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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

Reference number
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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).

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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*

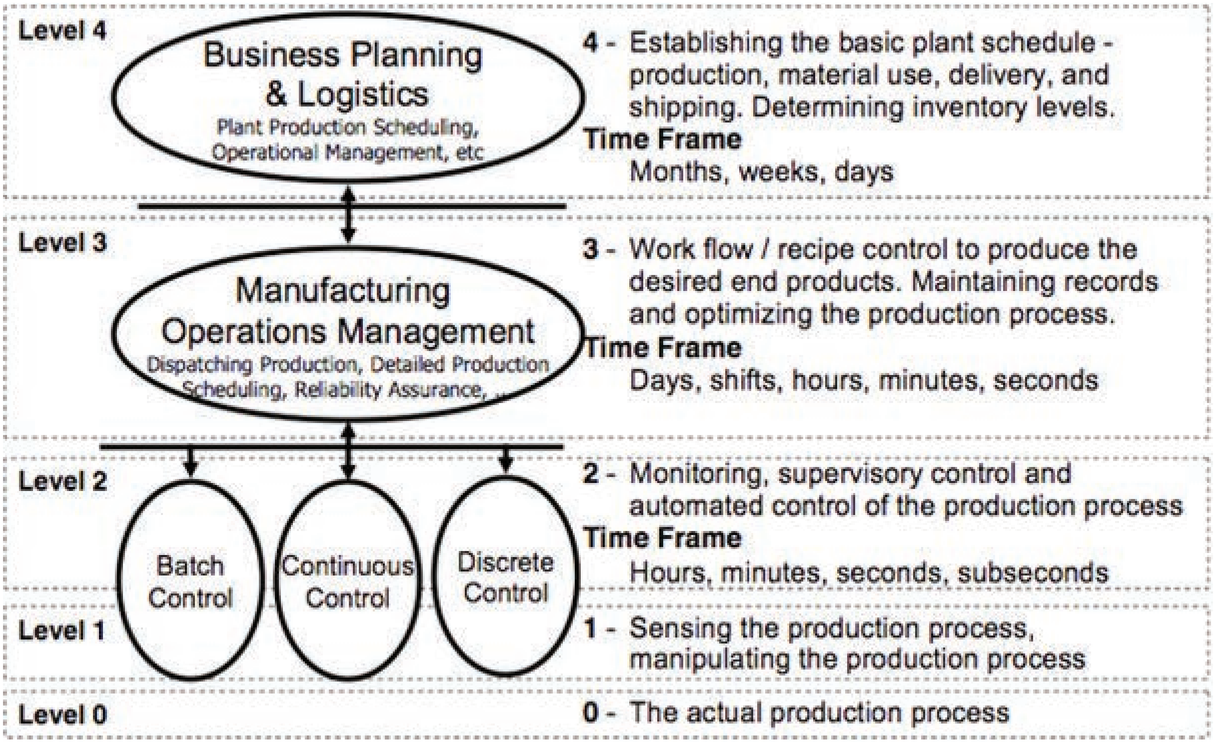
— *Part 4: Relationships and dependencies*

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.

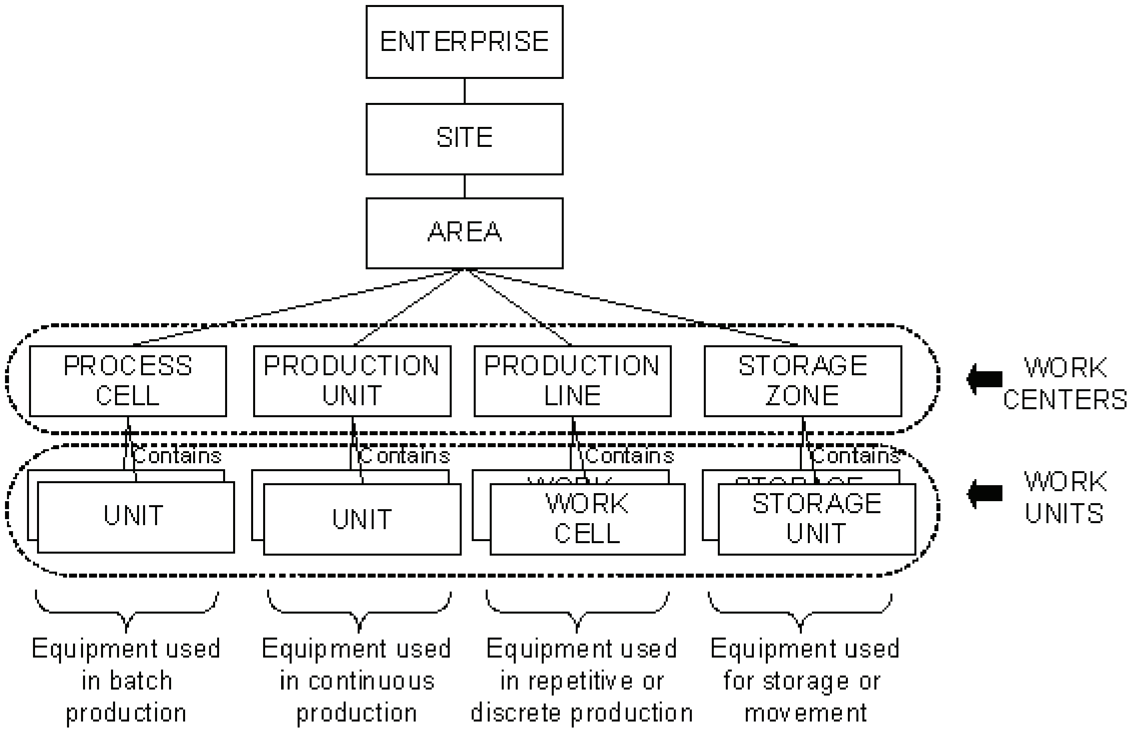
Manufacturing operations management (MOM) is a term used in IEC 62264 to specify a portion of the functional hierarchy model of a manufacturing enterprise. Figure 1 depicts the different levels of the functional hierarchy model: business planning and logistics (Level 4), manufacturing operations and 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.

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

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
σ	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
σ^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

KPI description	
Content:	
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
Context:	
Timing	A KPI can be calculated either in • real-time - after each new data acquisition event • on demand - after a specific data selection request • periodically - done at a certain interval, e.g. once per day
Audience	Audience is the user group typically using this KPI. The user groups used in this part of ISO 22400 are • Operators – personnel responsible for the direct operation of the equipment • Supervisors – personnel responsible for directing the activities of the operators • Management – personnel responsible for the overall execution of production
Production methodology	Specifies the production methodology that the KPI is generally applicable for • Discrete • Batch • Continuous
Effect model diagram	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. NOTE This is a quick analysis which supports rapid efficiency improvement by corrective actions, and thus reduces errors
Notes	Can contain additional information related to the KPI. Typical examples are • Constraints • Usage • Other information

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.

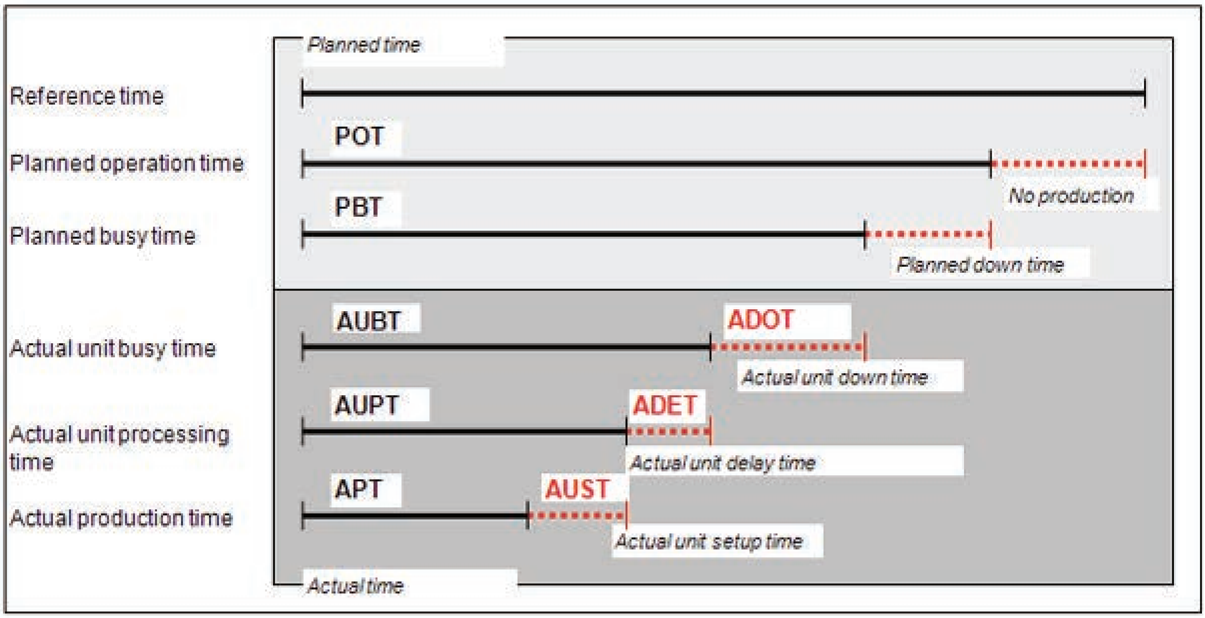


Figure 3 — Time lines for work units

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.

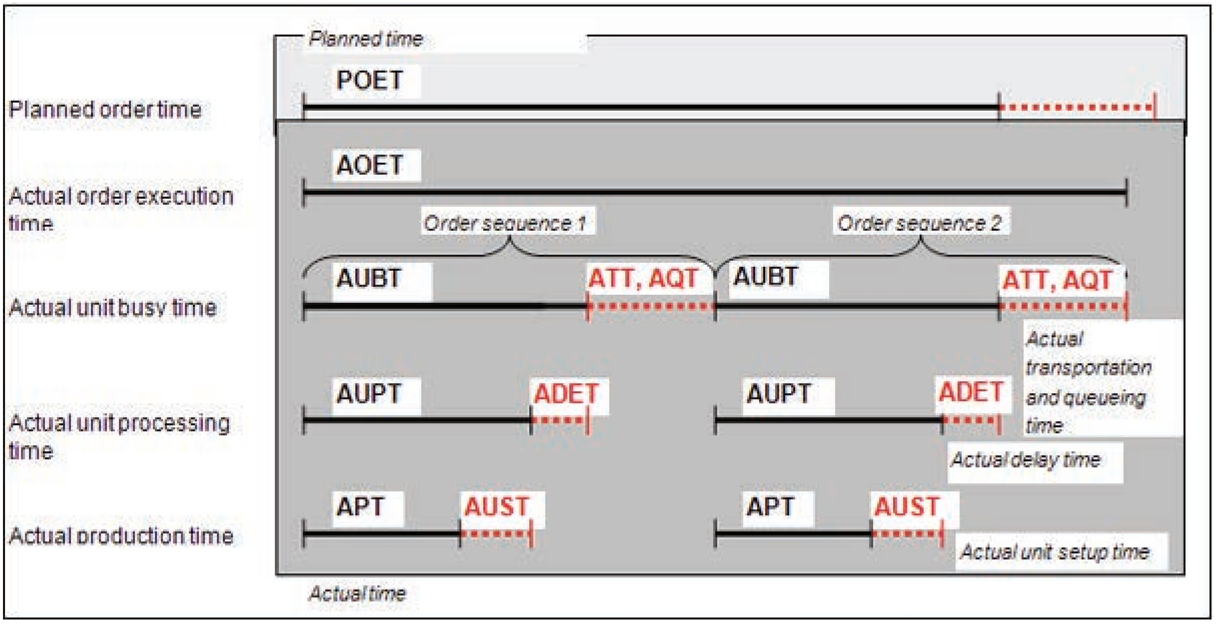


Figure 4 — Time lines for production order processing

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 $x_1,\ldots,x_i,\ldots,x_n$ 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 (σ)

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 (σ^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	
Content	
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% Max: 100%
Trend	The higher the better
Context	
Timing	Periodically
Audience	Supervisor, management
Production methodology	Discrete, batch, continuous
Effect model diagram	see Figure A.1
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 = ∑AUBT / AOET ∑AUBT = sum of the AUBT of all work units involved in a production order.
Unit of measure	%
Range	Min: 0% Max: 100% >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 Figure A.2
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 = PQ/AOET
Unit of measure	Quantity unit / Time unit
Range	Min: 0 quantity units / time unit Max: product-specific
Trend	The higher the better
Context	
Timing	On demand, periodically
Audience	Supervisor, management
Production methodology	Discrete, batch
Effect model diagram	see Figure A.3
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 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% Max: 100%
Trend	The higher the better
Context	
Timing	On-demand
Audience	Operator, supervisor, management
Production methodology	Discrete, batch, continuous
Effect model diagram	see Figure A.4
Notes	The allocation efficiency indicates how strongly the planned capacity of the work unit is already used and how much planned capacity is still available The allocation efficiency is only affected by the actual unit idle time while the availability KPI takes the actual unit delay time into account.

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% 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 Figure A.5
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 Table 9), the effectiveness of the work unit (see Table 10), and the quality ratio (see Table 11) 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% 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 Figure A.6
Notes	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. The calculation of OEE based on the hierarchy structure (see Figure 2) 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.

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 Table 10) and the quality ratio KPI (see Table 11) 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% Max: 100%
Trend	The higher, the better
Context	
Timing	On-demand, periodically
Audience	Supervisor, management
Production methodology	Discrete, batch, continuous
Effect model diagram	See Figure A.7
Notes	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. The NEE index indicates losses by work unit delays, cycle time losses and losses by rework.

