Revised DIS for final handling (DIS2/FDIS)

Formalism on document stage (WD) comes from original document which was worked on by editors group.
Document stage will be adjusted after WG9 meeting on May 13th 2013

ISO TC 184/SC 5 N

Date: 2013-05-10

ISO/WD 22400-2

ISO TC 184/SC 5/WG 9 **/ N23**

Secretariat: ANSI

Manufacturing operations management — Key performance indicators — Part 2: Definitions and descriptions of KPIs

Document type: International Standard
Document subtype:
Document stage: (20) Preparatory
Document language: E

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Foreword

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The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

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.

ISO 22400-2 was prepared by 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 planned 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

— Part 3: Exchange and use (planned)

— Part 4: Relationships and dependencies (planned)

Introduction

This International Standard focuses on Key Performance Indicators (KPIs) for manufacturing operations management.

KPIs are defined as quantifiable and strategic measurements that reflect an organization's critical success factors. Key Performance Indicators 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 is defined in IEC 62264. It defines a functional hierarchy model of a manufacturing enterprise. see Figure 1. 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.

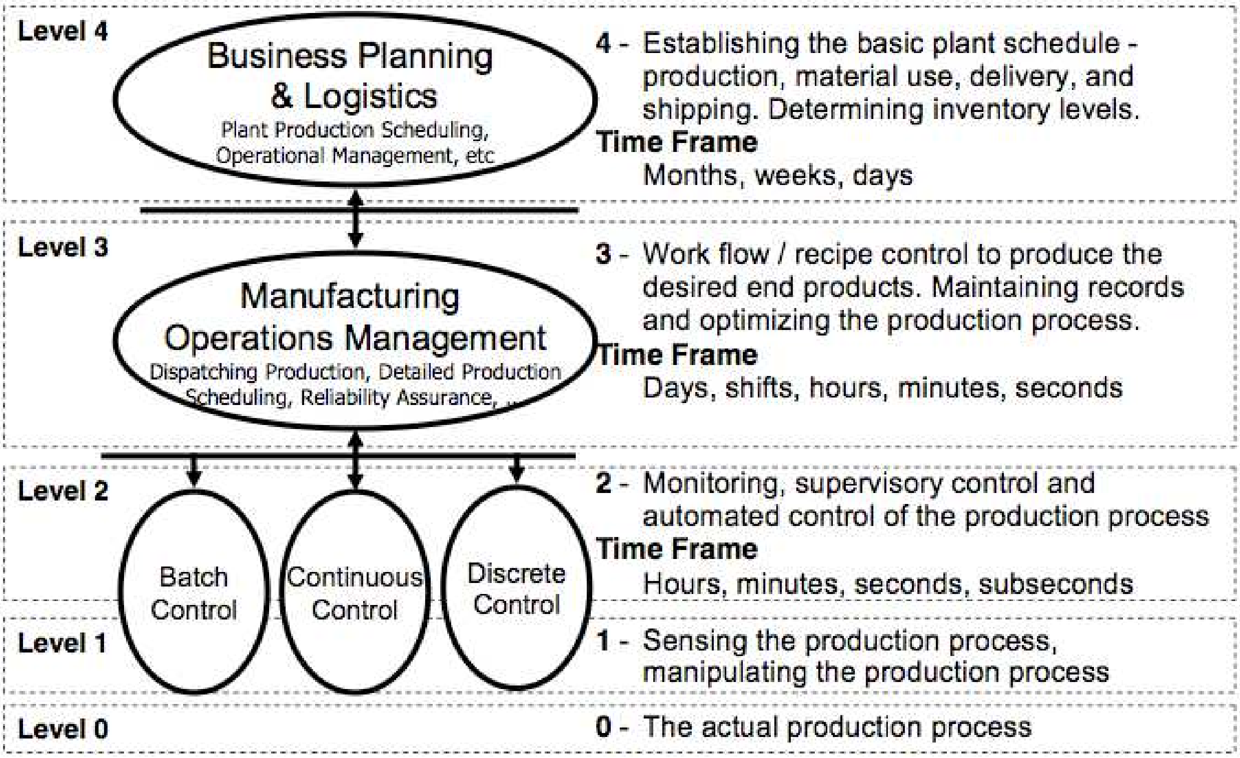


Figure 1 — Functional hierarchy (from Figure 2 in IEC 62264-3)

The IEC 62264 standard also defines an hierarchical structure for the physical equipment, see Figure 2. Enterprise, site and areas are generic terms, whereas there are specific terms for work centers and work units that apply to batch production, continuous production, discrete or repetitive production, and for storage and movement of materials and equipment.

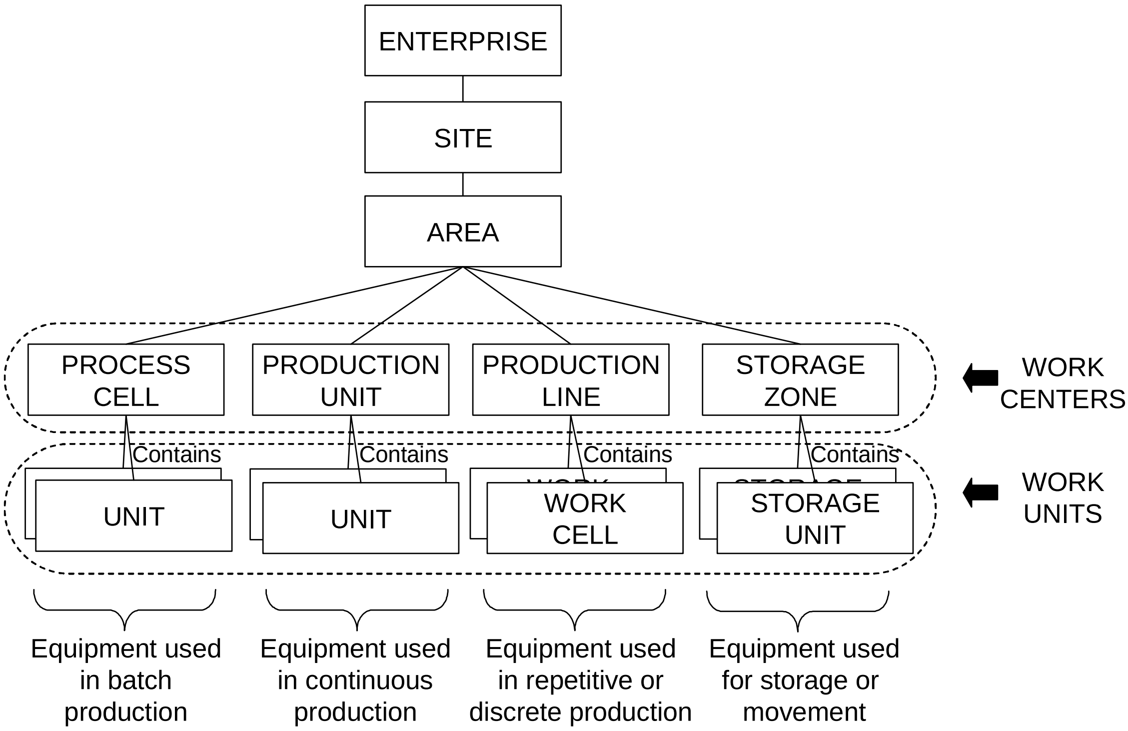


Figure 2 — Role based equipment hierarchy (from Figure 8 in IEC 62264-3)

This International Standard defines the KPIs “residing” at Level 3, i.e., related to manufacturing operations management. 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 International Standard use the most generic terms possible, e.g., work centers and work units, instead of industry specific terms.

Manufacturing Operations Management, sometimes referred to as Manufacturing Execution Systems (MES), is modeled using four major categories of operations to be managed: production operations management, maintenance operations management, quality operations management, and inventory operations management. Each category is further detailed by an activity model. Each activity model includes eight activities: detailed scheduling, dispatching, execution management, resource management, definition management, tracking, data collection, and 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 more effectively used in 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; and

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 key performance indicators (KPIs) for the purpose of managing manufacturing operations. The audience are 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 out of scope for this International Standard. 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 (behavior management) of important facts and relationships within the company

Manufacturing operations management — Key performance indicators — Part 2: Definitions and descriptions of KPIs

1 Scope

ISO 22400 defines Key Performance Indicators used in Manufacturing Operations Management.

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 behavior, unit/dimension and rating. It also indicates the User group where the KPIs are used, and to what production methodology they fit.

Referring to equipment the KPI’s in this standard relates to work units.

2 Abbreviations and symbols

Most of the abbreviations specified in this International Standard are composed of the first letter for each word in the phrase being abbreviated. In some cases, abbreviations deviate from this general rule to accommodate common industrial practice

$\bar{x}$	Arithmetic average
$\bar{\bar{x}}$	Average of average values
σ	Estimated deviation
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 queueing time
ASUT	Actual set up 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 maintanance time
C_p	Process capability index
C_{pk}	Critical process capability index
DAY	Day
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
MEPC	Maximum equipment production capacity
MOM	Manufacturing operation management
NEE	Net overall equipment effectiviness index
NOT	Net operating time
OC	operation cluster
OEE	Overall equipment effectiviness index
OL	Other loss
OPT	Operating time
PBT	Planned busy time
PL	Production loss
PMT	Preventive maintanance 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
PSUT	Planned setup time
REPC	Rated equipment production capacity
RMI	Raw material inventory
RQ	Rework quantity
s	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
WU	work unit
σ^2	Variance

3 Structure of KPI definitions

3.1 Attributes of KPIs

KPI definitions shall be expressed using the structure in Figure 3 in accordance with ISO 22400-1.

KPI description	
Content:	
Name	
Id	
Description	
Scope	
Formula	
Unit-of-Measure	
Range	
Trend	
Context:	
Timing	
Audience	
Production methodology	
Effect model diagram	
Notes	

Figure 3 – Structure of KPI definition

3.2 Name

Name of the KPI.

3.3 ID

A user defined unique identification of the KPI in the user environment.

3.4 Description

A brief description of the KPI.

3.5 Scope

Identification of the element that the KPI is relevant for. This can be a work unit, work center or production order, product or personnel.

3.6 Formula

The mathematical formula of the KPI defined in terms of elements.

3.7 Unit of measure

The basic unit or dimension in which the KPI is expressed.

3.8 Range

Defines the upper and lower logical limits of the KPI

3.9 Trend

Is the information about the improvement direction, higher is better or lower is better.

3.10 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., one time per day

3.11 Audience

Defines the user group typically using this KPI. The user groups used in this International Standard 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

3.12 Production methodology

Defines the production methodology that the KPI is generally applicable for

- Discrete
- Batch
- Continuous

3.13 Effect model diagram

Defines the clause number of the corresponding 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

3.14 Notes

Can contain additional information related to the KPI. Typical examples are

- Constraints

- Usage
- Other information

4 Elements used in KPI description

4.1 Definitions

For the purpose of this document the following definitions apply

4.1.1 Reference time

A reference time is the base timeline used for the time models defined in this International Standard. It is the planned maximum time interval available for production and maintenance tasks.

EXAMPLE 1
A reference time may be a calendar day with 24 hours.

EXAMPLE 2
A reference time may be a week.

4.1.2 Planned time

The duration a specific time period, e.g., the duration of an operation or the duration of a resource state should have according to the planning,

4.1.3 Actual time

The realized duration of a specific time period, e.g., the duration of an operation or the duration of a resource state.
NOTE:
Actual time periods may be less than, equal to, or greater than corresponding planned time periods.

4.1.4 Time model

A partition of the reference time

4.2 Time elements

4.2.1 Notations

In this model, a production order is processed and completed when one or more tasks are performed by a set of production resources, e.g., production personnel, equipment and materials.

The identifying name for a time element is extended with a simple abbreviation in round brackets, which is used below in KPI calculations.

Definitions of maintenance elements have been extracted from the standard IEC 60050-191 ed1.0 International Electro-technical Vocabulary. Chapter 191: Dependability and quality of service.

NOTE: The term “time” in the element definition refers to a duration of time.

4.2.2 Planned times

4.2.2.1 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.

4.2.2.2 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.

4.2.2.3 Planned unit setup time (PSUT)

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

4.2.2.4 Planned busy time (PBT)

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

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

4.2.2.5 Planned run time per unit (PRI)

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

4.2.3 Actual times

4.2.3.1 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.

4.2.3.2 Actual unit processing time (AUPT)

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

4.2.3.3 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.

4.2.3.4 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.

4.2.3.5 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 (i.e. lunch). It shall be the difference between login and logout excluding breaks.

4.2.3.6 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.

4.2.3.7 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.

4.2.3.8 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.

4.2.3.9 Actual unit delay time (ADET)

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

4.2.3.10 Actual unit setup time (ASUT)

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

4.2.3.11 Actual transport time (ATT)

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

4.2.3.12 Actual unit processing time (AUPT)

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

4.2.3.13 Actual unit busy time (AUBT)

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

4.2.3.14 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.

4.2.4 Maintenance times

4.2.4.1 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 and production time related to the orders being processed and without delay times.

4.2.4.2 Time to repair (TTR)

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

4.2.4.3 Time to failure (TTF)

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

4.2.4.4 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.

4.2.4.5 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 (IEC 60050-191).

4.2.4.6 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 (IEC 60050-191).

