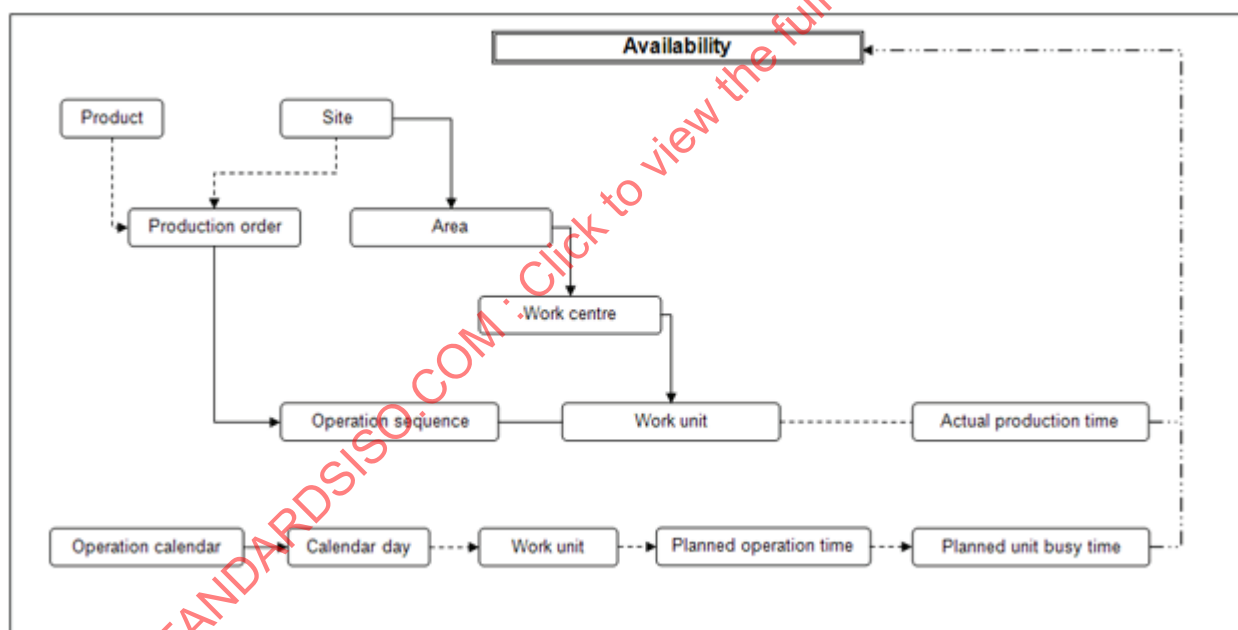


Figure A.8 — Availability

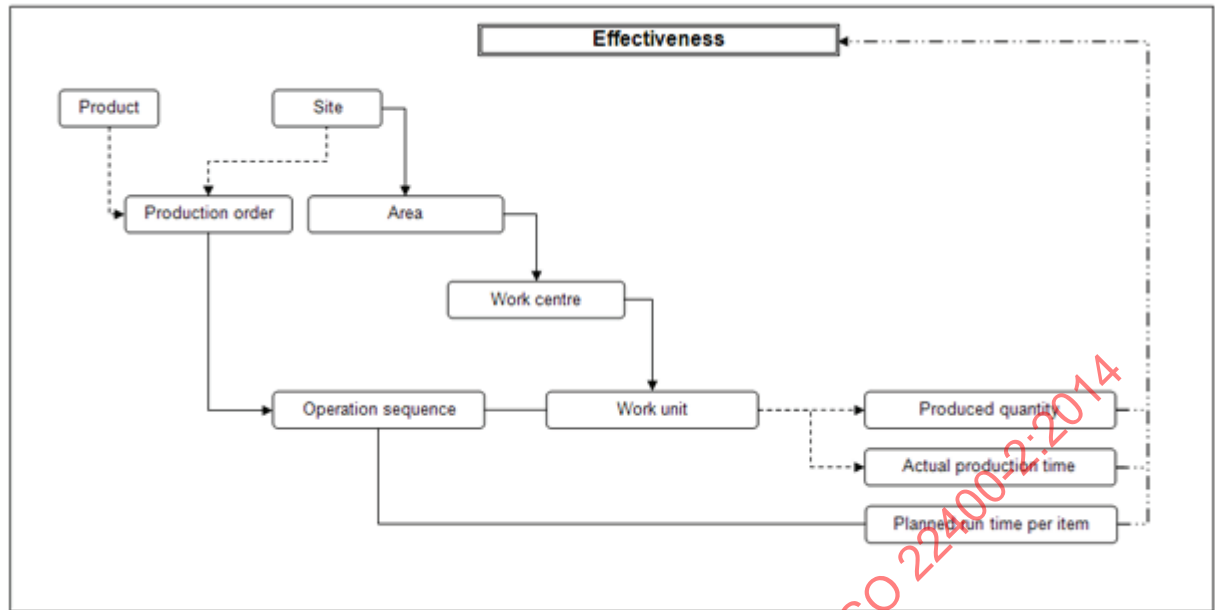


Figure A.9 — Effectiveness