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	Availability = APT / PBT
Unit of measure	%
Range	Min: 0% Max: 100%
Trend	The higher, the better
Context	
Timing	On-demand, periodically
Audience	Supervisor, management
Production methodology	Discrete, batch, continuous
Effect model diagram	See Figure A.8
Notes	Availability indicates how strongly the capacity of a work unit for the production is used in relation to the available capacity. 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	Effectiveness = PRI * PQ / APT
Unit of measure	%
Range	Min: 0% 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 Figure A.9
Notes	The effectiveness can be calculated in short periods and indicates how effective a work unit will be during the production time. 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% 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 Figure A.10
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% Max: 100%
Trend	The lower, the better
Context	
Timing	On-demand, periodically
Audience	Supervisor, management
Production methodology	Discrete, batch, continuous
Effect model diagram	See Figure A.11
Notes	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. 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.

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% 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 Figure A.12
Notes	The technical efficiency does not include setup time in contrast to the utilization efficiency. 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 = ∑APT / AOET ∑APT = sum of the APT of all work units and work centres involved in a production order.
Unit of measure	%
Range	Min: 0% Max: 100% >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 Figure A.13
Notes	The production process ratio is an index for the efficiency of the production. 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% 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 Figure A.14
Notes	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). A low value indicates that the less scrap is produced than expected. This is good as a short term goal. 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. The planned scrap quantity (which can be expected) is typically already specified in the ERP system in order to ensure the necessary material allocation.

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% 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 Figure A.15
Notes	For identifying the first pass it is necessary to label each part with an identification number (serial number). See 5.6.1 for the explanation how the concept of a part is used in discrete and batch manufacturing methodologies. 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% 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 Figure A.16
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	Rework ratio = RQ / PQ
Unit of measure	%
Range	Min: 0% 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 Figure A.17
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 = $(PQ_{\text{of first production order sequence}} - GQ_{\text{of current production order sequence}}) / PQ_{\text{of first production order sequence}}$
Unit of measure	%
Range	Min: 0% Max: 100%
Trend	The lower, the better
Context	
Timing	On-demand
Audience	Operator, supervisor, management
Production methodology	Discrete, batch
Effect model diagram	See Figure A.18
Notes	The KPI is typically used in a concatenated processes, where a product (e.g. motherboard) is produced in the first manufacturing step and but may have scrap in the further operations. The fall of ratio is usable as indicator after the order sequence will be finished. The mother products can be serialized in the first manufacturing step. 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. 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 Table 26) can be used to calculate the quality.

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 6σ 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 *σ)
Unit of measure	N/A
Range	Min: >0, C_m approaches 0 if σ approaches infinite. 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 Figure A.19
Notes	The machine capability index (C_m) 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 C_m is a characteristic value of a short time capability investigation. Usually the normal distribution will be the statistical method. The machine capability value is usually specified by customer requirements. Typical value is C_m > 1,67. The value can be used for characteristic with upper and lower specification limits only.

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 3σ 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 *σ) ; C_{mkl} = ($\bar{x}$ – LSL) / (3 *σ) C_{mk} = Min (C_{mku} , C_{mkl})
Unit of measure	N/A
Range	Min: >0, C_{mk} approaches 0 if σ approaches infinite. 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 Figure A.19
Notes	The critical machine capability index (C_{mk}) 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 C_{mk} is a characteristic value of a short time capability investigation. Usually the normal distribution will be the statistical method. The critical machine capability target is usually specified by customer requirements. Typical value is C_{mk} > 1,67.

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 6σ 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. 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 Figure A.20
Notes	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. The measurement has to be done in regular time steps or after specified quantity intervals with small samples (1-25). A process is usually called capable if the C_p > 1,33. $\hat{\sigma}$ will be calculated based on a confidence factor from the standard deviation, depending on the inspection sample size.

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 ($\bar{\bar{x}}$). The method compares the range between the upper or lower specification limit and its averages and the 3σ process dispersion.
Scope	Product, work unit, characteristic, and series of measurements
Formula	$C_{pku} = (USL - \bar{\bar{x}}) / (3 * \hat{\sigma})$; $C_{pkl} = (\bar{\bar{x}} - LSL) / (3 * \hat{\sigma})$ $C_{pk} = Min (C_{pku}, C_{pkl})$
Unit of measure	N/A
Range	Min: >0, C_{pk} approaches 0 if $\hat{\sigma}$ approaches infinite. 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 Figure A.20
Notes	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. The measurement has to be done in regular time steps or after specified quantity intervals with small samples (1-25). A process is usually called capable if C_{pk} > 1,33. $\hat{\sigma}$ will be calculated based on a confidence factor from the standard deviation, depending on the inspection sample size.

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 =(∑Mi*Ri + Q)/ PQ where e: unit energy consumption of an equipment, E: comprehensive energy consumption, Mi: actual consumption of certain kind of energy (kilowatt hour) Ri[a]: conversion coefficient of certain kind of energy Q: algebraic sum of effective energy exchanges with the environment
Unit of measure	Joule / (number of units) or amount
Range	Min: 0 Joule / (number of units) or amount Max: product specific
Trend	The lower, the better
Context	
Timing	On-demand, periodically
Audience	Operator, supervisor, management
Production methodology	Discrete, batch, continuous
Effect model diagram	See Figure A.21
Notes	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. Energy consumption is an important factor impacting the production costs and company profits. National laws and regulation have to be considered and may require additional KPI calculation on energy consumption.
[a] 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	

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 Max: product specific
Trend	The higher, the better
Context	
Timing	On-demand, periodically
Audience	Operator, supervisor, management
Production methodology	Continuous (Inventory turns is typically a Level 4 KPI in discrete and batch manufacturing)
Effect model diagram	See Figure A.22
Notes	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. The four types of inventory are described below. 1) Raw materials (RM): The materials that are changed into finished goods through the production. 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.) 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. 4) Work in process inventory (WIP)[a]: 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.
[a] 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.	

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% 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 Figure A.23
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 Table 11).

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% 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 Figure A.24
Notes	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”. 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.

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 ration = PL / CM
Unit of measure	%
Range	Min: 0% 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 Figure A.25
Notes	Typically scrap and reworking are not measured in the process industries. Instead, the focus is on loss, where: • Integrated goods ratio + Loss ratio = 1 • Loss ratio = Production loss ratio + Storage and • Transportation loss ratio + Other loss ratio For these calculations the following apply. • Production loss: for quantity lost during production, calculate as output minus input. • 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. • Other loss: the quantity lost due to extraordinary incidents, e.g. natural disasters.

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% 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 Figure A.26
Notes	See also production loss ratio (see Table 28)

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% 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 Figure A.27
Notes	The other loss ratio evaluates loss that is not occurred during production, storage, or transportation. See also production loss ratio (see Table 28)

Table 31 — Equipment load ratio

KPI description	
Content	
Name	Equipment load ratio
ID	
Description	The equipment loss ratio considers the produced quantity (PQ) in relation to the equipment production capacity (EPC). Equipment production capacity is either "rated" or "maximum:" • Maximum equipment production capacity: the upper limit value of production demarcated before the equipment delivery. • Rated equipment production capacity: the upper limit value of production promised the stable operation of the equipment.
Scope	Work unit
Formula	Equipment load ratio = PQ / EPC.
Unit of measure	%
Range	Min: 0% Max: 100%, > 100% if more is produced than specified as the rated equipment production capacity.
Trend	The higher, the better. A value > 100% may indicate a quality issue (see notes)
Context	
Timing	On-demand, periodically
Audience	Supervisor, management
Production methodology	Batch, continuous
Effect model diagram	See Figure A.28
Notes	Production capacity and the load rate of equipment are important indicators in a manufacturing enterprise. 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. A value > 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.

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	$MTBF = \frac{\sum_{i=1}^{i=FE} TBF_i}{FE + 1}$
Unit of measure	Time unit
Range	Min: 0 Max: infinite
Trend	The higher, the better
Context	
Timing	On-demand, periodically
Audience	Supervisor, management
Production methodology	Discrete, batch, continuous
Effect model diagram	See Figure A.29
Notes	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. 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. MTBF numbers are usually stated in terms of hours. The indicator is calculated in each work unit. Every time a failure happens, a new TBF is obtained to calculate the MTBF. The MTBF is the sum of MTTR and MTTF.

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	$\mathrm{MTTF} = \frac{\sum_{i=1}^{i=\mathrm{FE}} \mathrm{TTF}_i}{\mathrm{FE}+1}$
Unit of measure	Time unit
Range	Min: 0 Max: infinite
Trend	The higher, the better
Context	
Timing	On-demand, periodically
Audience	Supervisor, management
Production methodology	Discrete, batch, continuous
Effect model diagram	See Figure A.30
Notes	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. It represents the expectation of the time to failure (see IEC 60050-191). MTTF is used for both non repaired items and repairable items. It is equivalent to MTBF in case of a non-repairable work unit. MTTF numbers are usually stated in terms of hours. The indicator is calculated in each work unit. Every time a failure happens, a new TTF is obtained to calculate the MTTF.

Table 34 — Mean time to repair

KPI description	
Content	
Name	Mean time to repair (MTTR)
ID	
Description	Mean time to repair (MTTR) is the average time that an item required to restore a failed component in a work unit. 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).
Scope	Work unit
Formula	$\mathrm{MTTR} = \dfrac{\sum_{i=1}^{i=\mathrm{FE}} \mathrm{TTR}_i}{\mathrm{FE}+1}$
Unit of measure	Time unit
Range	Min: 0 Max: infinite
Trend	The higher, the better
Context	
Timing	On-demand, periodically
Audience	Supervisor, management
Production methodology	Discrete, batch, continuous
Effect model diagram	See Figure A.31
Notes	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). MTTR numbers are usually stated in terms of hours. The indicator is calculated in each work unit. Every time a failure has been restored, a new TTR is obtained to calculate the MTTR.

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	Corrective maintenance ratio = CMT / (CMT + PMT)
Unit of measure	%
Range	Min: 0% Max: 100%
Trend	The lower, the better
Context	
Timing	On-demand, periodically
Audience	Supervisor, management
Production methodology	Discrete, batch, continuous
Effect model diagram	See Figure A.32
Notes	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. This ratio gives the idea of the time spent in corrective tasks on work units compared with the whole maintenance time. The lower the ratio the better. It should be remarked that excessive preventive maintenance would have the same effect on the ratio by increasing the overall maintenance function.

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

		Key Performance Indicators																									
		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	Fall-off rate	Machine capability index	Critical machine capability index	Process capability index	Critical process capability index	Mean operation time between failures	Mean time to failure	Mean time to repair	Corrective maintenance ratio
Planned time	Planned busy time (PBT)				•			•	•																		
	Planned run time per unit (PRTU)									•																	
Real time	Actual personnel work time (APWT)	•																									
	Actual unit processing time (AUPT)							•				•															
	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)											•															
Logistical quantities	Scrap quantity (SQ)														•		•										
	Planned scrap quantity (PSQ)														•												
	Good quantity (GQ)										•								•								
	Rework quantity (RQ)																	•									
	Produced quantity (PQ)			•						•	•						•	•									
	Produced quantity (PQ) in the first operation process																		•								
Quality numbers	Good part (GP)															•											
	Inspected part (IP)															•											
	Average of averages																						•				
	Upper specification limit (USL)																			•	•	•	•				
	Standard deviation (σ)																			•	•						
	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)

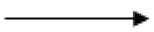
An operation cluster can be a work unit, a workstation or a group of it, or a work centre or a site. The operation clusters are specified hierarchically. An operation cluster is within a hierarchical level a configuration of one or more work centres up to a site.

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)