4.3 Time model for work units

This model applies to time considerations for the use of work units. Figure 4 shows the relationship of the defined periods. It is important to note that in figure 4 the difference between time elements constitutes a specific loss.

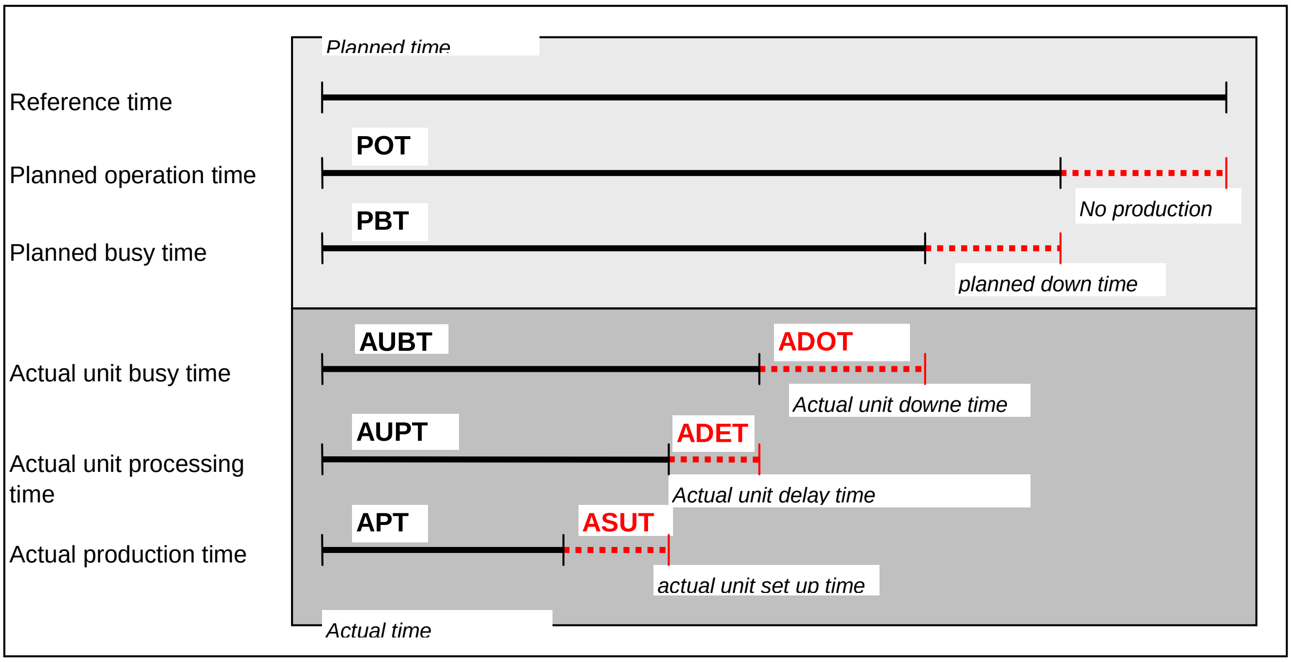


Figure 4 – Time lines for work units

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 0 of this part of ISO 22400.

4.4 Time model for production order

This time model is valid for executing the production order. Figure 5 shows the production order processing time line consisting of multiple occurrences of operations equipment time lines (see Figure 4). It should be noted that the work unit time lines for a production order may be carried out in separate operations at several work units.

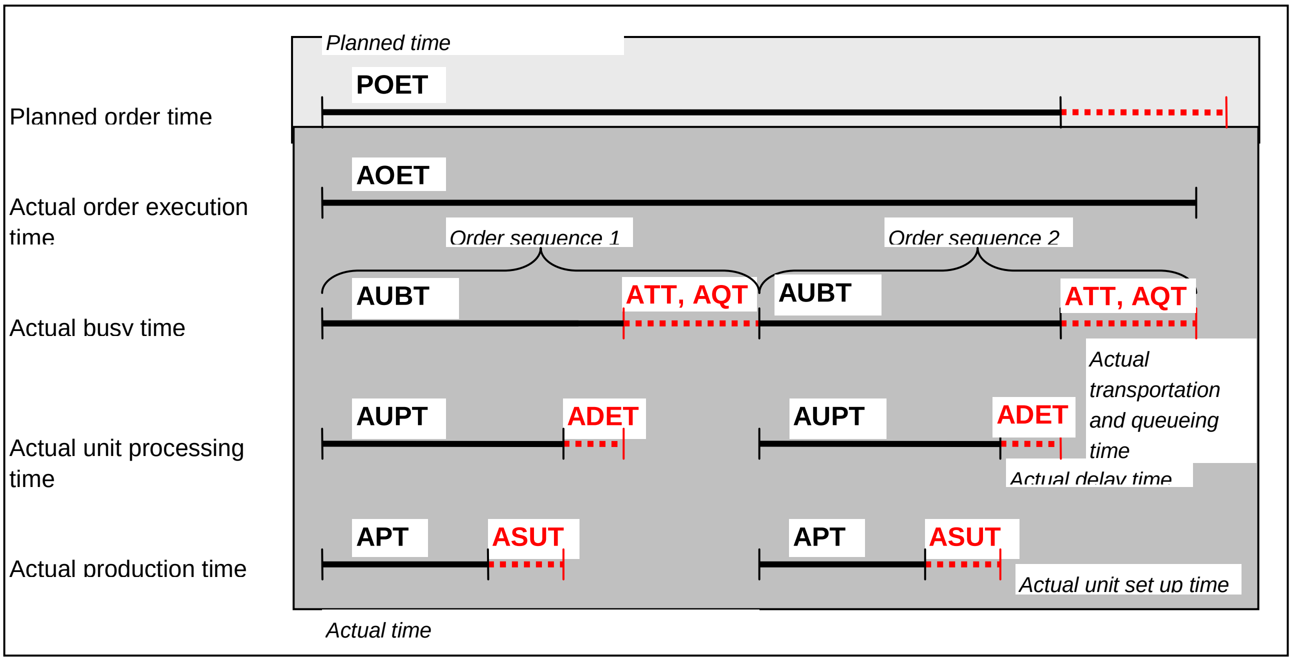


Figure 5 – Time lines for production order processing

4.5 Time model for personnel

This model applies to time considerations for personnel.

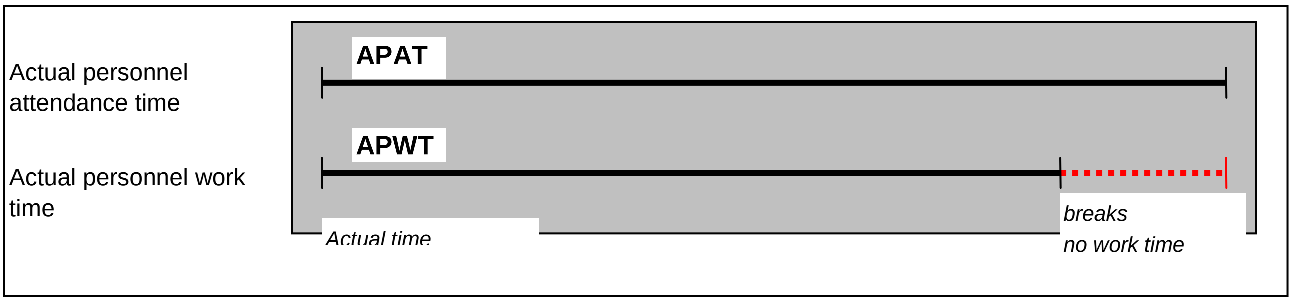


Figure 6 – Time lines for personnel

4.6 Logistical elements

4.6.1 Order quantity (POQ)

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

4.6.2 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.

4.6.3 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).

4.6.4 Good quantity (GQ)

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

4.6.5 Rework quantity (RQ)

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

4.6.6 Produced quantity (PQ)

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

4.6.7 Raw materials (RM)

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

4.6.8 Raw materials inventory (RMI)

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

4.6.9 Finished goods inventory (FGI)

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

4.6.10 Consumable inventory (CI)

These are materials which are transformed in quantity or quality during the production process and no longer available for use in production operations.

EXAMPLE
A catalyst

NOTE:
Consumables have been defined in detail in IEC 62264-1."

4.6.11 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.

4.6.12 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.

4.6.13 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

4.6.14 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

4.6.15 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

4.6.16 Equipment production capacity (EPC)

EPC is the maximum production quantity of production equipment.

NOTE:
Used in batch and continuous manufacturing

4.7 Quality elements

4.7.1 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 defined material lot

4.7.2 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 defined material lot.

4.7.3 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.

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

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

4.7.5 Upper specification limit (USL)

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

4.7.6 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.

4.7.7 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.

4.7.8 Lower specification limit (LSL)

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

4.7.9 Variance (σ)

The variance σ^2 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.

5 Description of KPIs

5.1 Worker efficiency

KPI definition	
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	Personnel
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 A.3
Notes	When calculating worker efficiency be careful of possible double counts if the worker is working on several work units or production orders simultaneously

5.2 Allocation ratio

KPI definition	
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 = $\sum$AUBT / AOET $\sum$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 A.4
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.

5.3 Throughput rate

KPI definition	
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% 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.5
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.

5.4 Allocation efficiency

KPI definition	
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 A.6
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 Note that the allocation efficiency is only affected by the actual unit idle time while the availability KPI takes the actual unit delay time into account.

5.5 Utilization efficiency

KPI definition	
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 A.7
Notes	This indicator identifies the productivity of work units. Because only the production time effects an added value which will be paid by the market, the goal should be to get a high indicator value.

5.6 Overall equipment effectiveness index

KPI definition	
Content	
Name	Overall Equipment Effectiveness Index
ID	
Description	The OEE Index represents the availability of a work unit (see 5.8), the effectiveness of the work unit (see 5.9), and the quality ratio (see 5.10) KPI's 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 A.8
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 fig 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 a comparability should be checked.

5.7 Net equipment effectiveness index

KPI definition	
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 and the Quality Ratio KPI 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 A.9
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.

5.8 Availability

KPI definition	
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 A.10
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 utilisation or capacity factor.

5.9 Effectiveness

KPI definition	
Content	
Name	Effectiveness
ID	
Description	It 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 A.11
Notes	The effectiveness can be calculated in short periods and indicates how effective a work unit will be during the production time. The definition uses the element planned runtime per unit (PRU) also known as cycle time. This defines how long it takes to produces a fixed quantity if produced material. Batch and continuous production methodologies typically express the expected output per time as the quantity that can be produced in a defined period of time (e.g., HL/hour). This value is reciprocal to the PRU element and can be converted into a PRU by defining a fixed quantity of the produced material.

5.10 Quality ratio

KPI definition	
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 A.12
Notes	This indicator is usable as real-time indicator for the operator level. .

5.11 Setup ratio

KPI definition	
Content	
Name	Setup ratio
ID	
Description	The Setup ratio is the ratio of Actual Setup Time (ASUT) to Actual Unit Processing Time (AUPT). It defines the percentage time used for setup compared to the actual time used for processing.
Scope	Work unit, product, production order
Formula	Setup ratio = ASUT / 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 A.13
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 set up time in relation to the processing time of a production order which adds value to the product. For an enterprise a high setup rate means a consumption of (potential) value added time. The setup rate 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.

5.12 Technical efficiency

KPI definition	
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 A.14
Notes	The technical efficiency does not include setup time in contrast to the utilisation efficiency. 100% corresponds to maximum attainable technical efficiency without malfunction-caused interruptions.

5.13 Production process ratio

KPI definition	
Content	
Name	Production Process Ratio
ID	
Description	The Production Process Ratio defines 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 A.15
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.

5.14 Actual to planned scrap ratio

KPI definition	
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 A.16
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 defined 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 defined in the ERP system in order to ensure the necessary material allocation.

5.15 First pass yield

KPI definition	
Content	
Name	First Pass Yield
ID	
Description	The 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 A.17
Notes	For identifying the first pass it is necessary to label each part with an identification number (serial number). Refer to 4.7.1 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.

5.16 Scrap ratio

KPI definition	
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 A.18
Notes	The scrap ratio will be also used for the commercial rating.

5.17 Rework ratio

KPI definition	
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 A.19
Notes	The rework ratio will be also used for the commercial rating.

5.18 Fall off ratio

KPI definition	
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 on the current production order sequence
Scope	Production order sequence, Product
Formula	Fall off ratio of the current production order sequence = $\frac{PQ_{\text{of first production order sequence}} - GQ_{\text{of current production order sequence}}}{PQ_{\text{of first production order sequence}}}$
Unit of measure	%
Range	Min: 0% Max: 100%
Trend	The lower, the better
Context	
Timing	On-demand
Audience	Operator, supervisor, management
Production methodology	Discrete, batch
Effect model diagram	See A.20
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. It can be used "Finished Goods Ratio" (section 8.25) to calculate the quality.

5.19 Machine capability index

KPI definition	
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	
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 A.21
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 defined by customer requirements. Typical value is C_m > 1,66. The value can be used for characteristic with upper and lower specification limits only.

5.20 Critical machine capability index

KPI definition	
Content	
Name	Critical machine capability index
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	
Formula	$C_{mku} = (USL - \bar{x}) / (3 * s)$; $C_{mkl} = (\bar{x} - LSL) / (3 * s)$ $C_{mk} = Min(C_{mku}, C_{mkl})$
Unit of measure	
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 A.21
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 defined by customer requirements. Typical value is C_{mk} > 1,66.