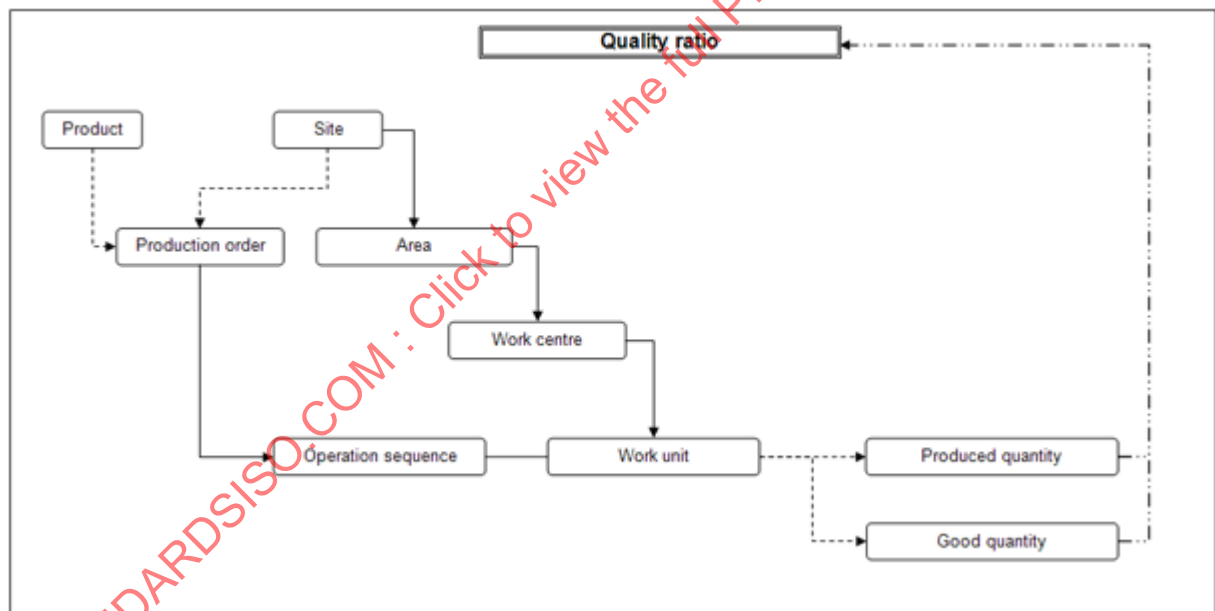


Figure A.10 — Quality ratio

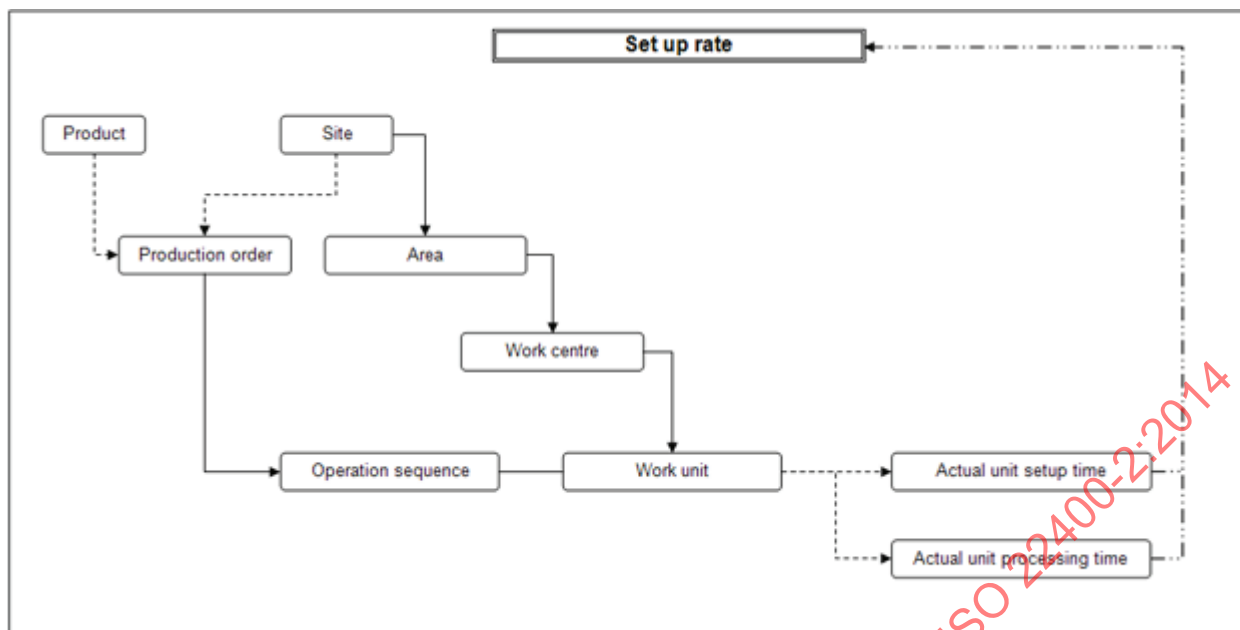


Figure A.11 — Setup ratio