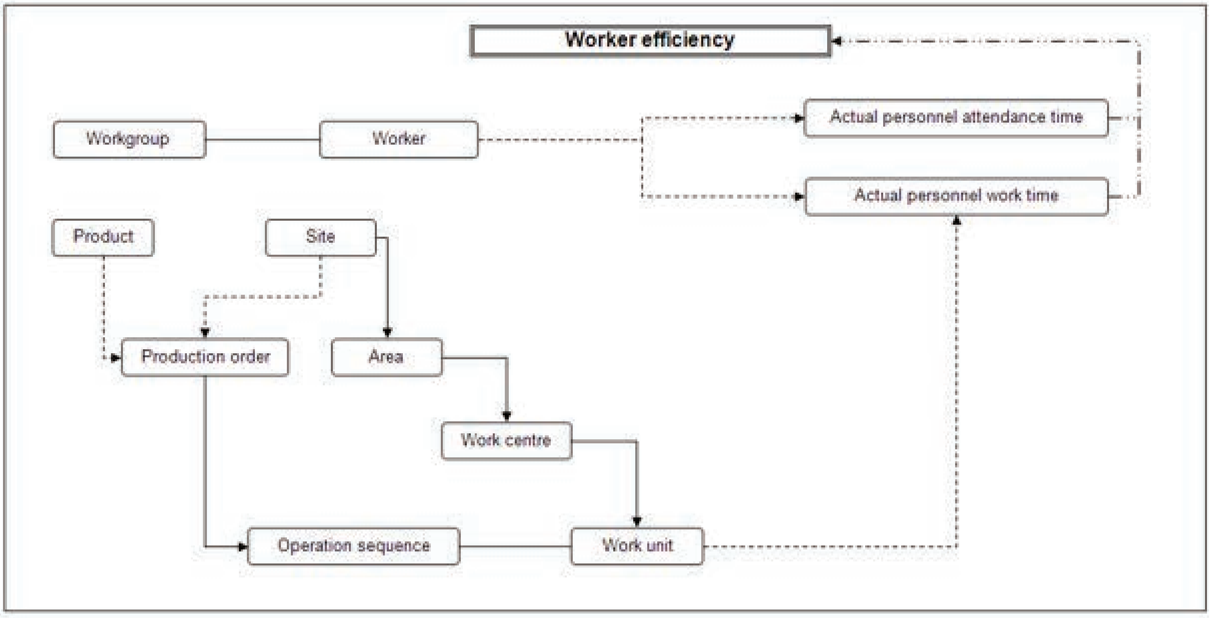


Figure A.1 — Worker efficiency

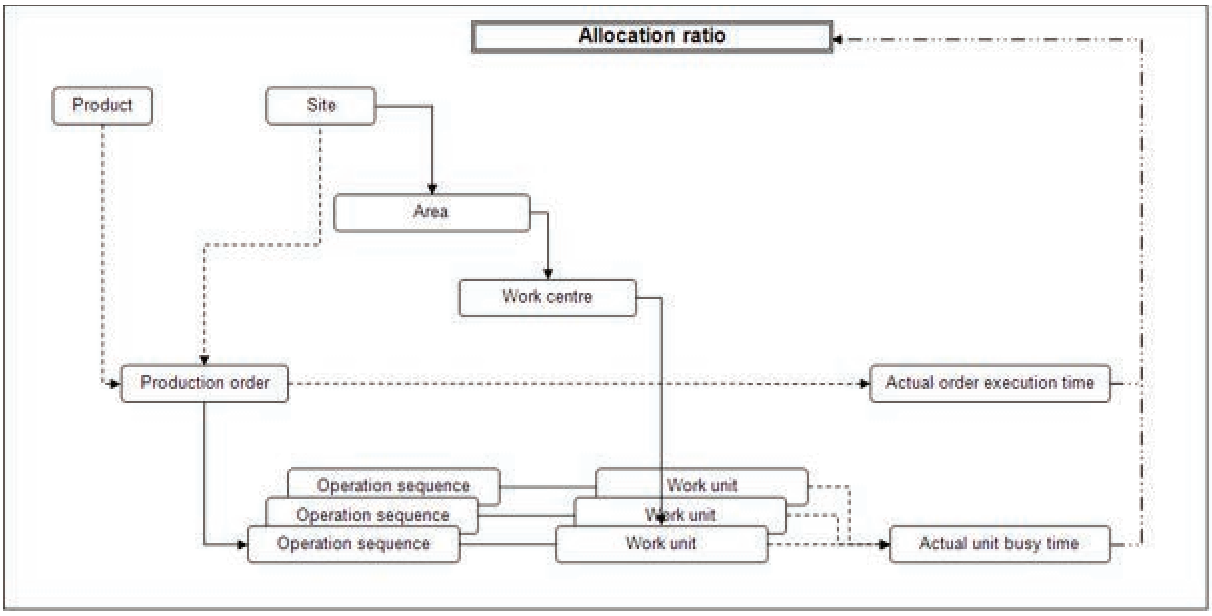


Figure A.2 — Allocation ratio

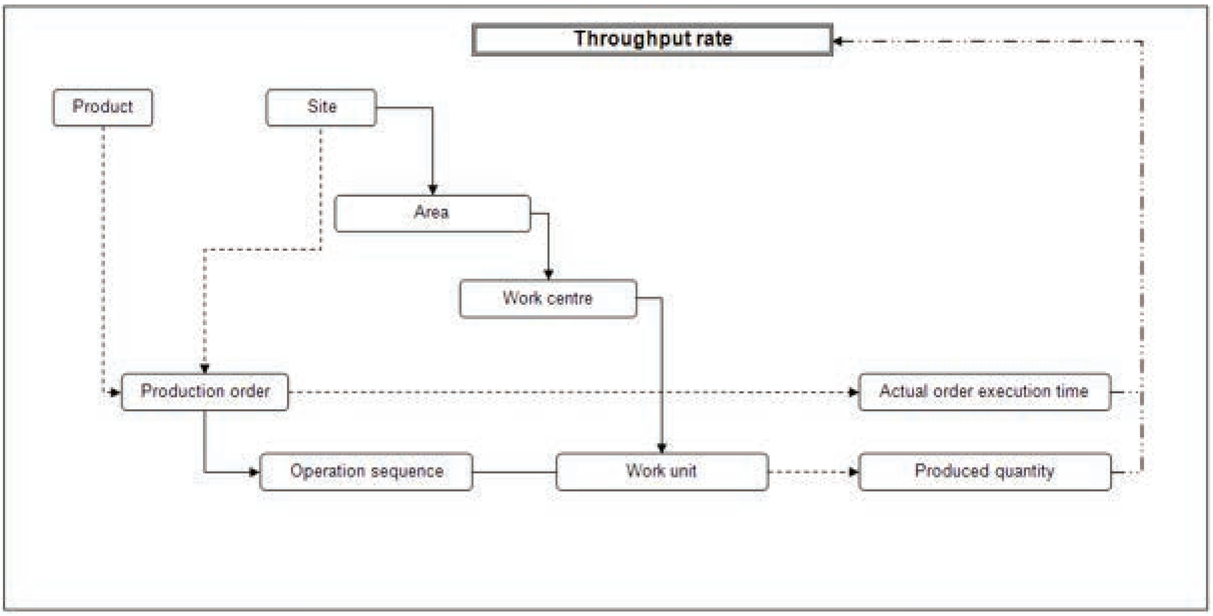


Figure A.3 — Throughput rate

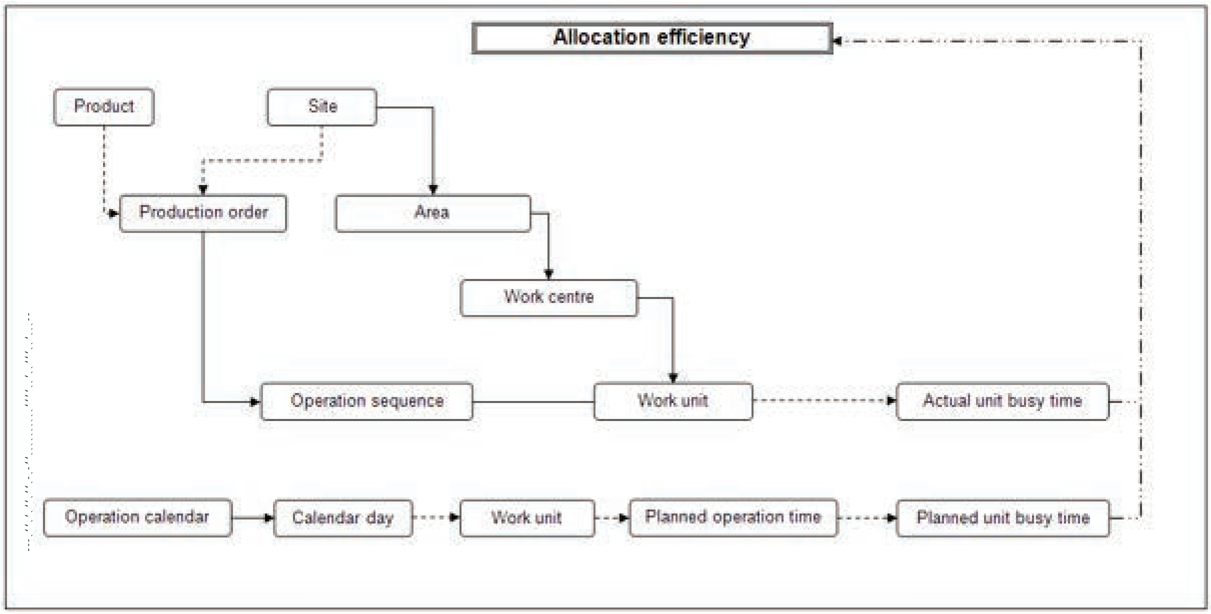


Figure A.4 — Allocation efficiency

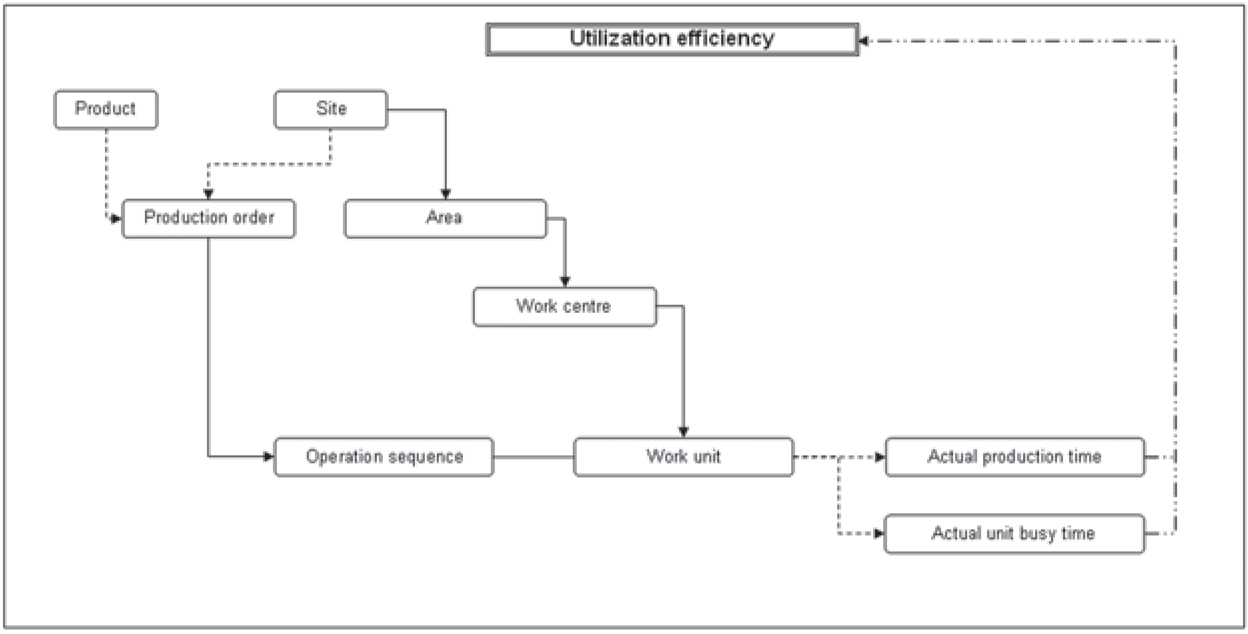


Figure A.5 — Utilization efficiency

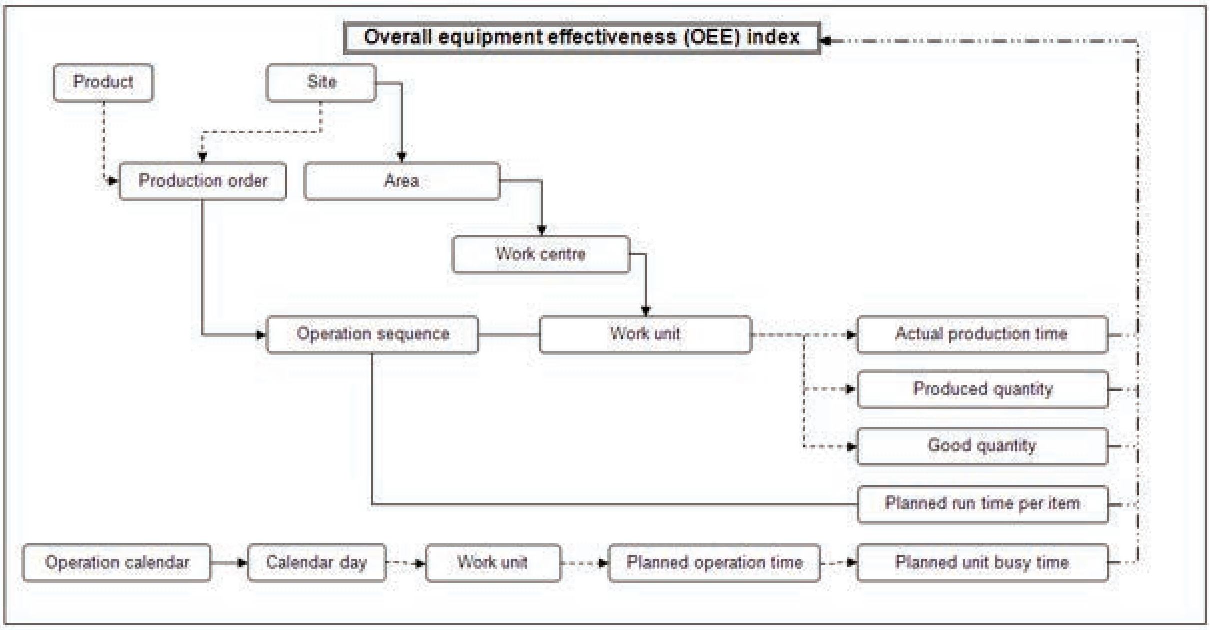


Figure A.6 — Overall equipment effectiveness index

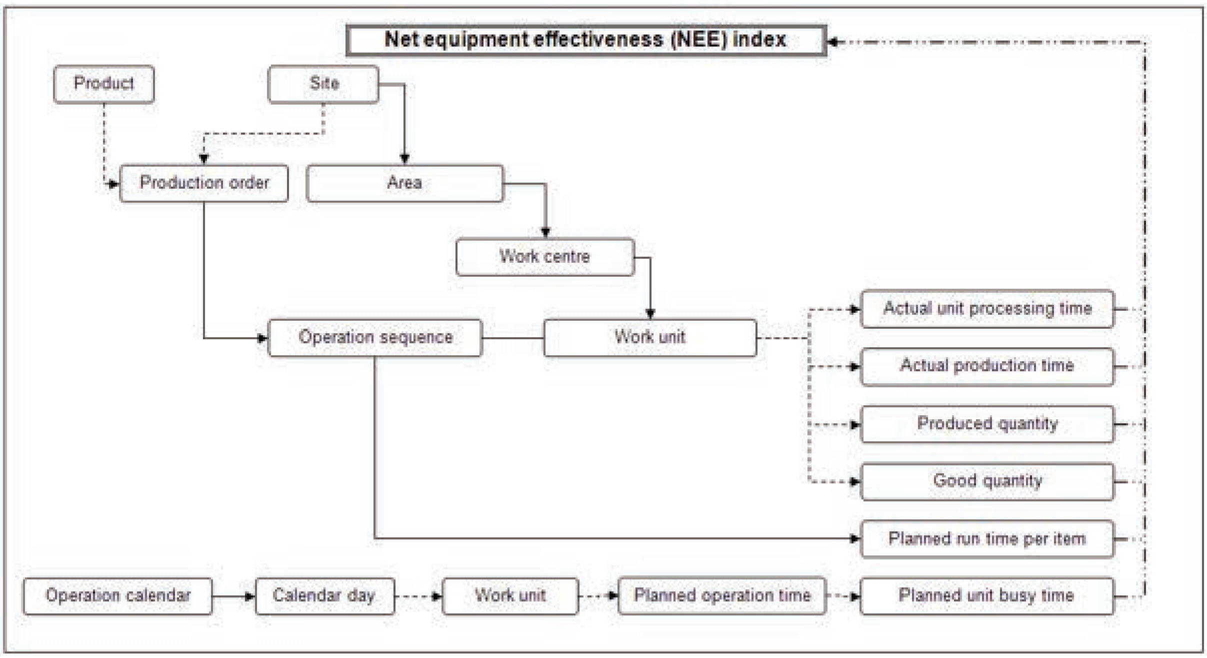


Figure A.7 — Net equipment effectiveness index

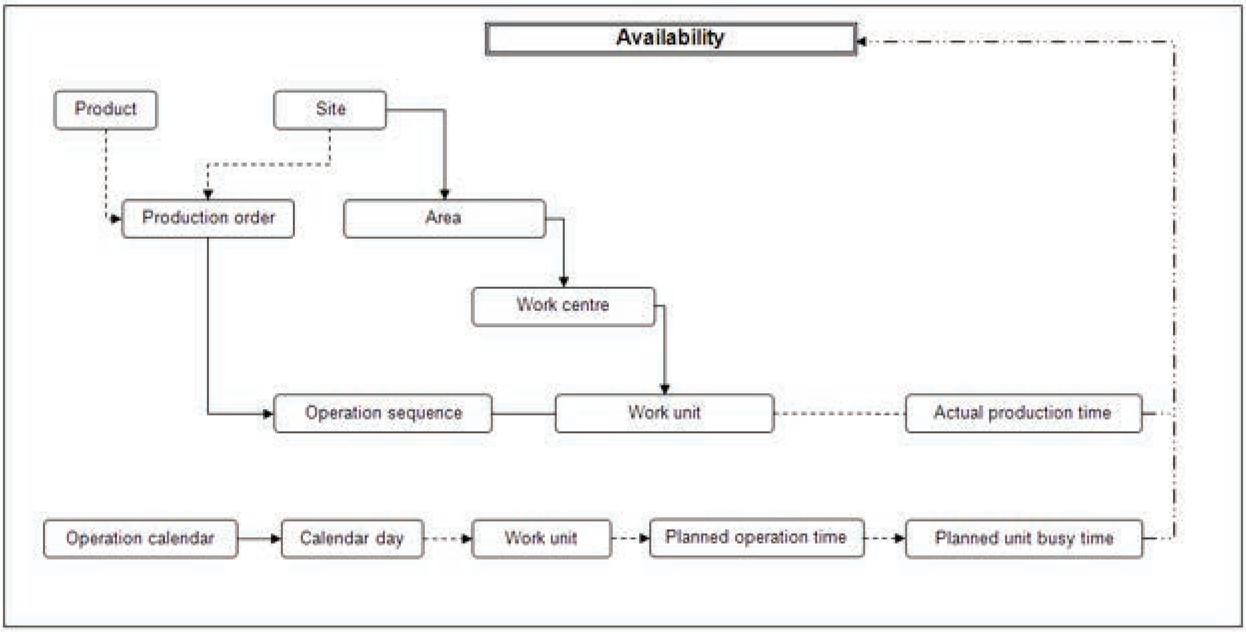


Figure A.8 — Availability

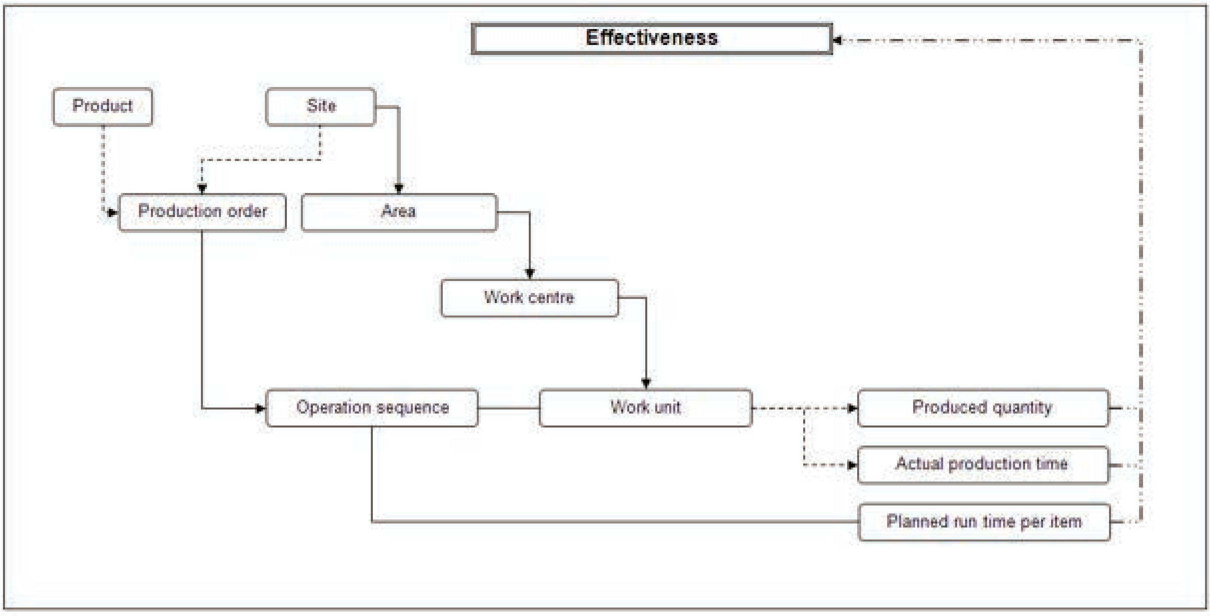


Figure A.9 — Effectiveness

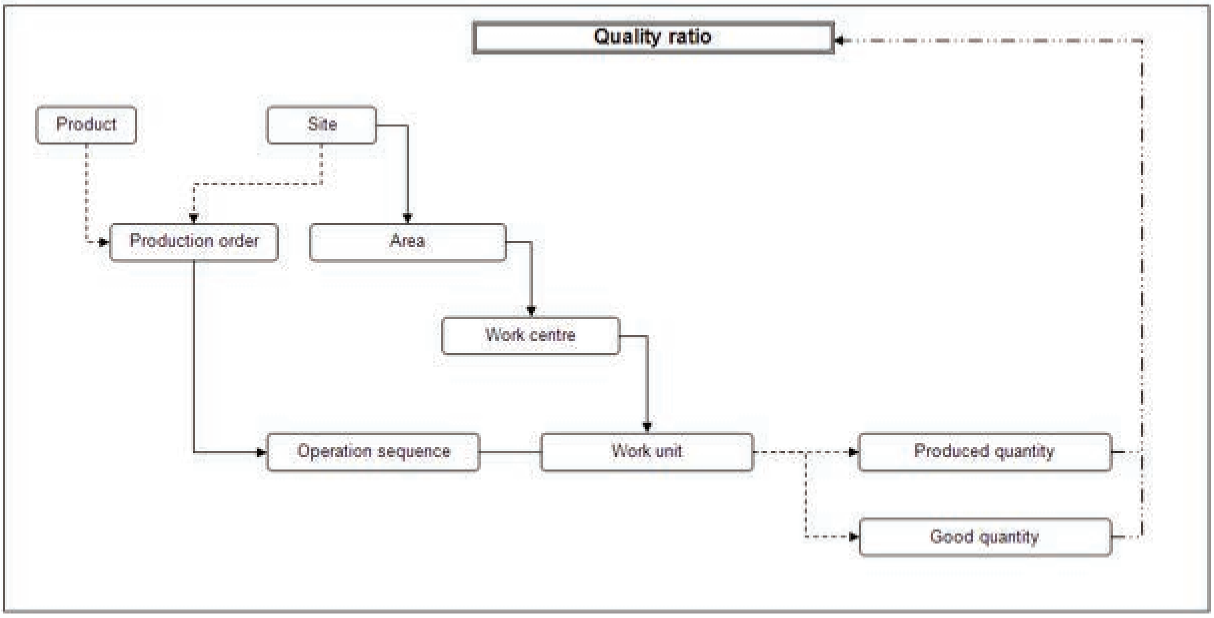


Figure A.10 — Quality ratio

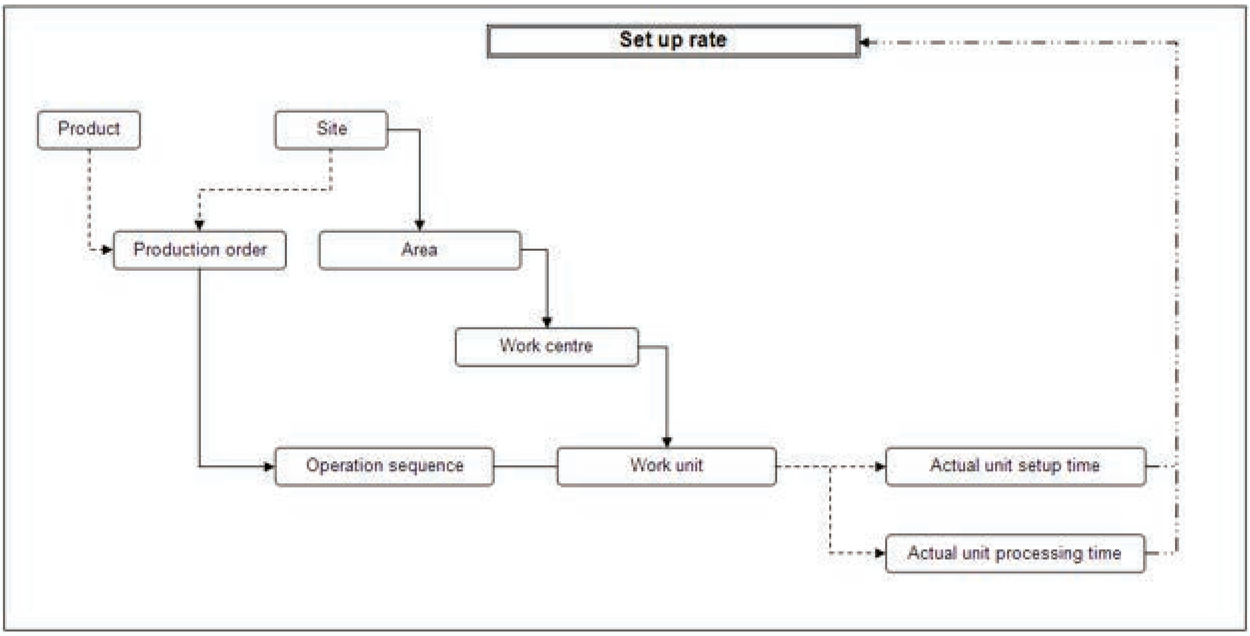


Figure A.11 — Setup ratio

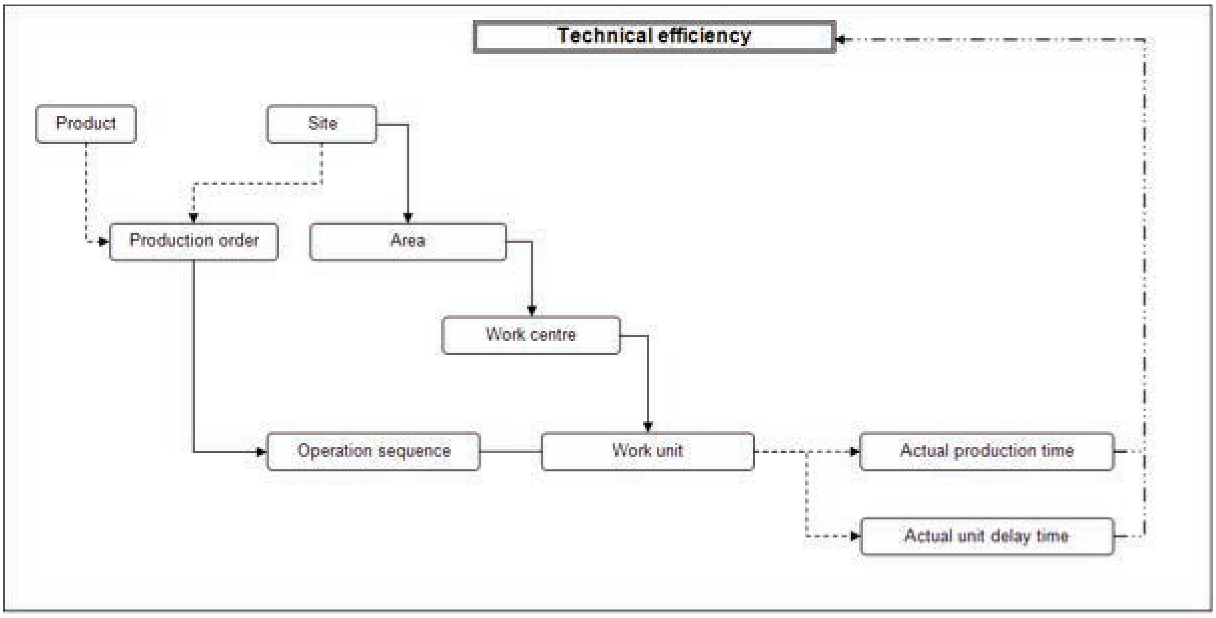


Figure A.12 — Technical efficiency

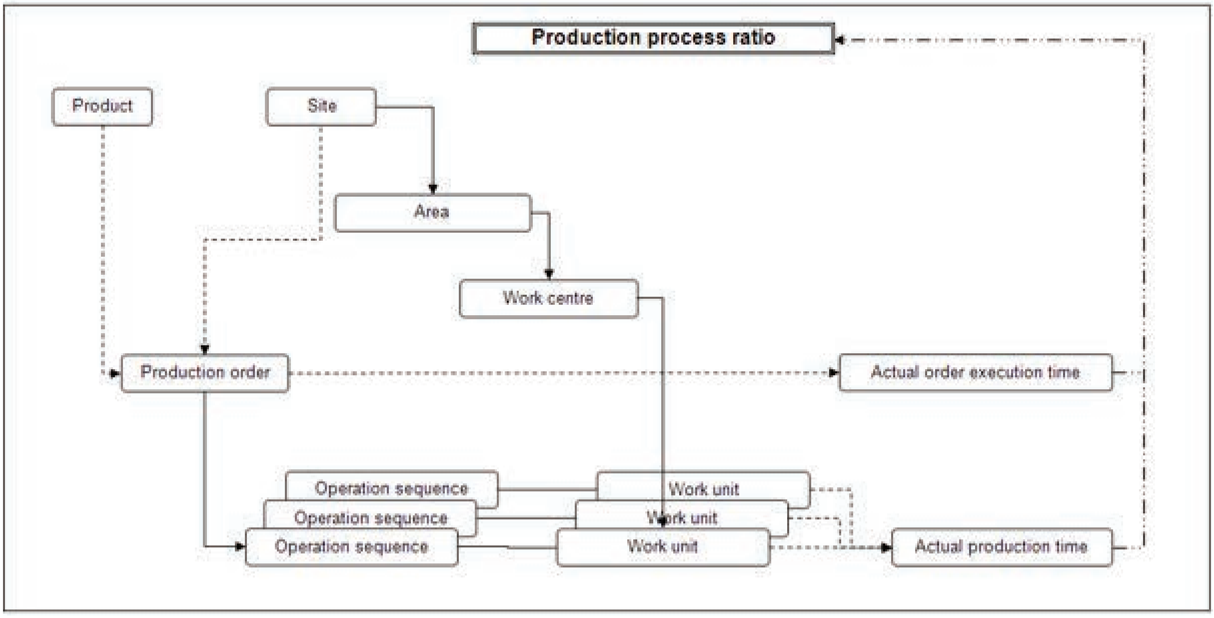


Figure A.13 — Production process ratio