5.21 Process capability index

KPI definition	
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	
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 A.22
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 defined quantity intervals with small samples (1-25). A process is usually called capable if the process capability index is > 1,33. $\hat{\sigma}$ will be calculated based on a confidence factor from the standard deviation, depending on the inspection sample size.

5.22 Critical process capability index

KPI definition	
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 (UCL,LCL) and its average of averages ($\overline{\overline{x}}$). 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	$C_p = (USL - LSL) / (6 * \hat{\sigma})$
Unit of measure	$C_{pku} = (USL - \overline{\overline{x}}) / (3 * \hat{\sigma})$; $C_{pkl} = (\overline{\overline{x}} - LSL) / (3 * \hat{\sigma})$ $Cpk = Min (C_{pku}, C_{pkl})$
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 A.22
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 defined quantity intervals with small samples (1-25). A process is usually called capable if the process capability index is > 1,33. $\hat{\sigma}$ will be calculated based on a confidence factor from the standard deviation, depending on the inspection sample size.

5.23 Comprehensive energy consumption

KPI definition	
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	$e = E/PQ = (\sum Mi*Ri + Q) / PQ$ 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 / quantity unit
Range	Min: 0% Max: 100%
Trend	The lower, the better
Context	
Timing	On-demand, periodically
Audience	Operator, supervisor, management
Production methodology	Discrete, batch, continuous
Effect model diagram	See A.23
Notes	Indicators to measure the consumption of energy are used by enterprises for energy savings, environmental protection, and cost reduction. 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 requires 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 / ton; for electricity the unit of Ri is standard quantity / kilowatt-hour.) The Comprehensive Energy Consumption indicator is used with a collection of standard quantity conversion tables, which are unique for different industries	

5.24 Inventory turns

KPI definition	
Content	
Name	Inventory Turns
ID	
Description	Inventory Turns is defined 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	
Formula	Inventory Turns = Throughput (TH) / average inventory
Unit of measure	Time unit
Range	Min: 0% Max: 100%
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 A.24
Notes	The definition 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 have been defined 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.	

5.25 Finished goods ratio

KPI definition	
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 A. 25
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. 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 (5.10).

5.26 Integrated goods ratio

KPI definition	
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 A.26
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” rises 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.

5.27 Production loss ratio

KPI definition	
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 A.27
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.

5.28 Storage and transportation loss ratio

KPI definition	
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 A.28
Notes	See also production loss ratio (5.27)

5.29 Other loss ratio

KPI definition	
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 A.29
Notes	The Other Loss Ratio evaluates loss that is not occurred during production, storage, or transportation. See also production loss ratio (5.27)

5.30 Equipment load ratio

KPI definition	
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 defined 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 A.
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, profits 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.

5.31 Mean operating time between failures

KPI definition	
Content	
Name	Mean operating time between failures
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 A.31
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 (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_i is obtained to calculate the MTBF. The MTBF is the sum of MTTR and MTTF.

5.32 Mean time to failure

KPI definition	
Content	
Name	Mean time to failures
ID	
Description	The mean time to failures 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	$MTTF = \frac{\sum_{i=1}^{i=FE} TTF_i}{FE+1}$
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 A.32
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. (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_i is obtained to calculate the MTTF.

5.33 Mean time to repair

KPI definition	
Content	
Name	Mean time to repair
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	$MTTR = \frac{\sum_{i=1}^{i=FE} TTR_i}{FE+1}$
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 A.33
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 (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_i is obtained to calculate the MTTR.

5.34 Corrective maintenance ratio

KPI definition	
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 A.34
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.

6 Conformance

To be compliant with the requirements of ISO 22400-2, KPIs shall conform to the relevant descriptions in clause 4.

Annex A
(normative)

Effect models

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 failures	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 busy 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 set up time (ASUT)											●															
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 (s)																			●	●						
	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) defines 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 defines a method of manufacturing (e.g., drilling, turning, hardening, etc.). 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 center or a site. The operation clusters are hierarchically defined. An operation cluster is within a hierarchical level a configuration of one or more work centers up to a site.

A.3 Effect model diagram key

The following key applies to all the figures in this clause.

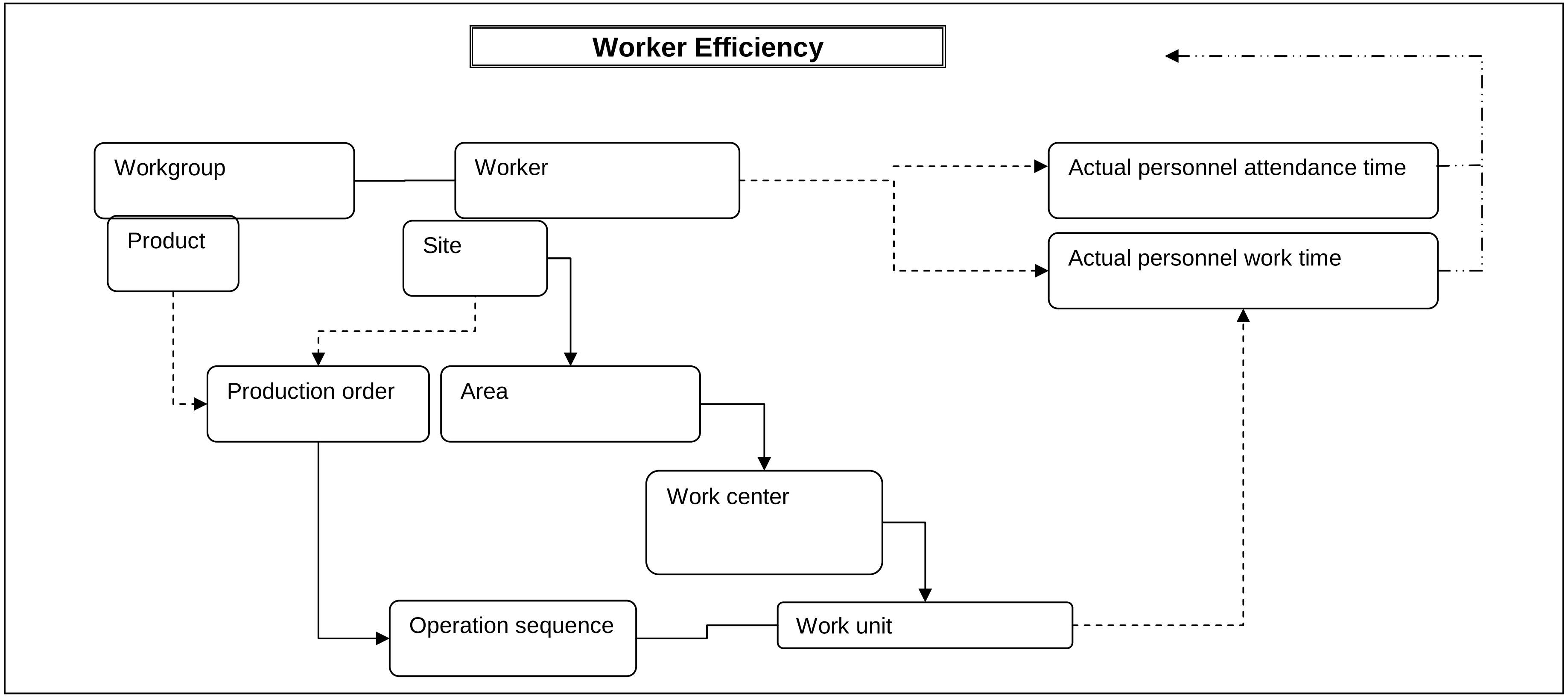
results, through use of a formula, in a KPI

includes (a 1:1 relationship)

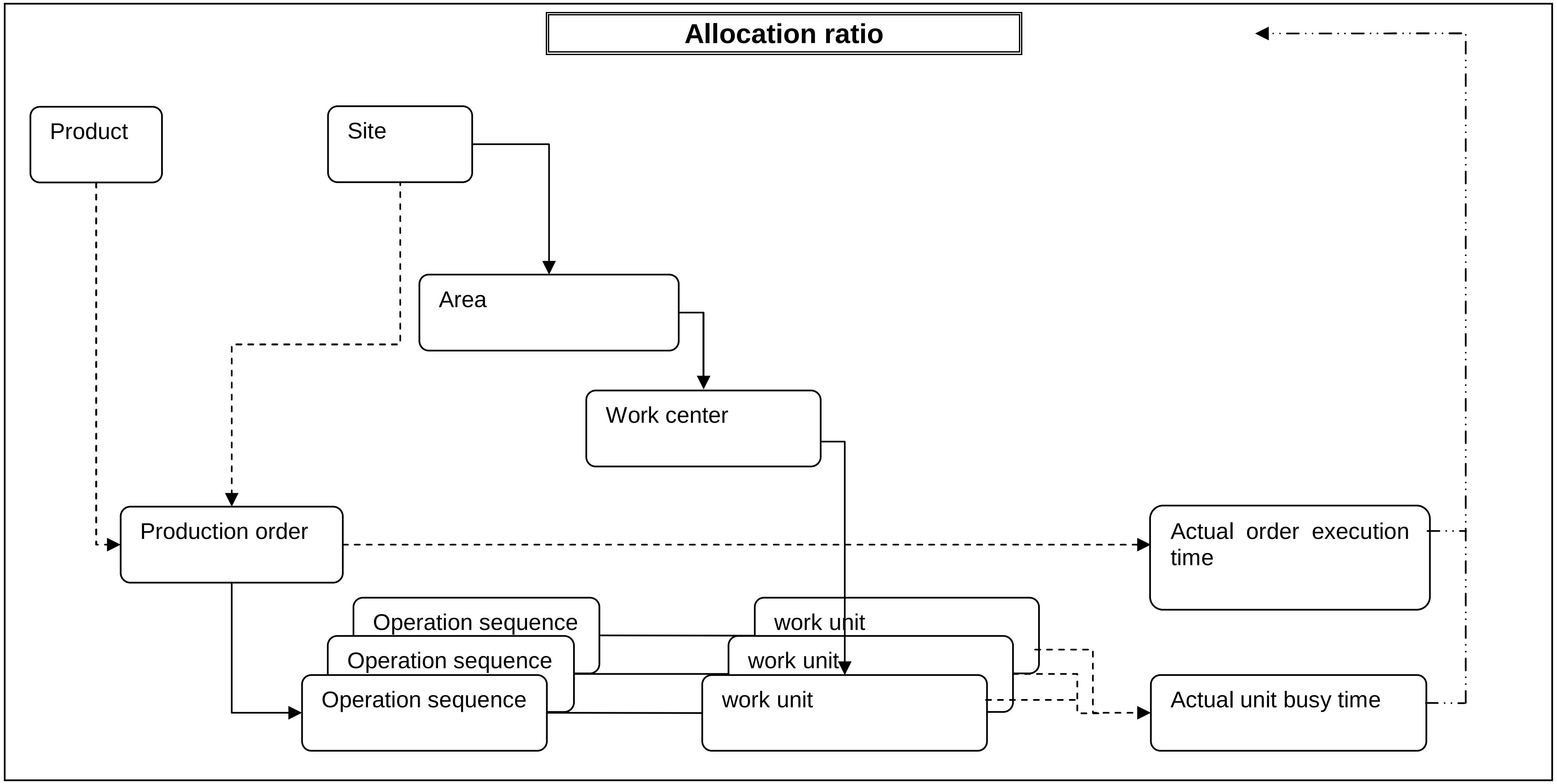
has (i.e. is booked or entered)

consists of (a 1:n relationship)