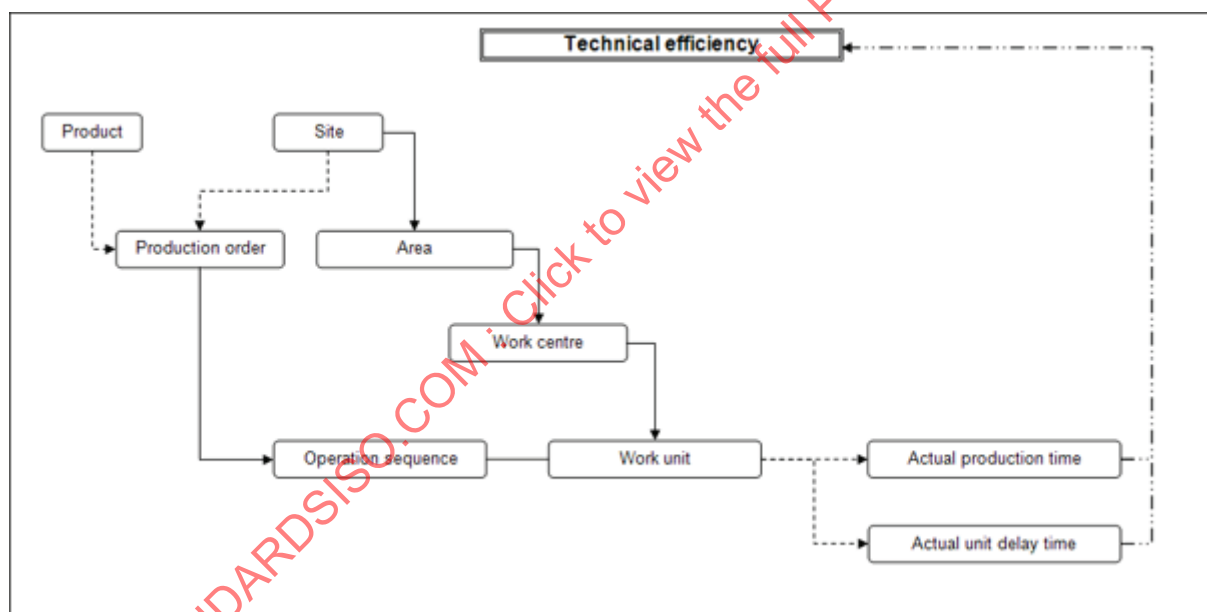


Figure A.12 — Technical efficiency

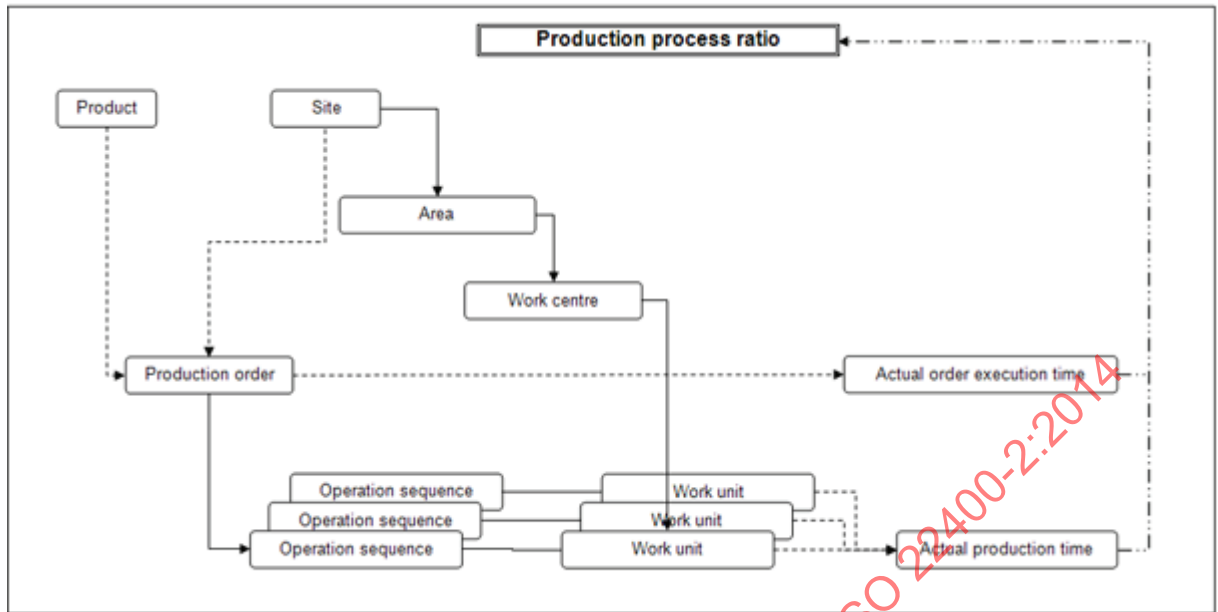