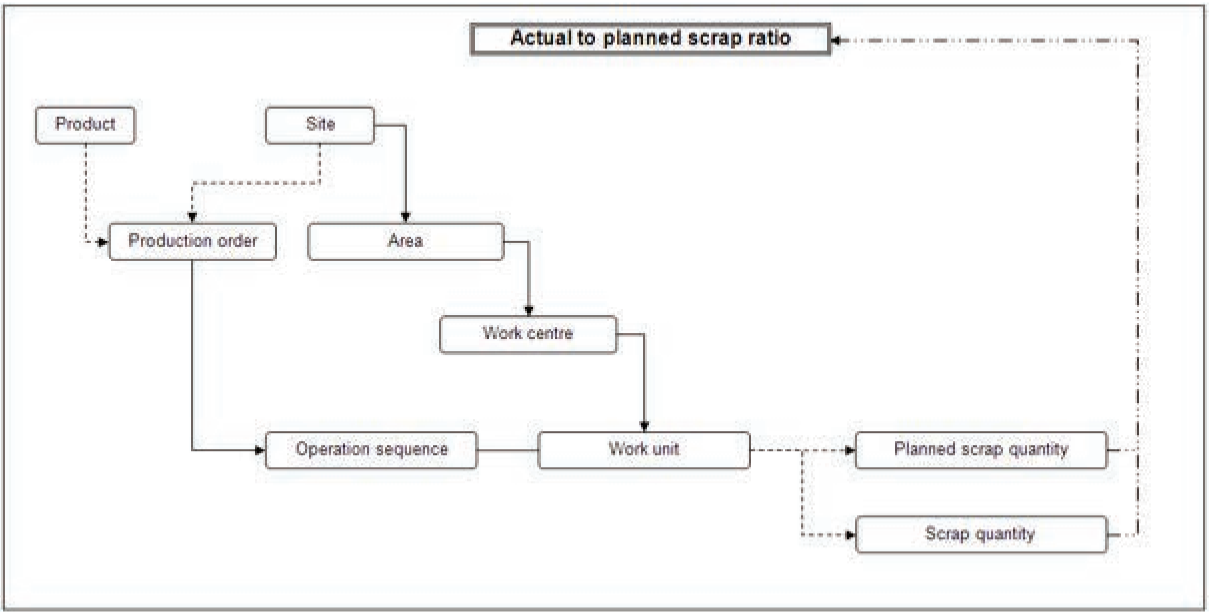


Figure A.14 — Actual to planned scrap ratio

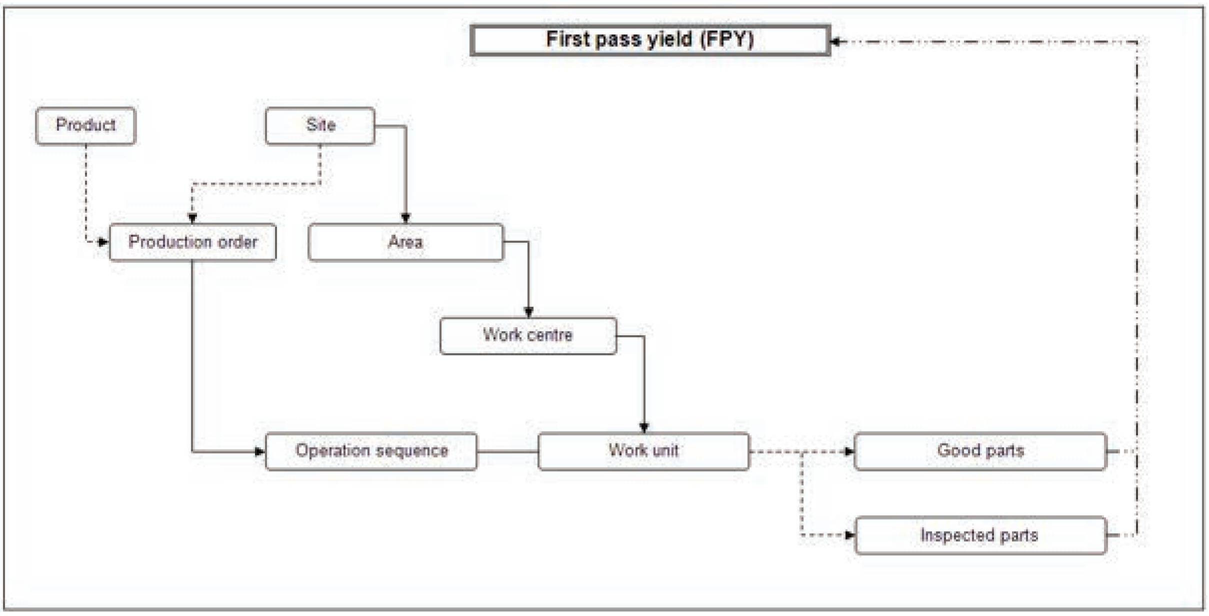


Figure A.15 — First pass yield

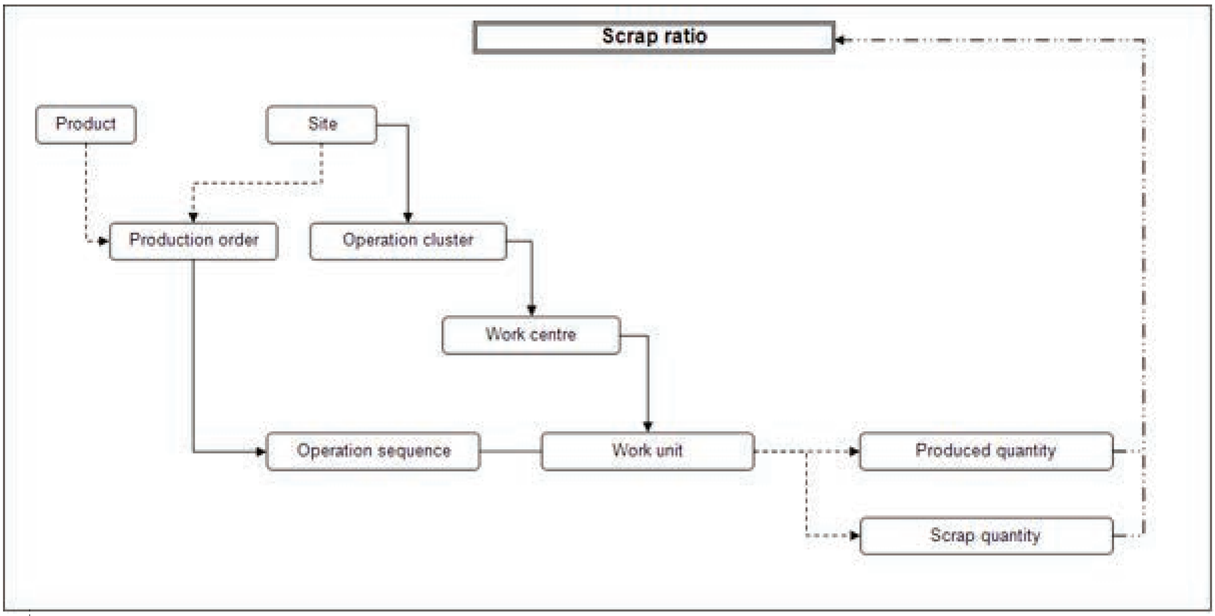


Figure A.16 — Scrap ratio

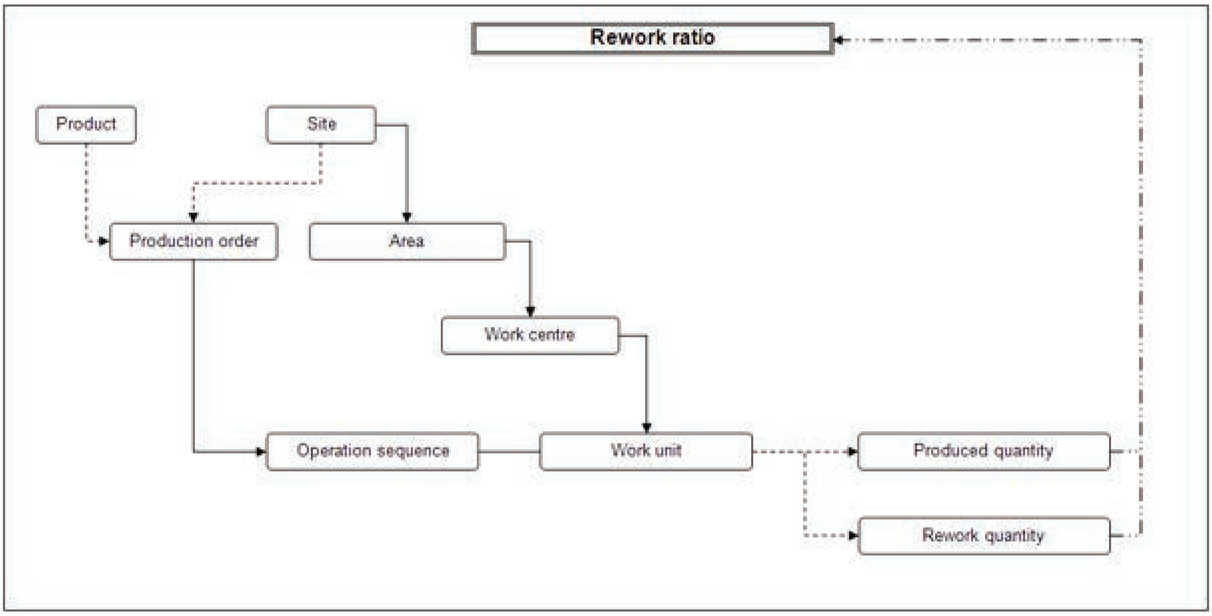


Figure A.17 — Rework ratio

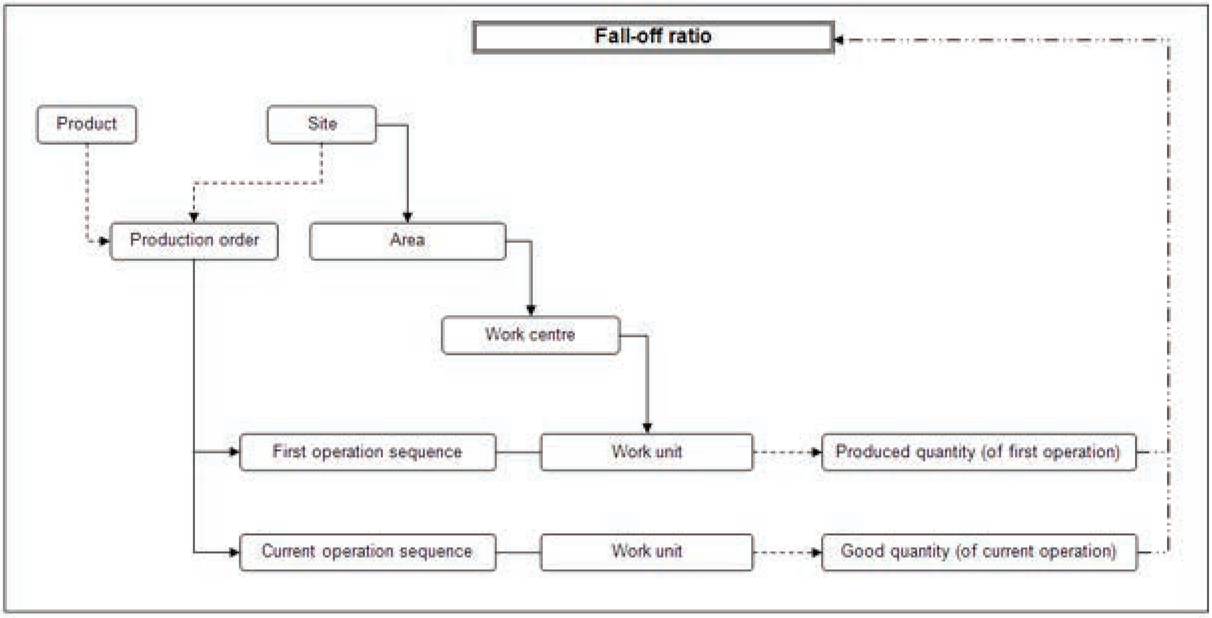


Figure A.18 — Fall-off ratio

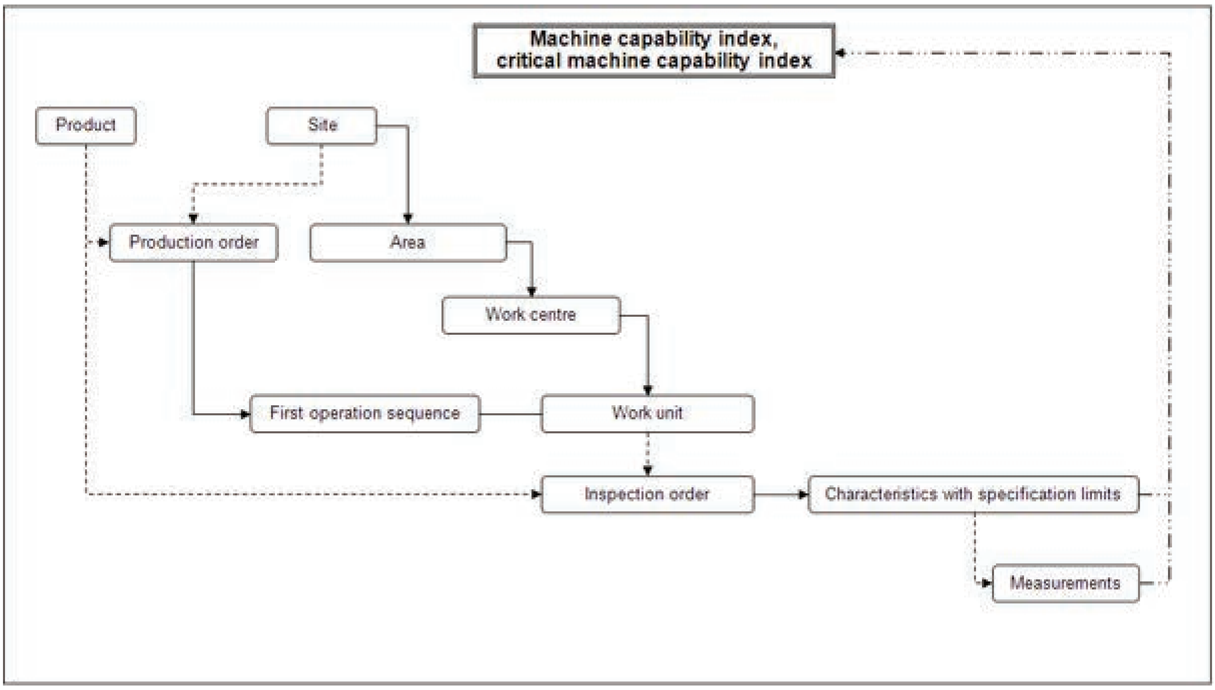


Figure A.19 — Machine capability index and critical machine capability index

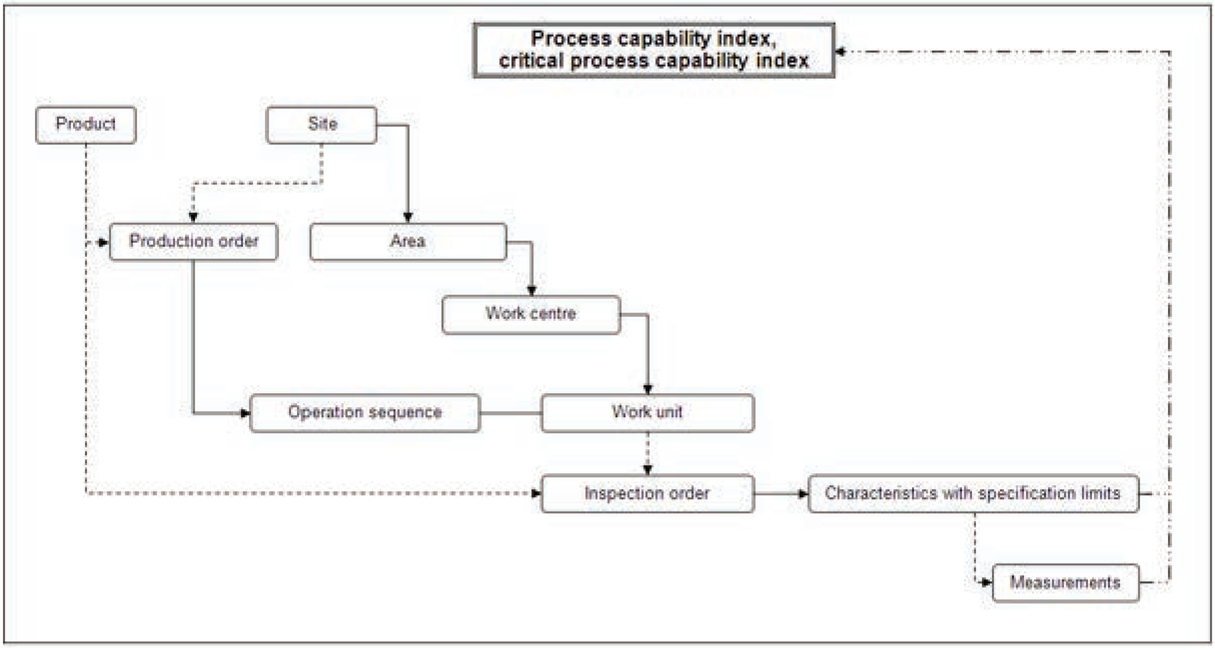


Figure A.20 — Process capability index and critical process capability index

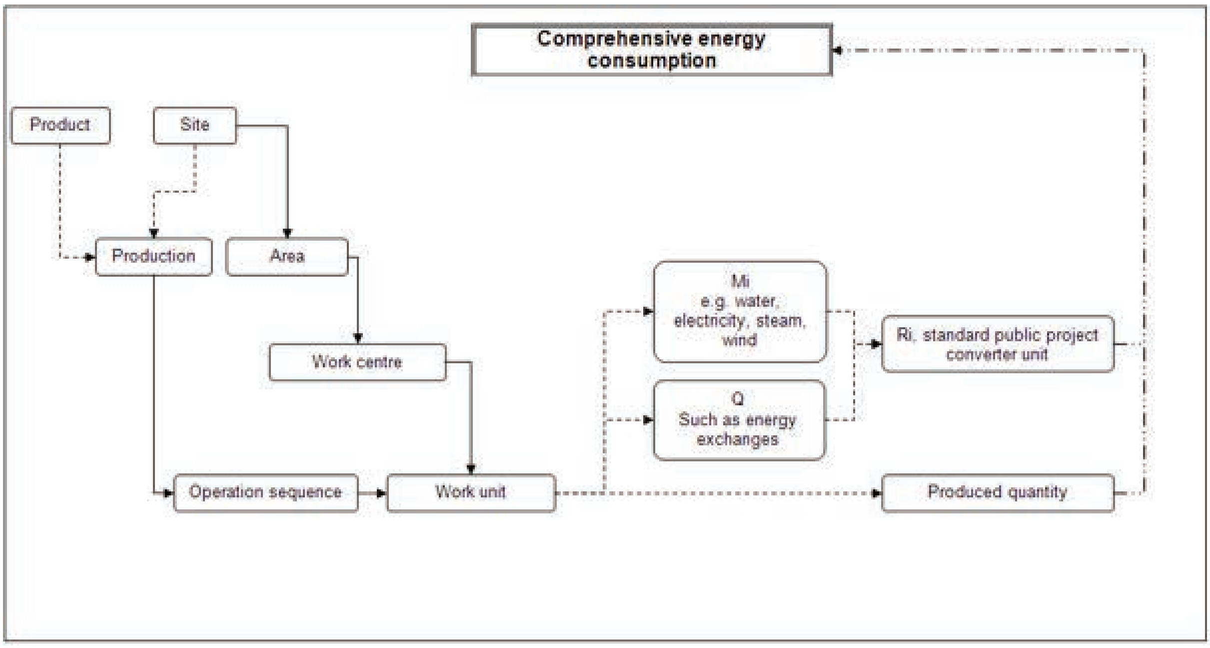


Figure A.21 — Comprehensive energy consumption

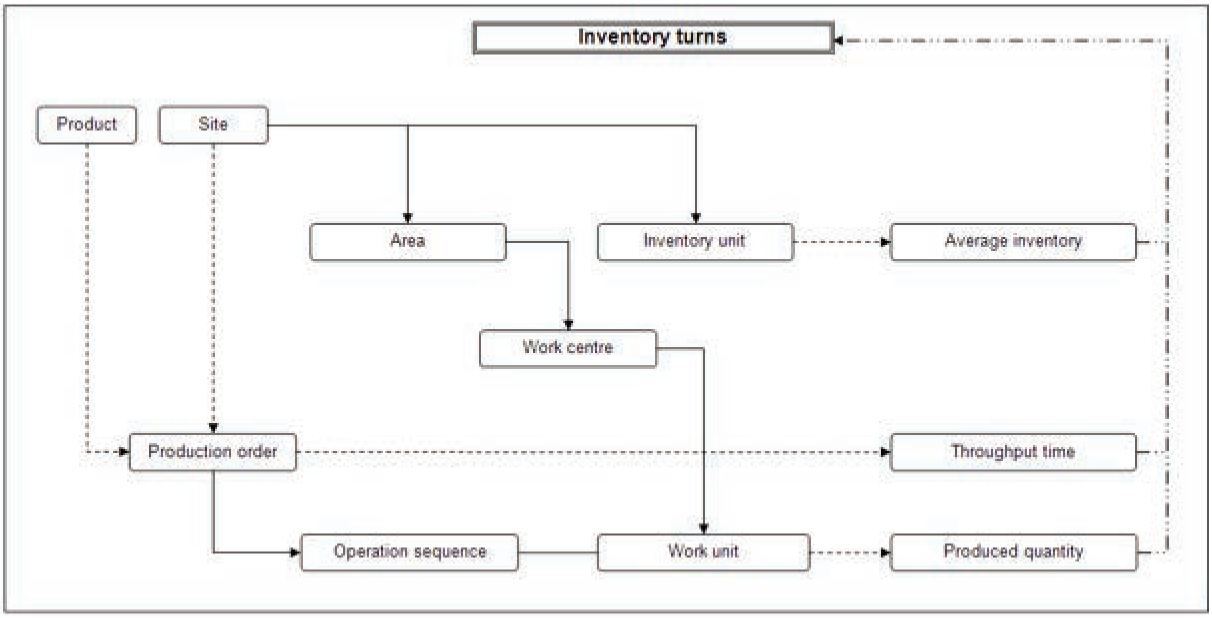


Figure A.22 — Inventory turns

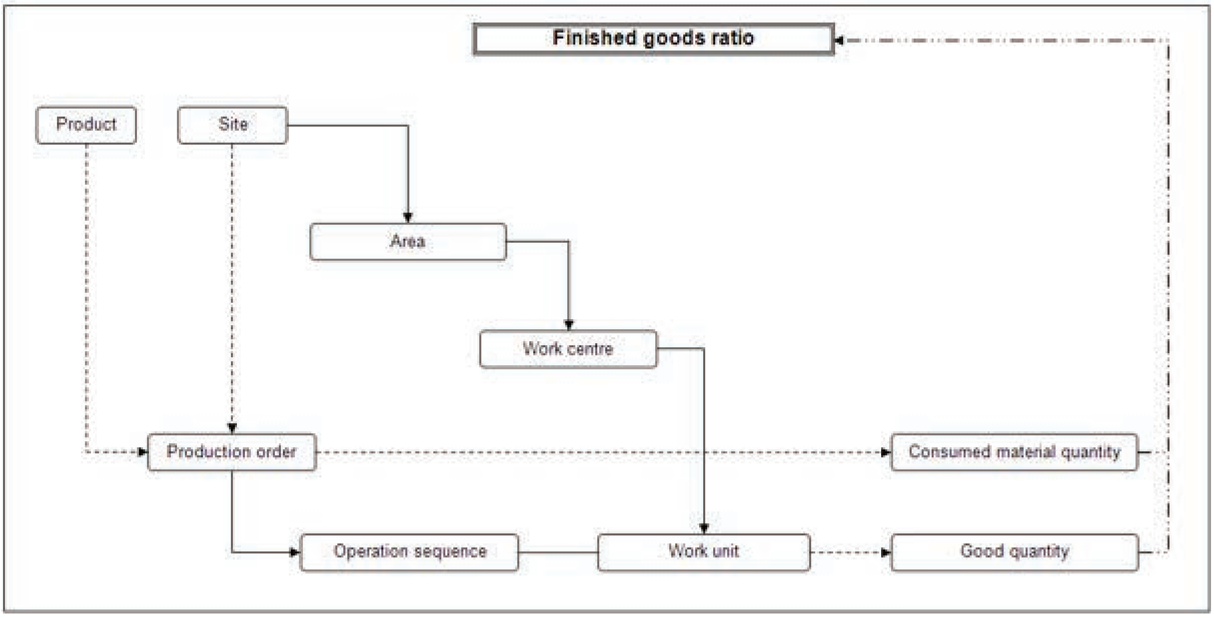


Figure A.23 — Finished goods ratio

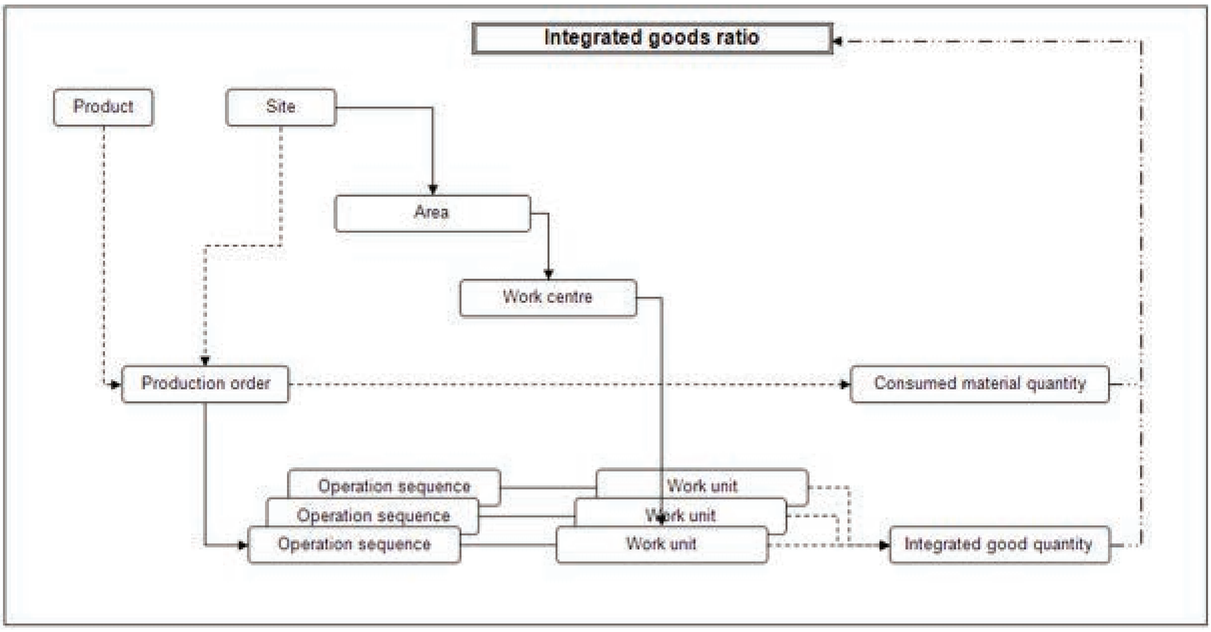


Figure A.24 — Integrated goods ratio

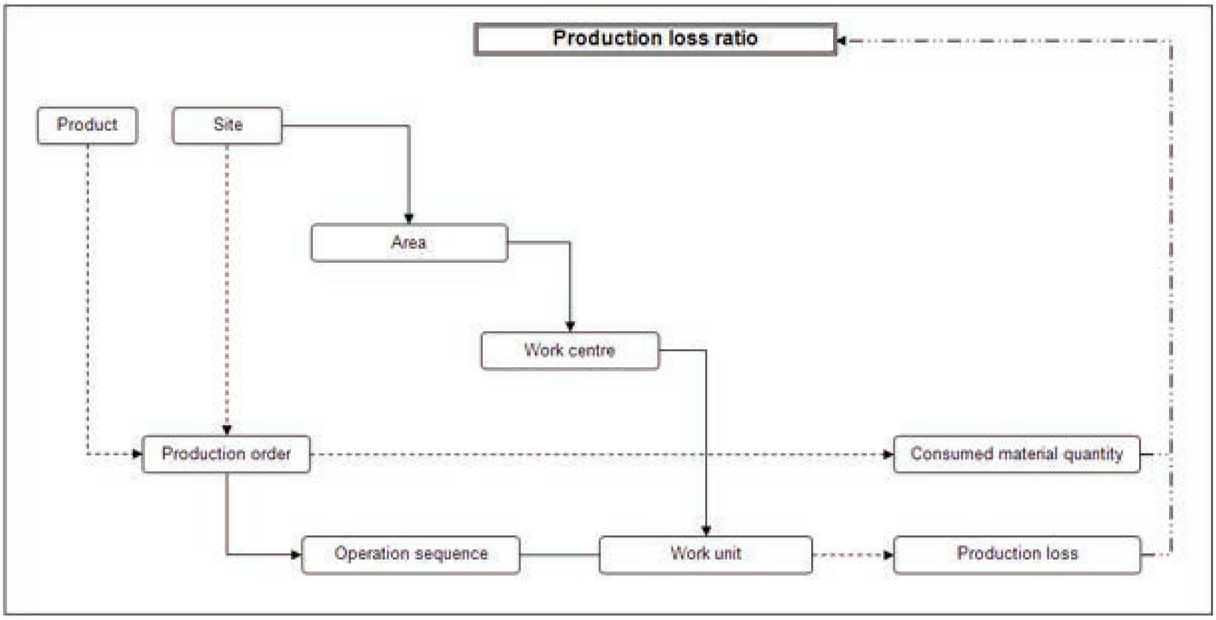


Figure A.25 — Production loss ratio