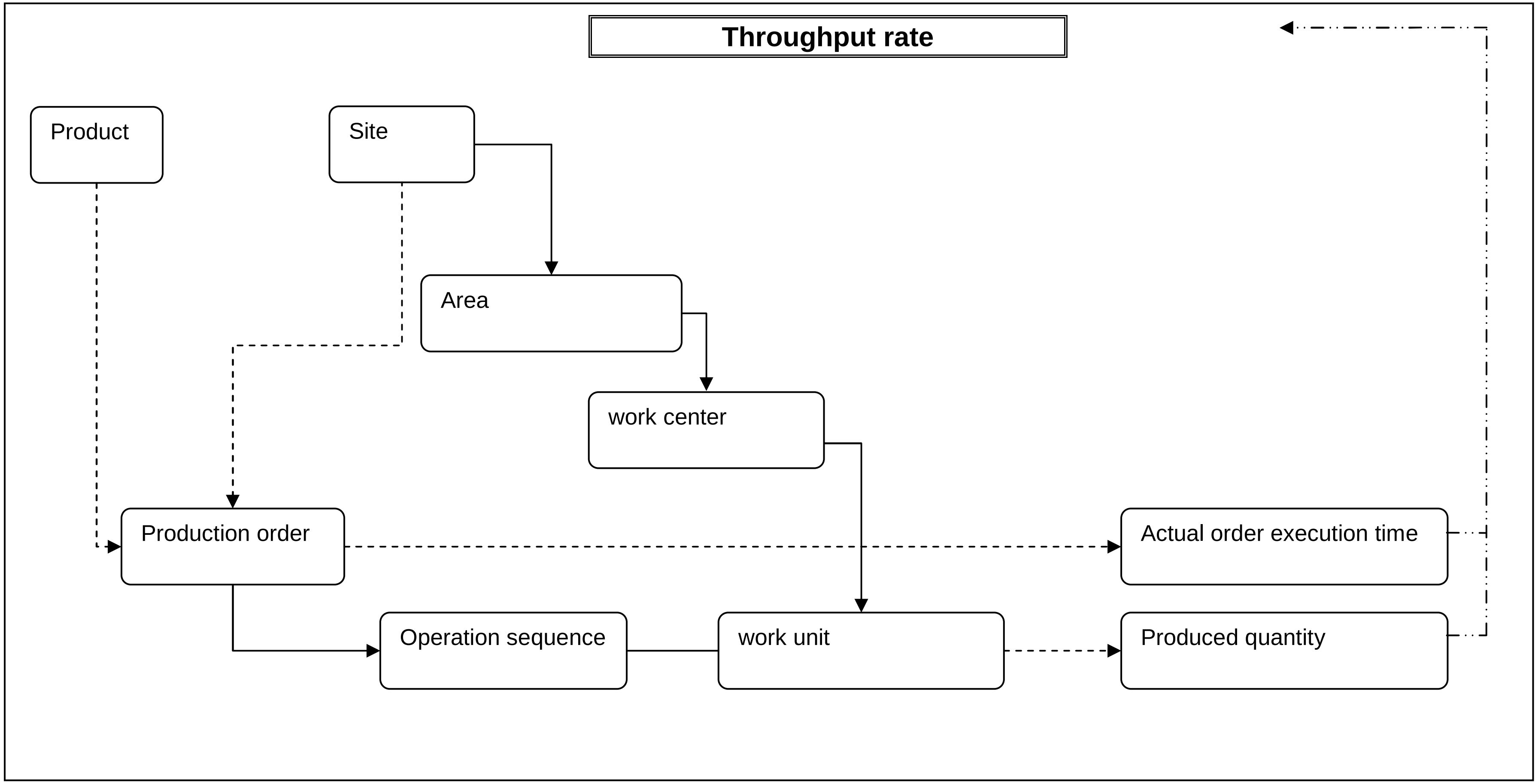
A.4 Worker efficiency



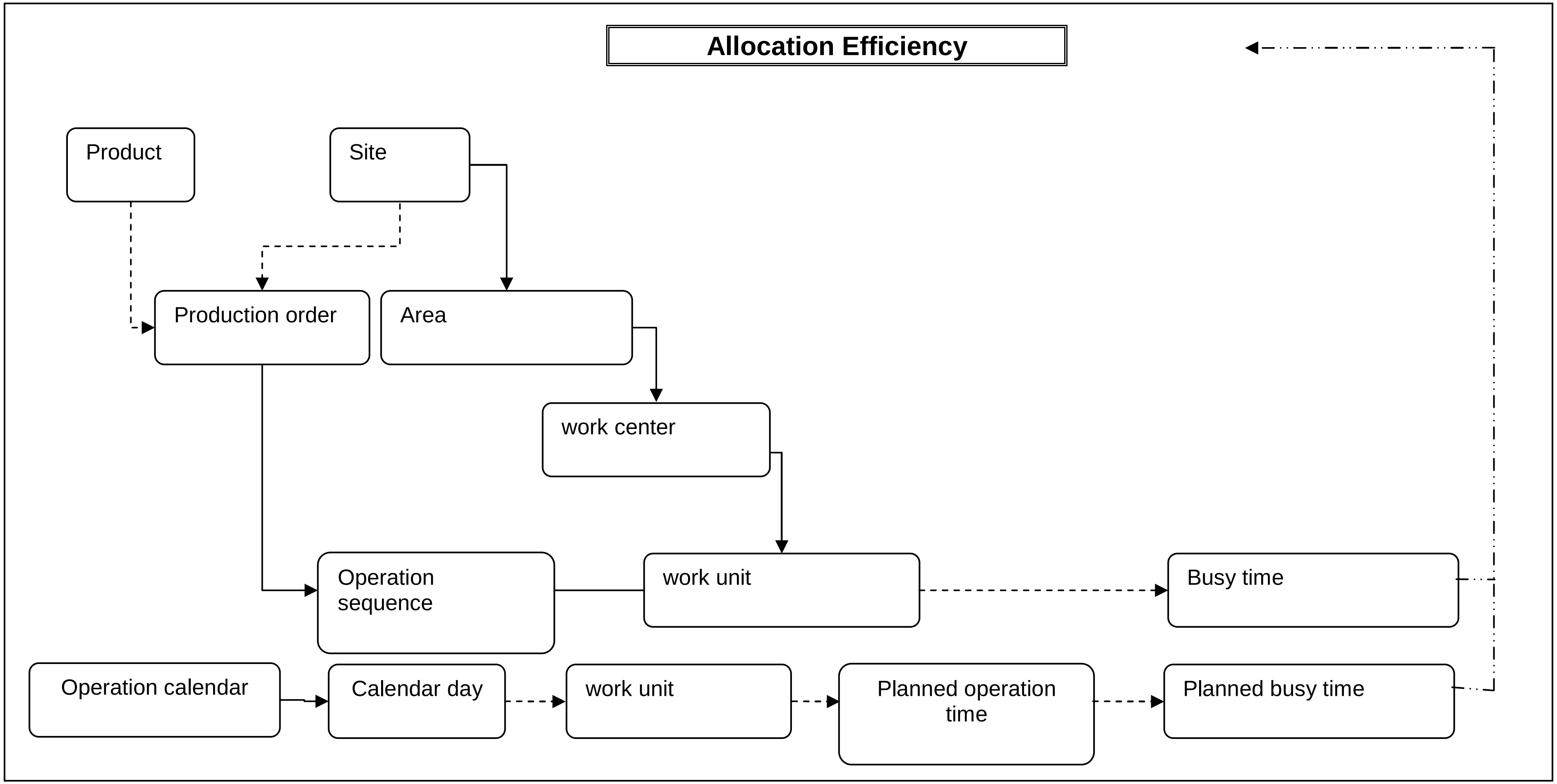
A.5 Allocation ratio



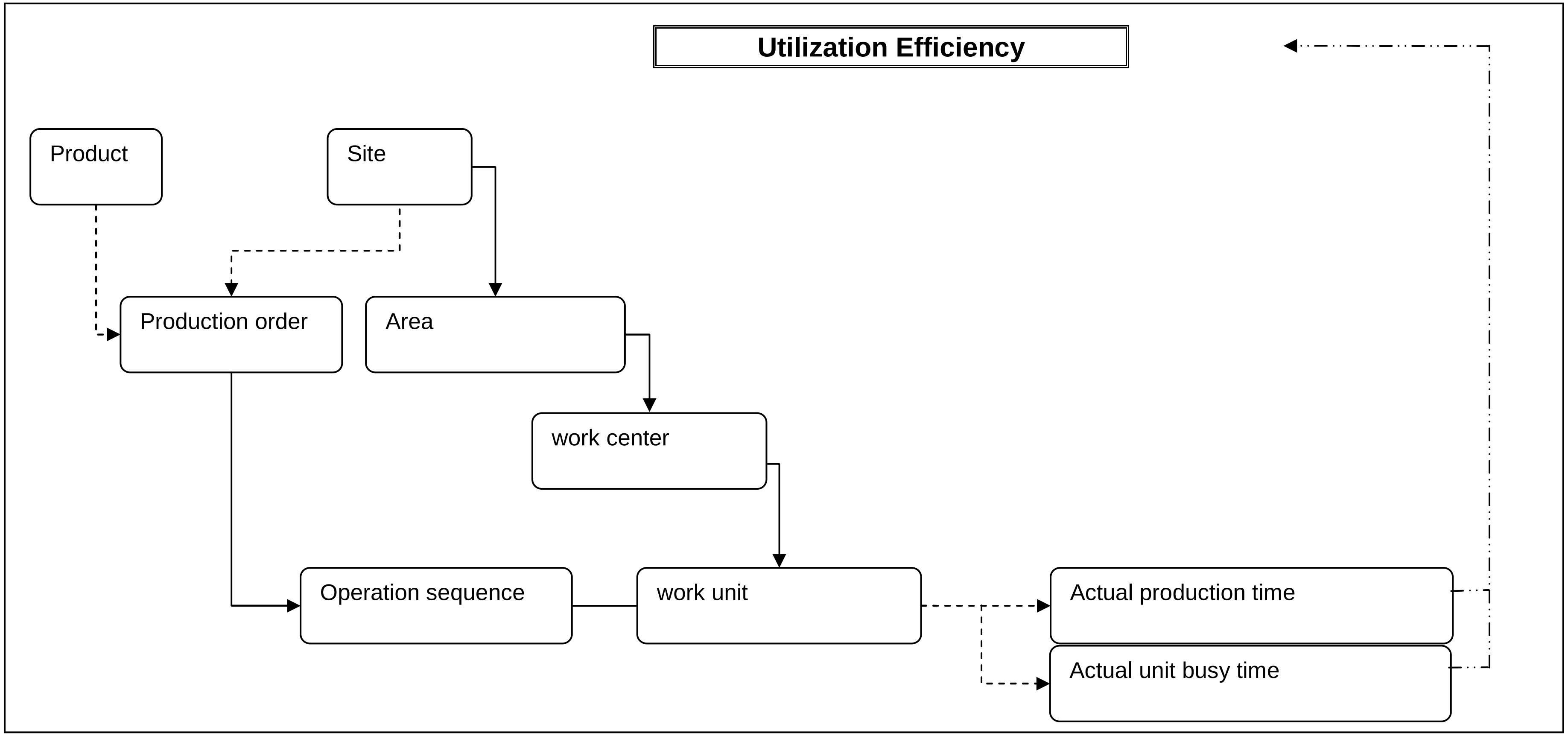
A.6 Throughput rate