Figure A.13 — Production process ratio

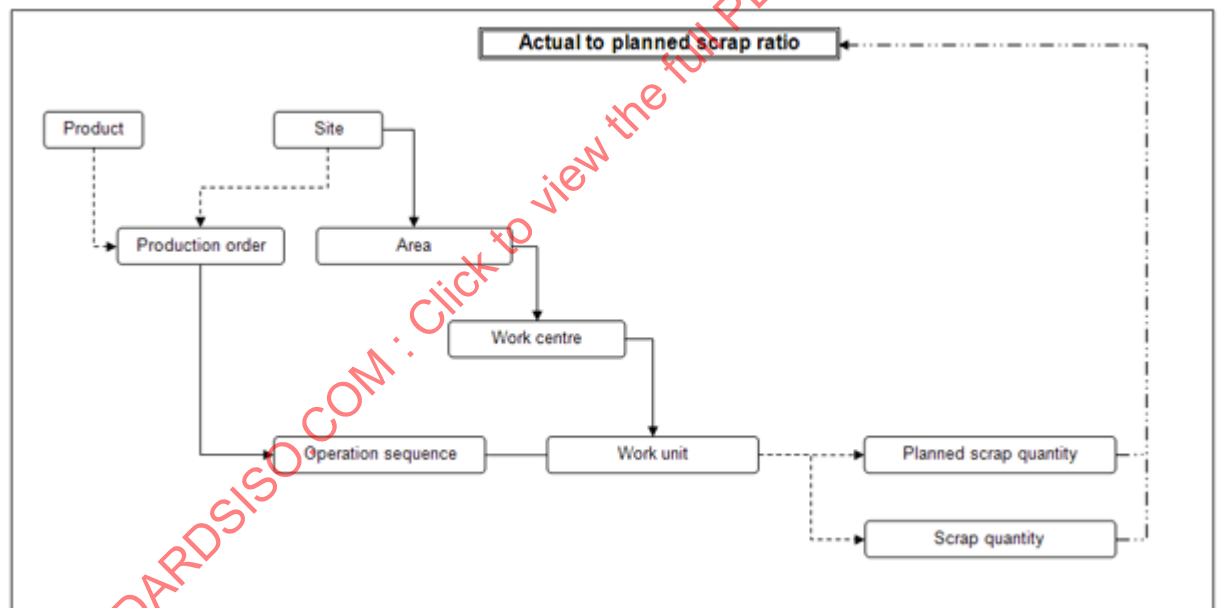


Figure A.14 — Actual to planned scrap ratio