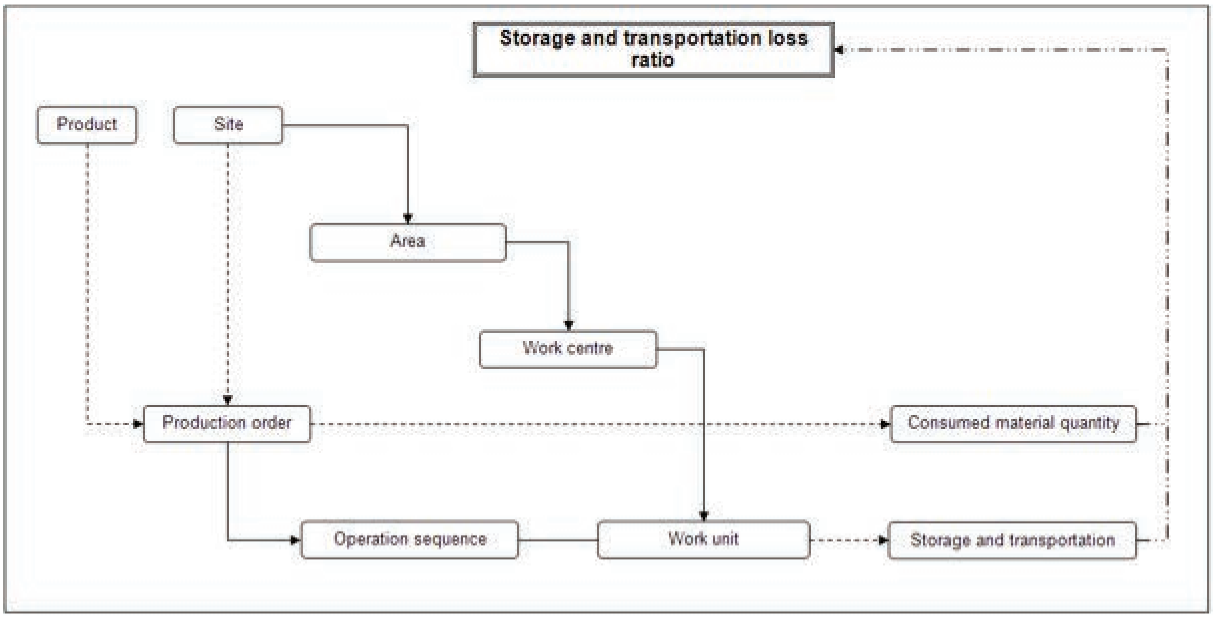


Figure A.26 — Storage and transportation loss ratio

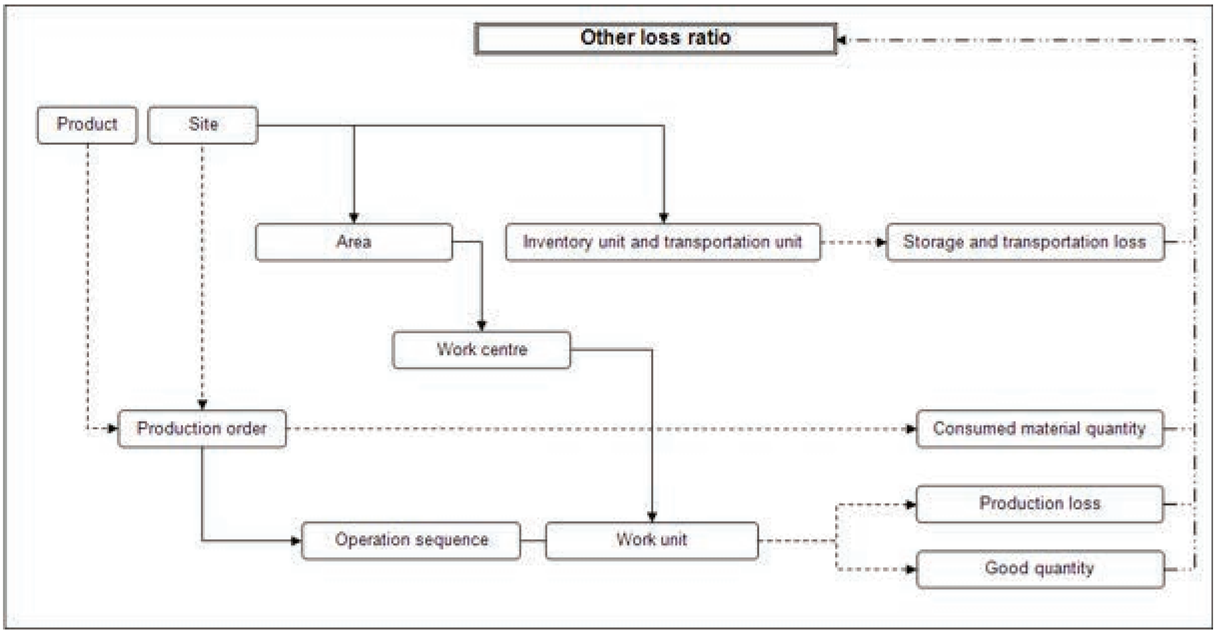


Figure A.27 — Other loss ratio

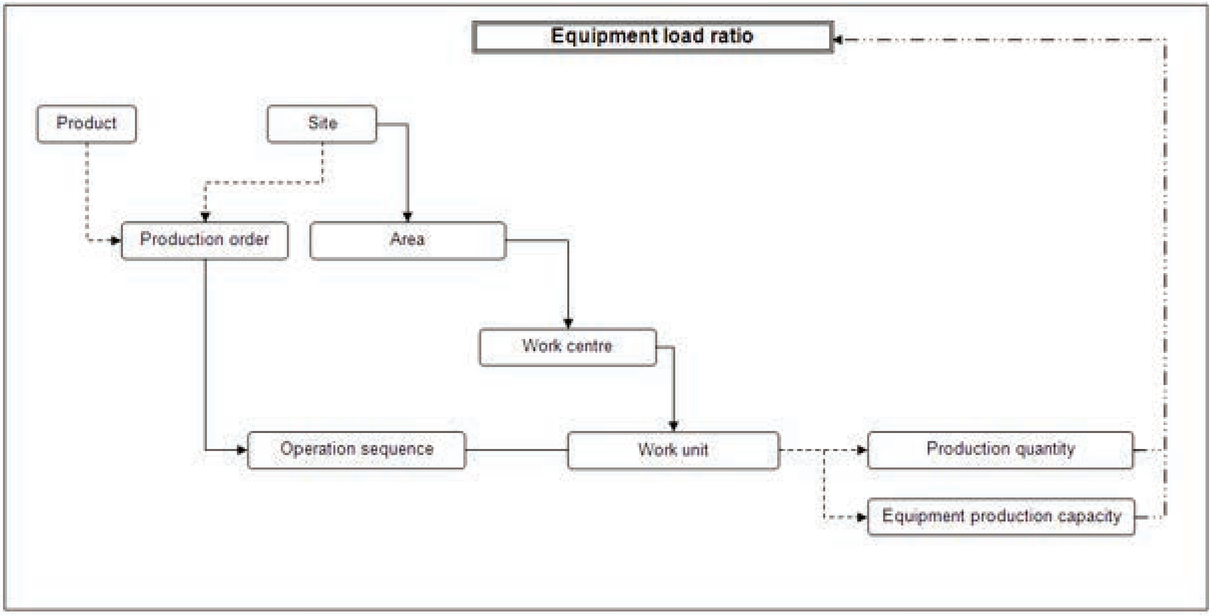


Figure A.28 — Equipment load ratio

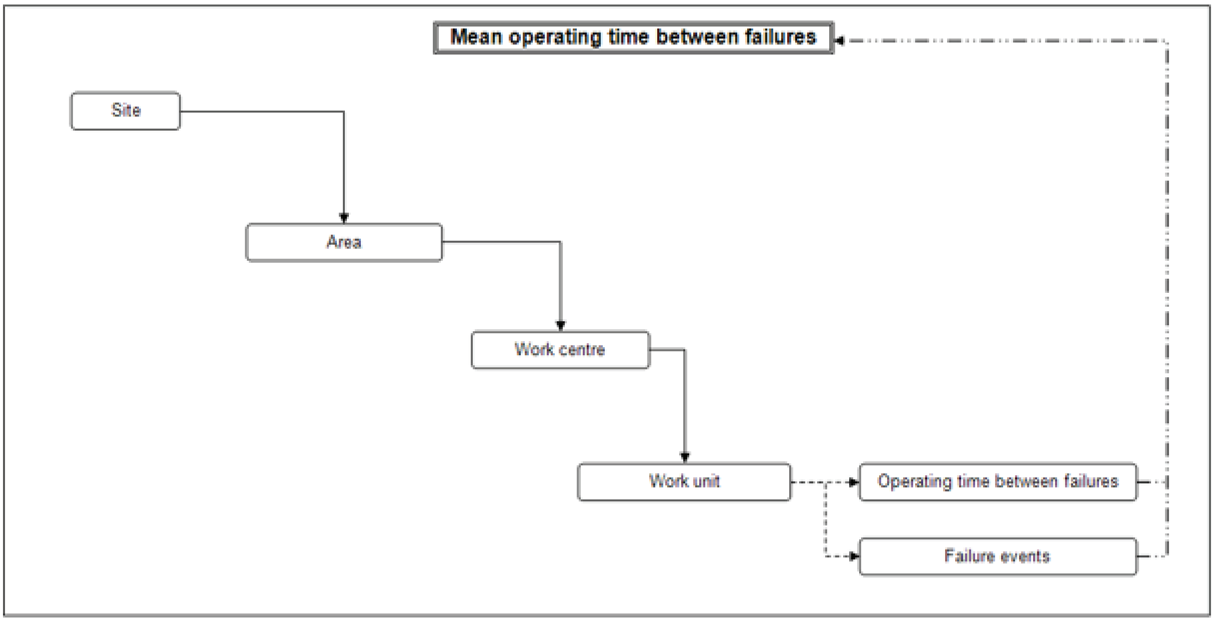


Figure A.29 — Mean operating time between failures

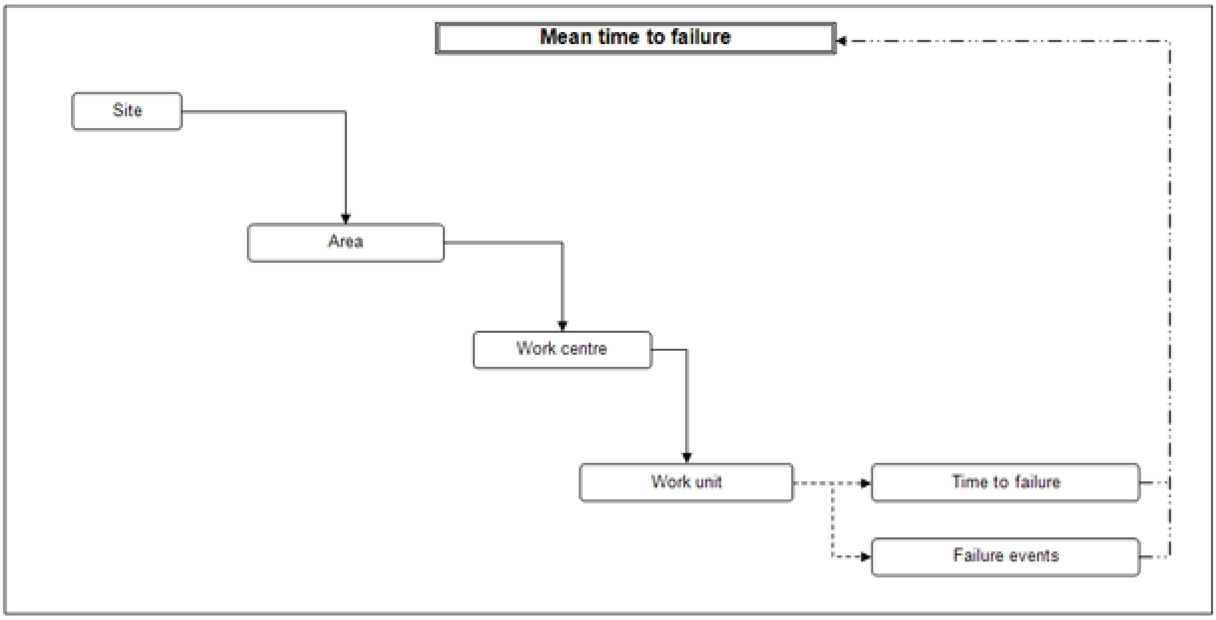


Figure A.30 — Mean time to failure

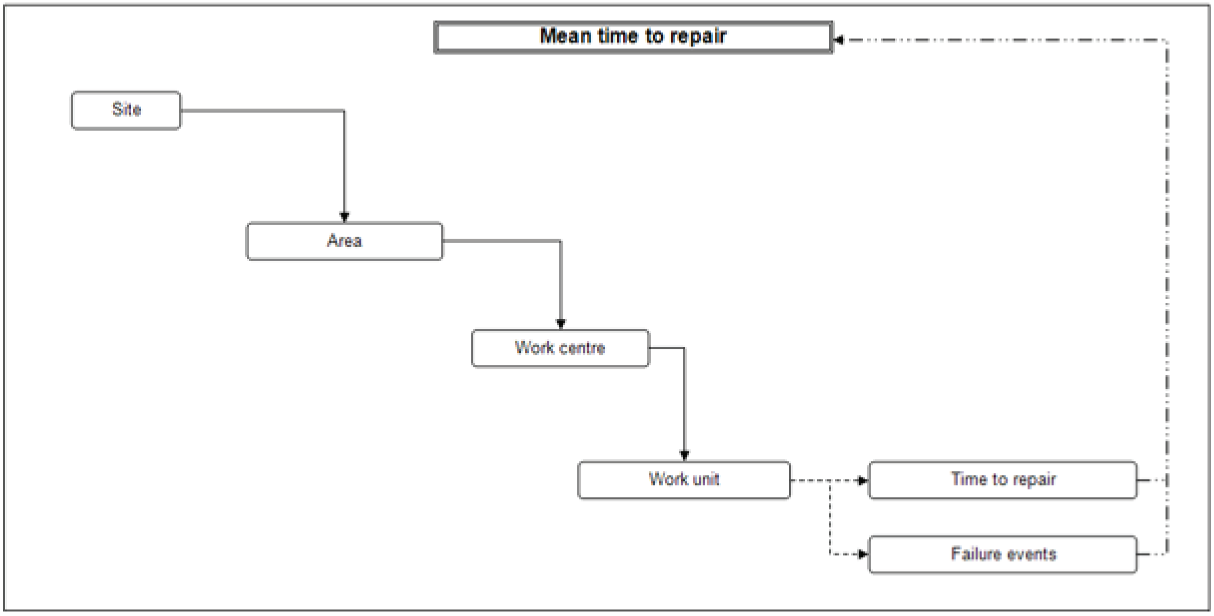


Figure A.31 — Mean time to repair

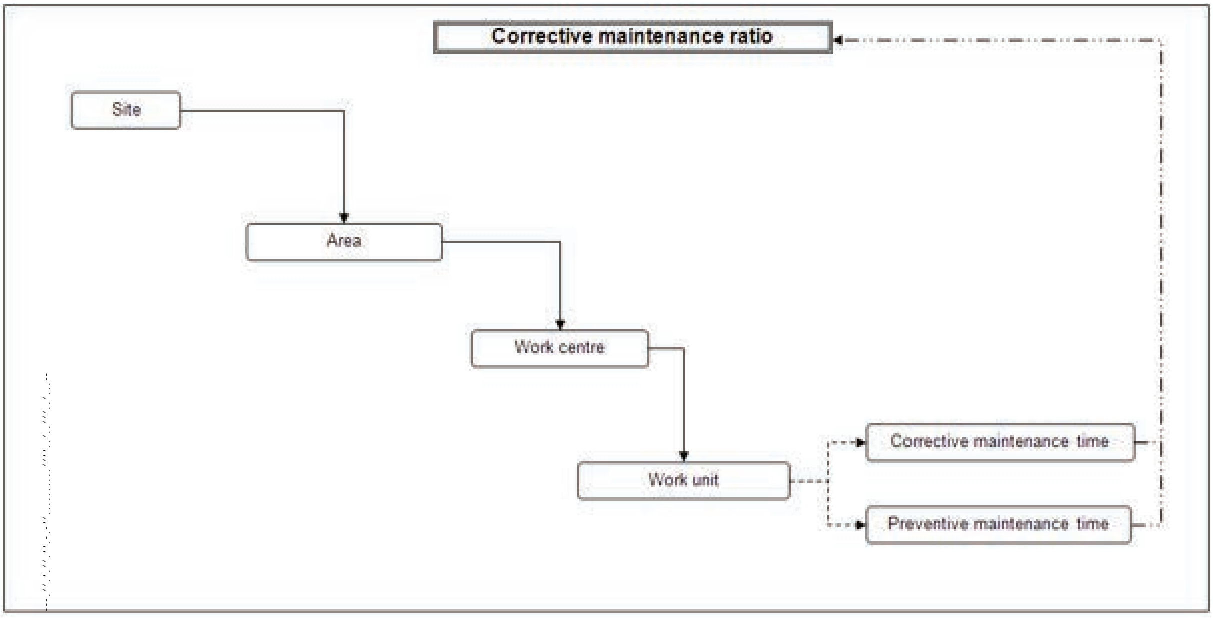


Figure A.32 — Corrective maintenance ratio

Annex B
(informative)

Alternative OEE calculation based on loss time model

B.1 General

This annex could be used to calculate the OEE (overall equipment efficiency) based on partitioning of the total time, e.g. amount of loss time for operation

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.

B.2 Time model for work units

Figure B.1 is the time model for calculation the OEE.

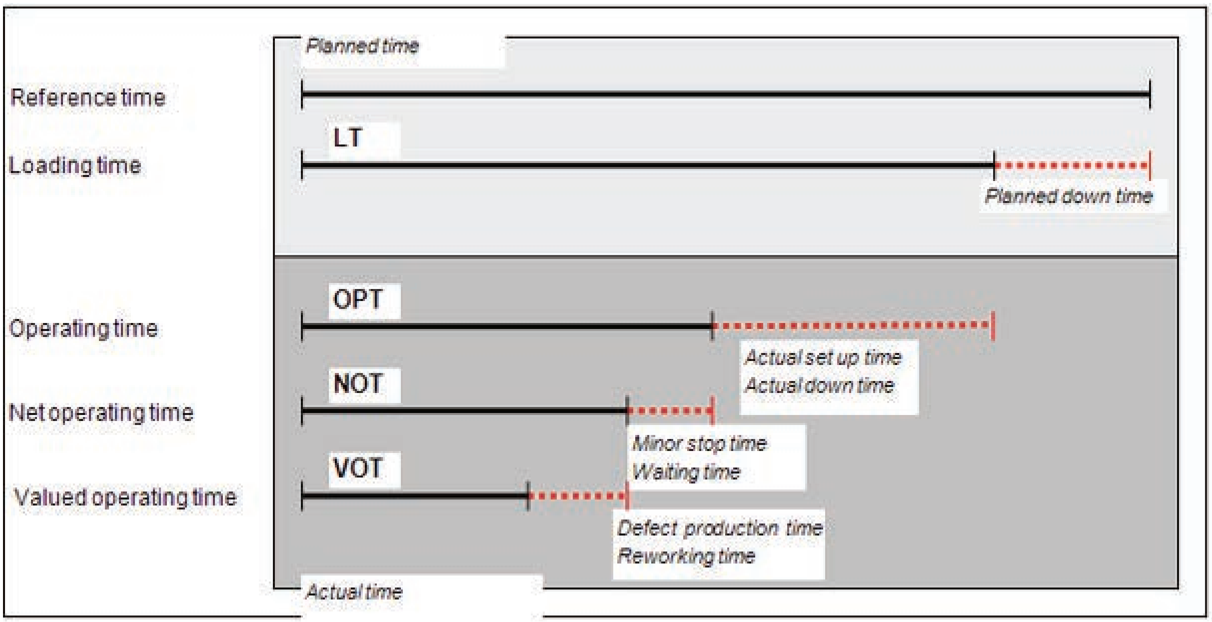