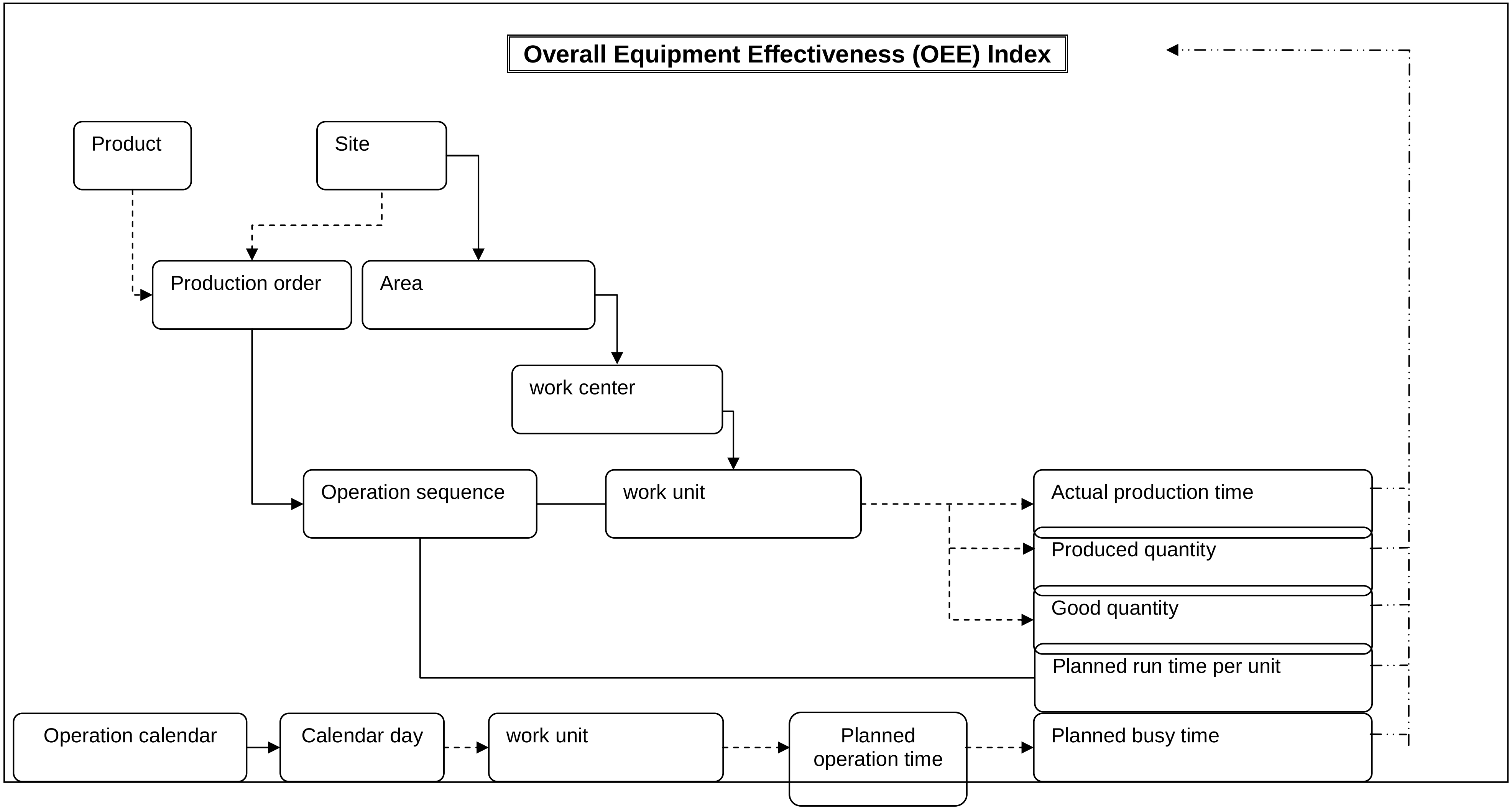
A.7 Allocation efficiency



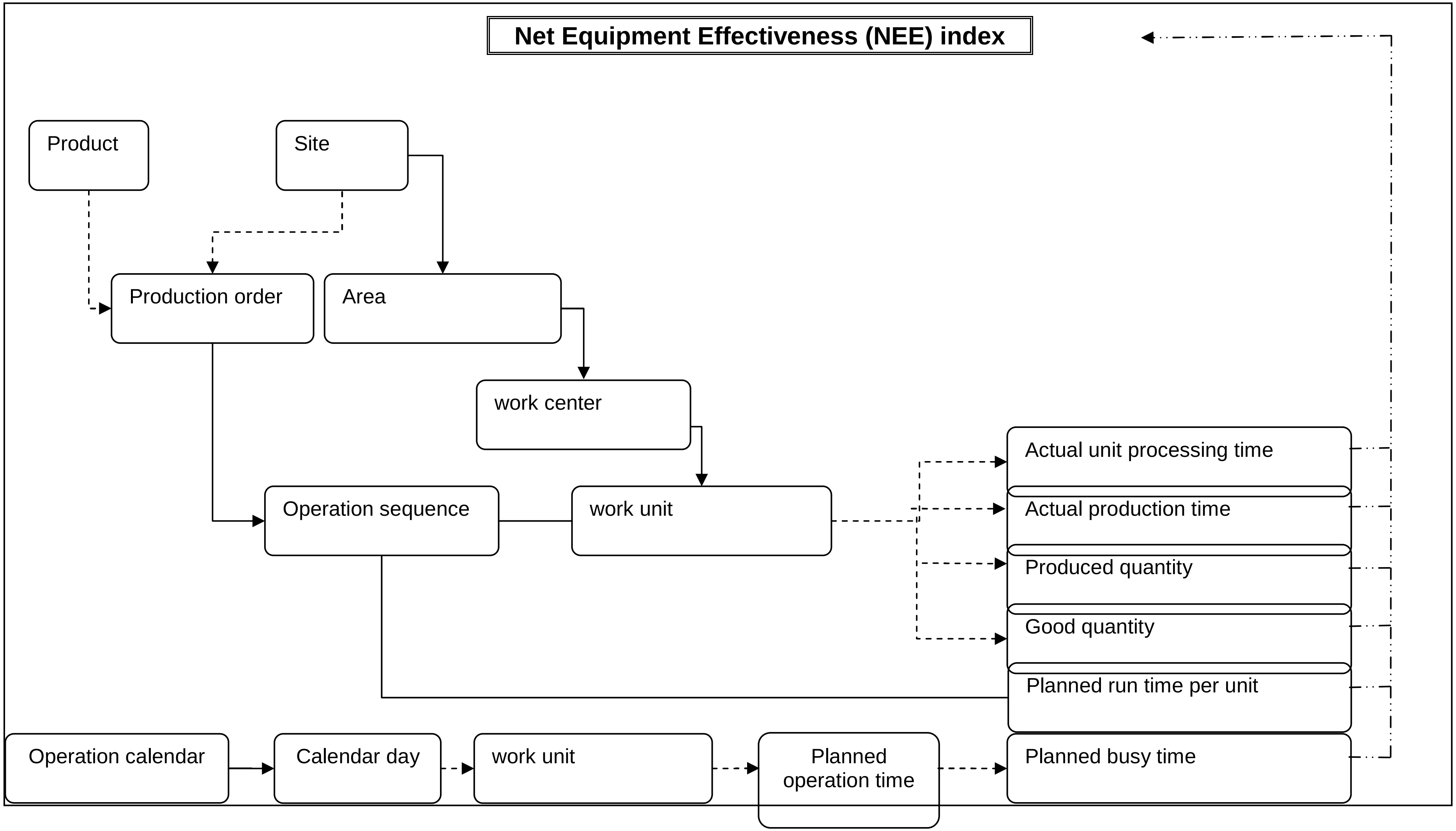
A.8 Utilization efficiency



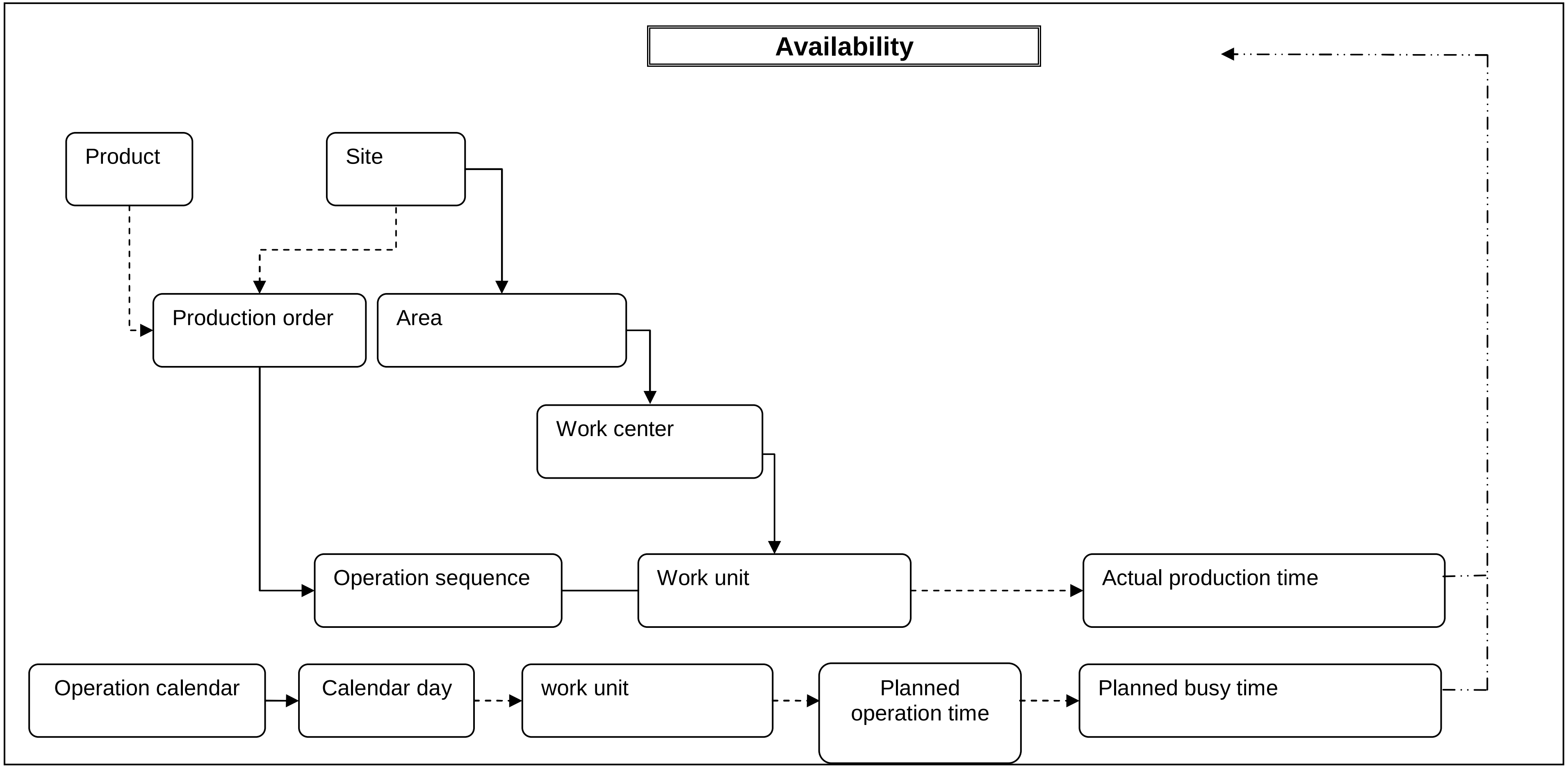
A.9 Overall equipment effectiveness index