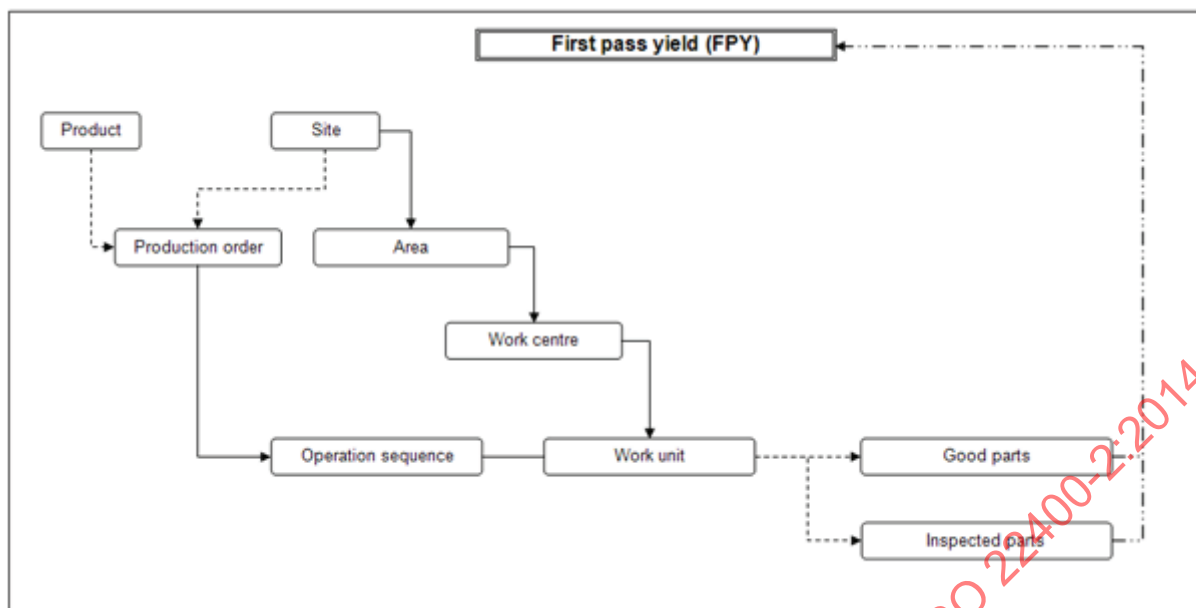


Figure A.15 — First pass yield

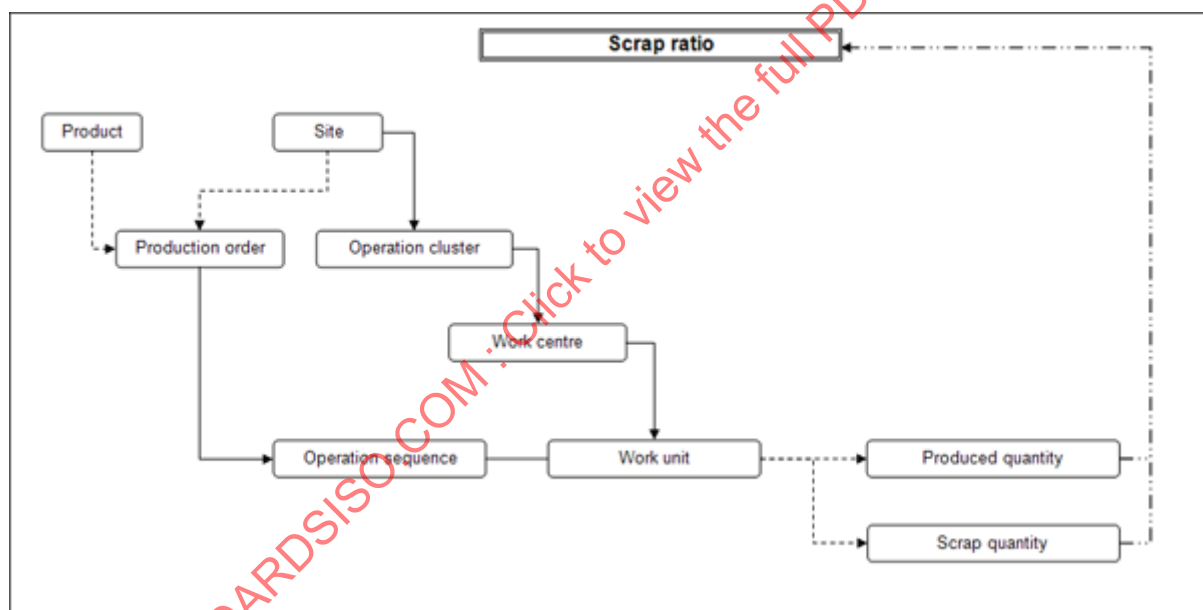


Figure A.16 — Scrap ratio