Figure B.1 — Time model for calculation of the OEE

B.3 KPIs

Tables B.1 to B.3 give KPIs.

Table B.1 — Overall equipment effectiveness index

KPI description	
Content	
Name	Overall equipment effectiveness index
ID	
Description	The OEE index represents the availability of a work unit, the effectiveness of the work unit, and the finished goods ratio integrated in a single indicator.
Scope	Work unit, product, defect type
Formula	OEE index = Availability * Performance rate * Finished goods ratio
Unit of measure	%
Range	Min: 0% Max: 100%
Trend	The higher, the better
Context	
Timing	On-demand, periodically
Audience	Supervisor, management
Production methodology	Batch, continuous
Effect model diagram	
Notes	Overall equipment effectiveness (OEE) is a measure for the efficiency of machines and/or plants, manufacturing cells with several machines or an entire assembly line. 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. The OEE index represents the used availability, the effectiveness of the work unit, and their finished goods rate summarized in a characteristic number. With the bench mark of manufacturing processes by means of the OEE index the criteria for comparability are to be examined before. The indicator finished goods ratio is specified in Table 26.

Table B.2 — Availability

KPI description	
Content	
Name	Availability
ID	
Description	Availability indicates the proportion of time the equipment is actually utilized (OPT) against the loading time (LT). The availability represents the magnitude of equipment stoppage loss.
Scope	Work unit
Formula	Availability = OPT / LT
Unit of measure	%
Range	Min: 0% Max: 100%
Trend	The higher, the better
Context	
Timing	On-demand, periodically
Audience	Supervisor, management
Production methodology	Batch, continuous
Effect model diagram	
Notes	The term availability is also called usage grade

Table B.3 — Performance ratio

KPI description	
Content	
Name	Performance ratio
ID	
Description	The performance ratio relates the net operating time (NOT) to the operating time (OPT)
Scope	Work unit, product, production order
Formula	Performance ratio = NOT / OPT
Unit of measure	%
Range	Min: 0% Max: 100% The 100% can be exceeded, if the planned production time for each work unit is larger than the actual production time
Trend	The higher, the better
Context	
Timing	On-demand, periodically, real-time
Audience	Operator, supervisor, management
Production methodology	Batch, continuous
Effect model diagram	
Notes	Performance rate is the measure for the performance of a process. The gap of the target cycle time and the actual cycle time is represented. This gap represents the speed loss. The performance rate is a characteristic number that can be calculated and displayed in short periodic distances at run time of a machine. Performance rate is also called efficiency factor or performance.

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[10] DIN NA 060-30-05-03, *Definition of MES and Quality Management Requirements on MES*

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