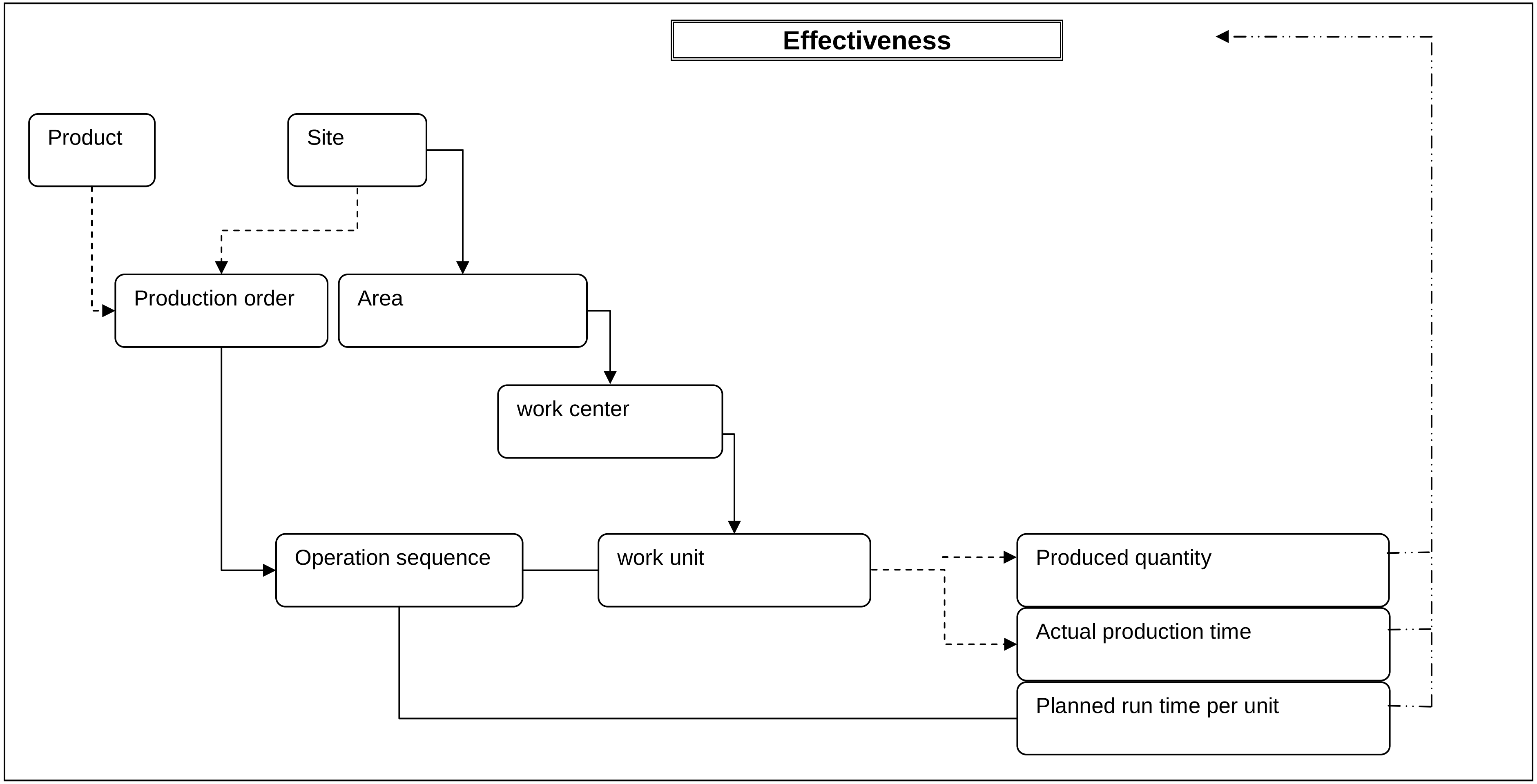
A.10 Net equipment effectiveness index



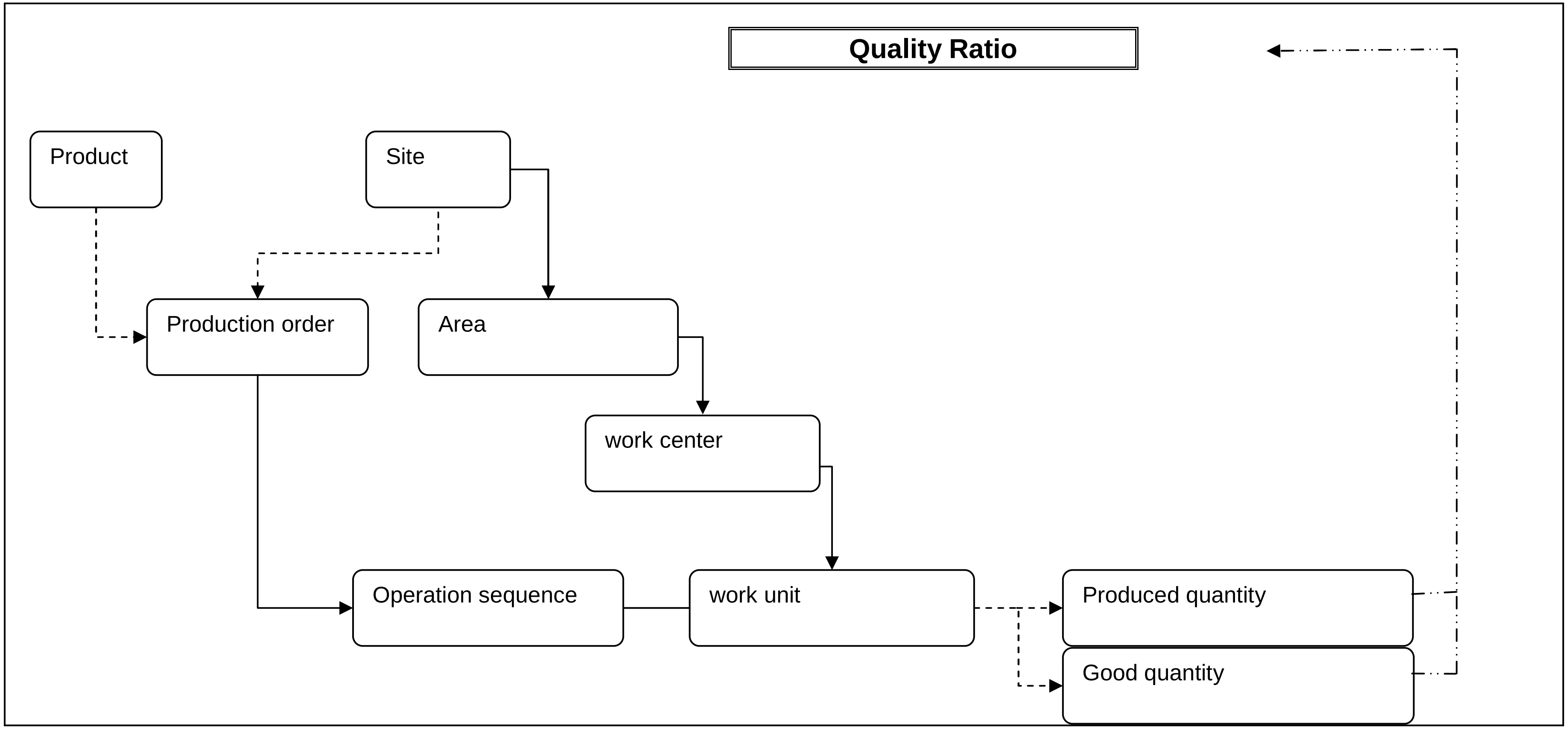
A.11 Availability



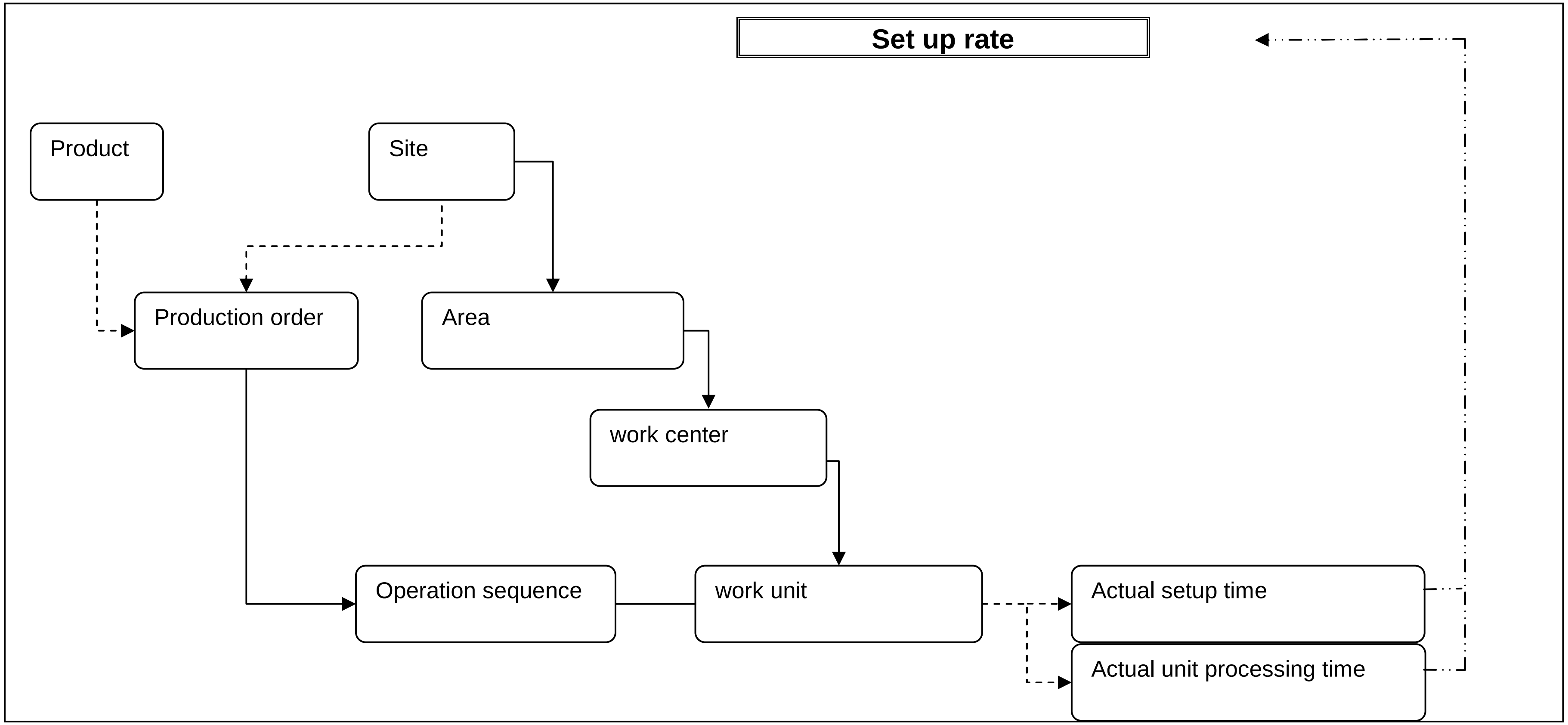
A.12 Effectiveness



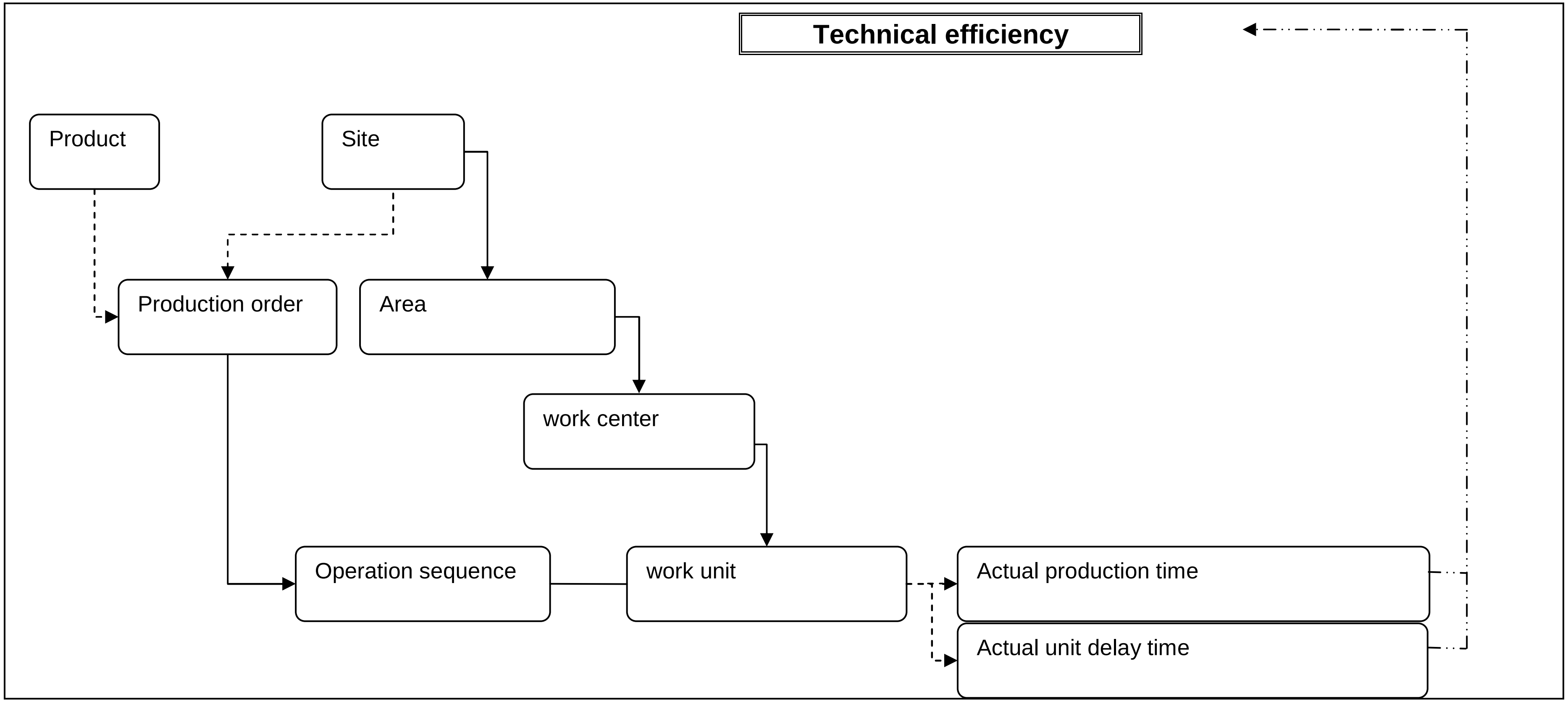
A.13 Quality ratio



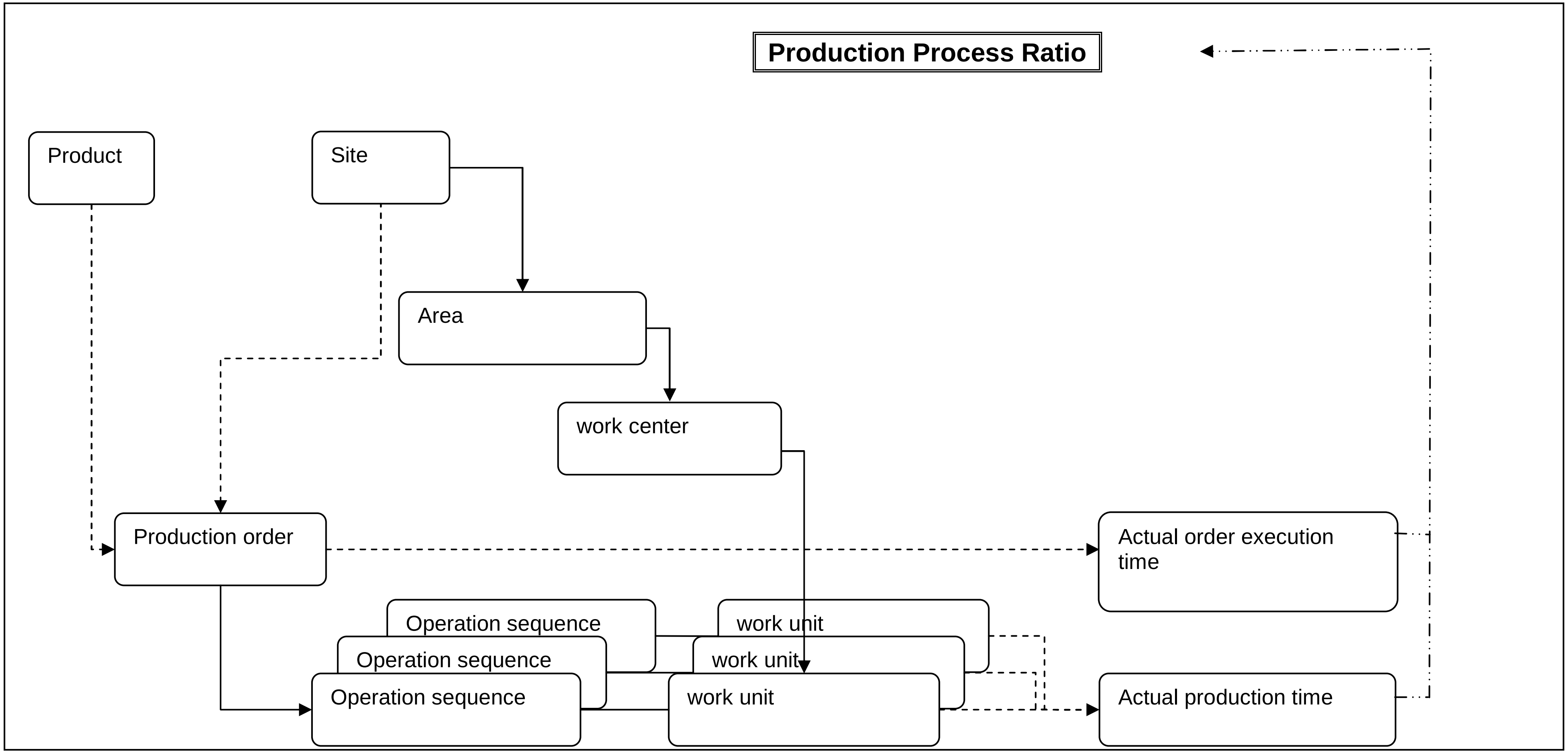
A.14 Set up rate



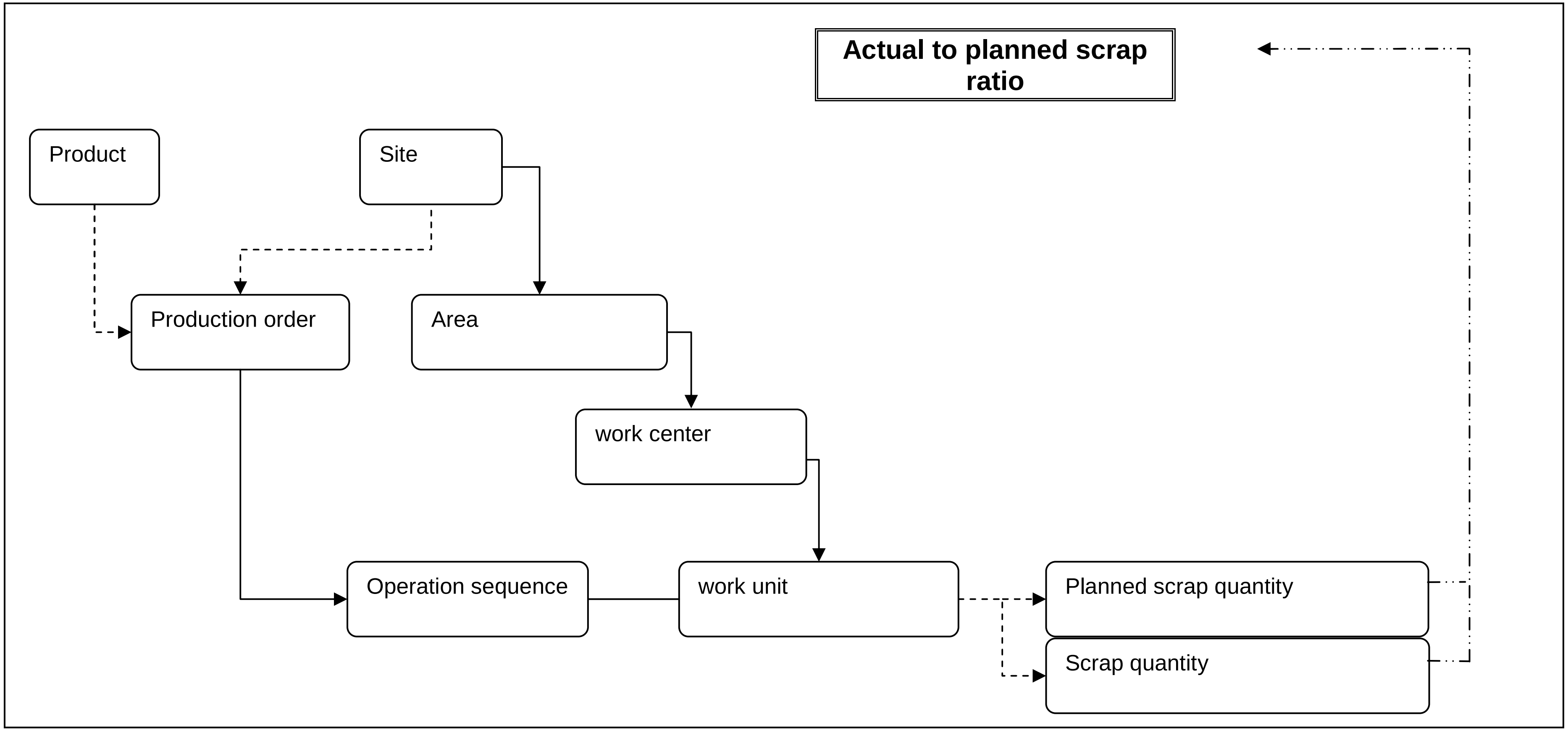
A.15 Technical efficiency



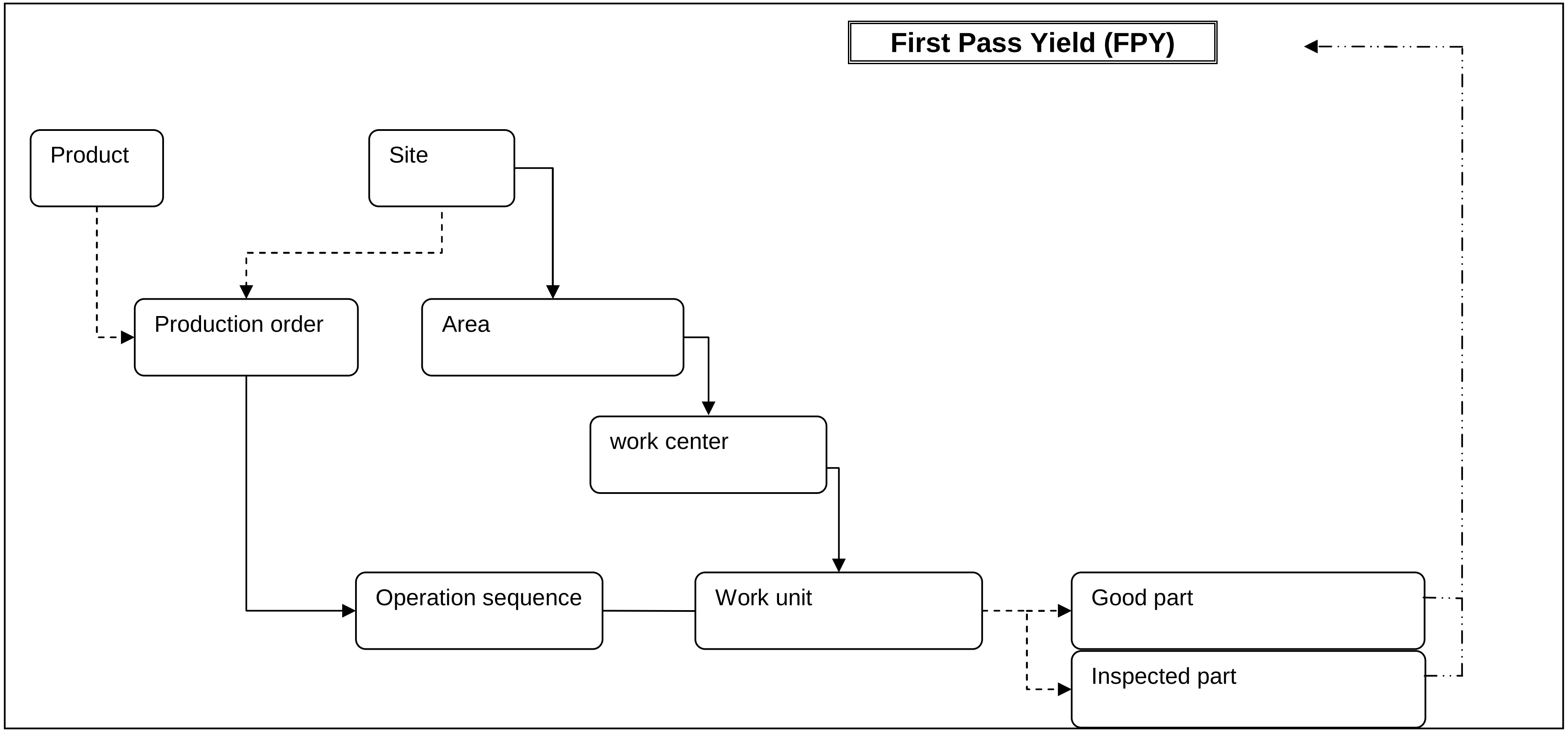
A.16 Production process ratio



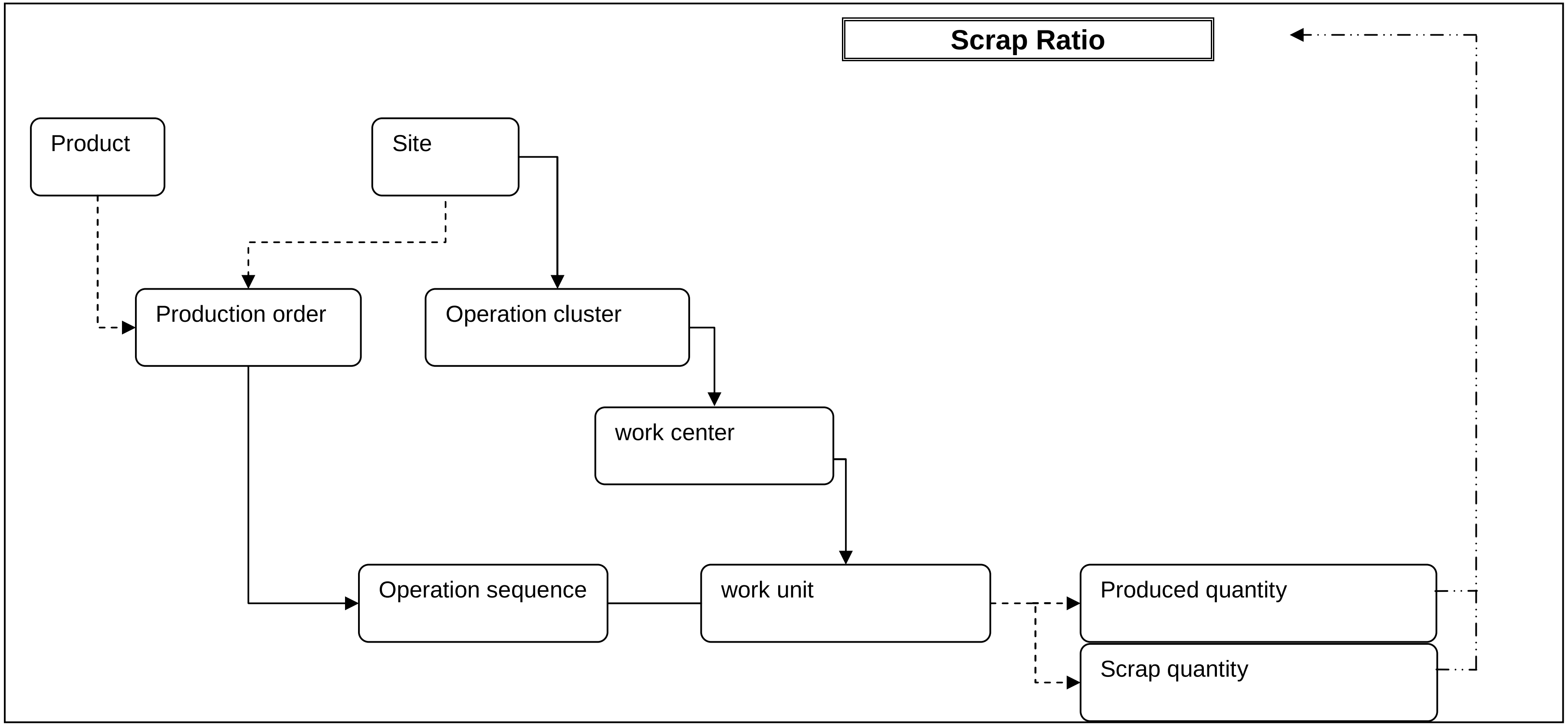
A.17 Actual to planned scrap ratio



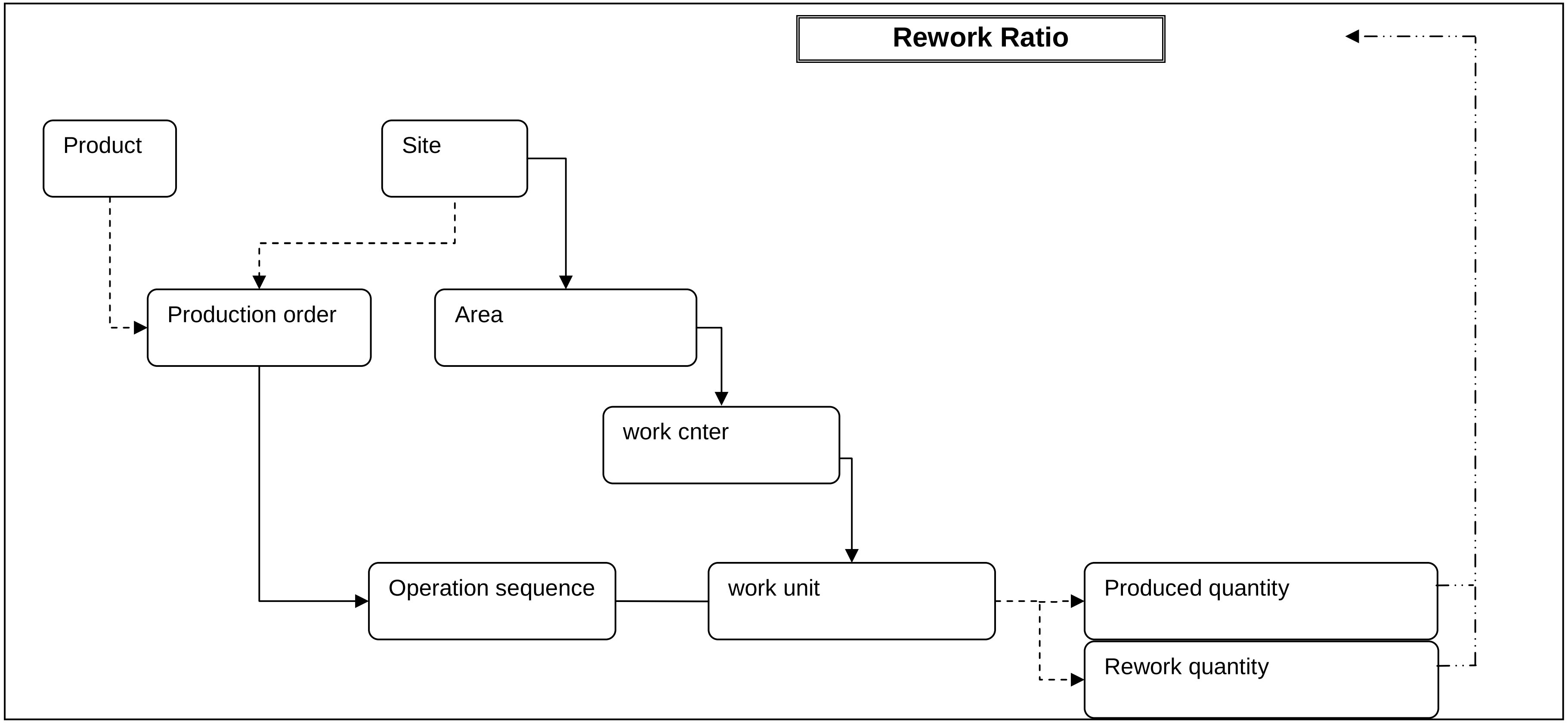
A.18 First pass yield



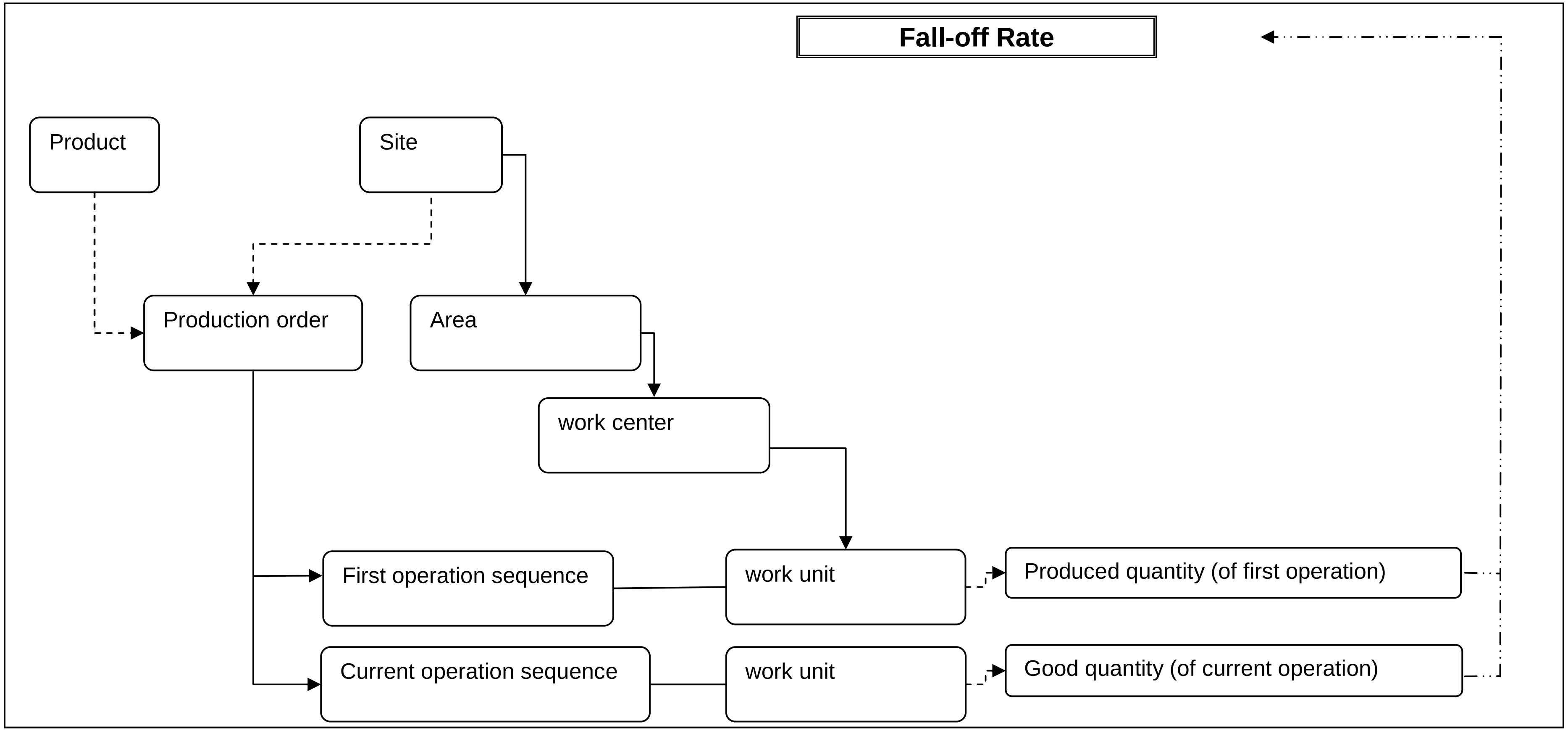
A.19 Scrap ratio



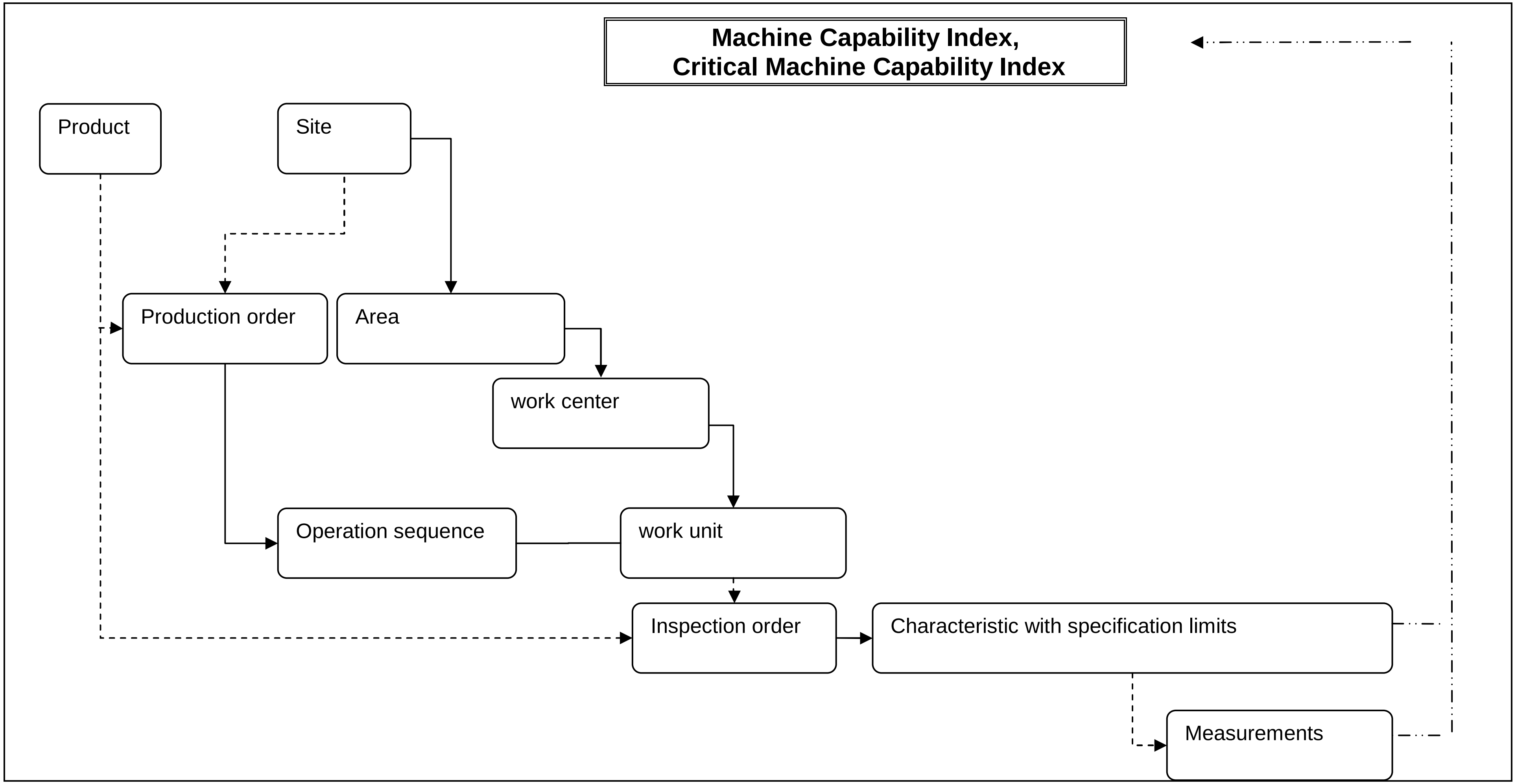
A.20 Rework ratio



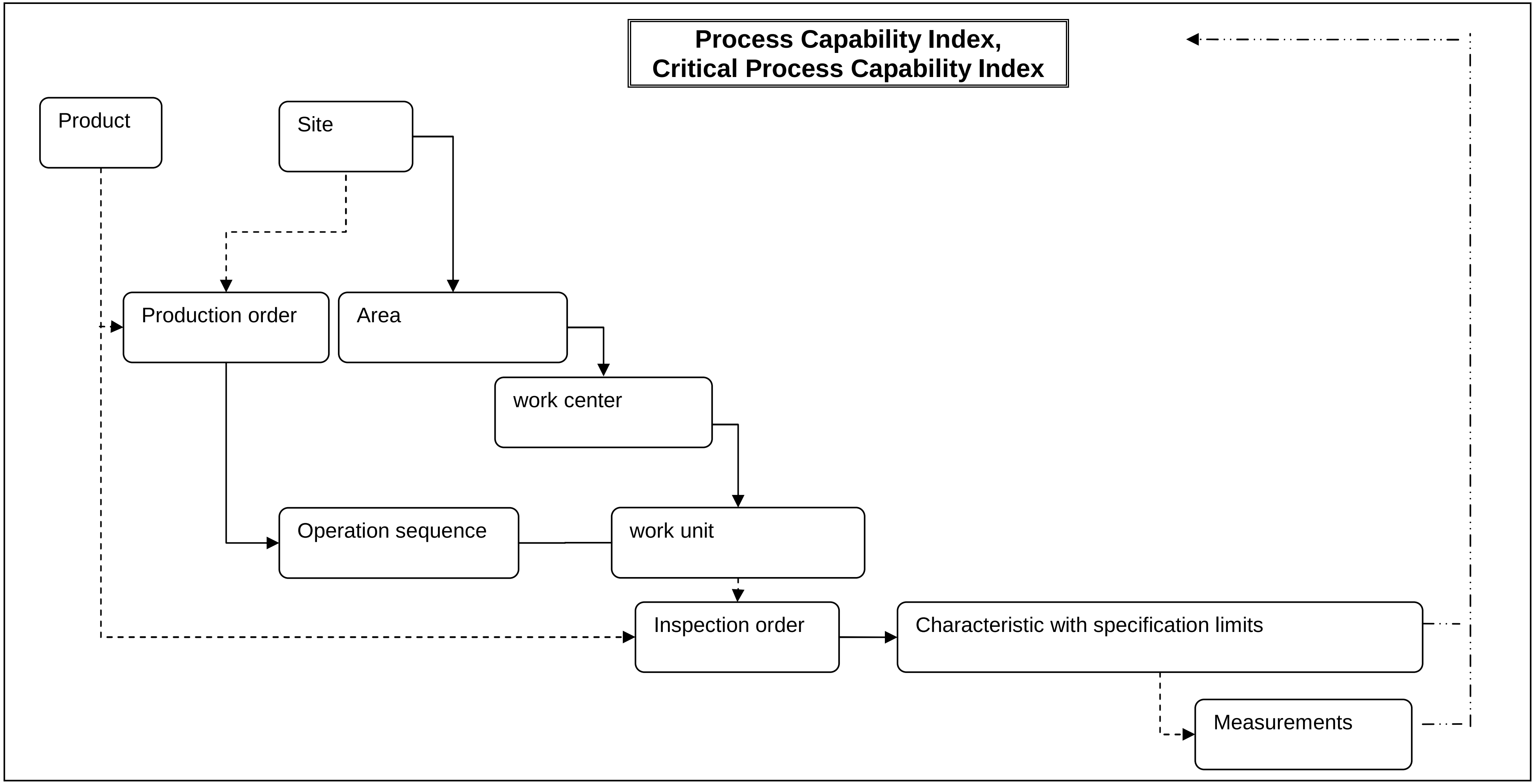
A.21 Fall-off rate



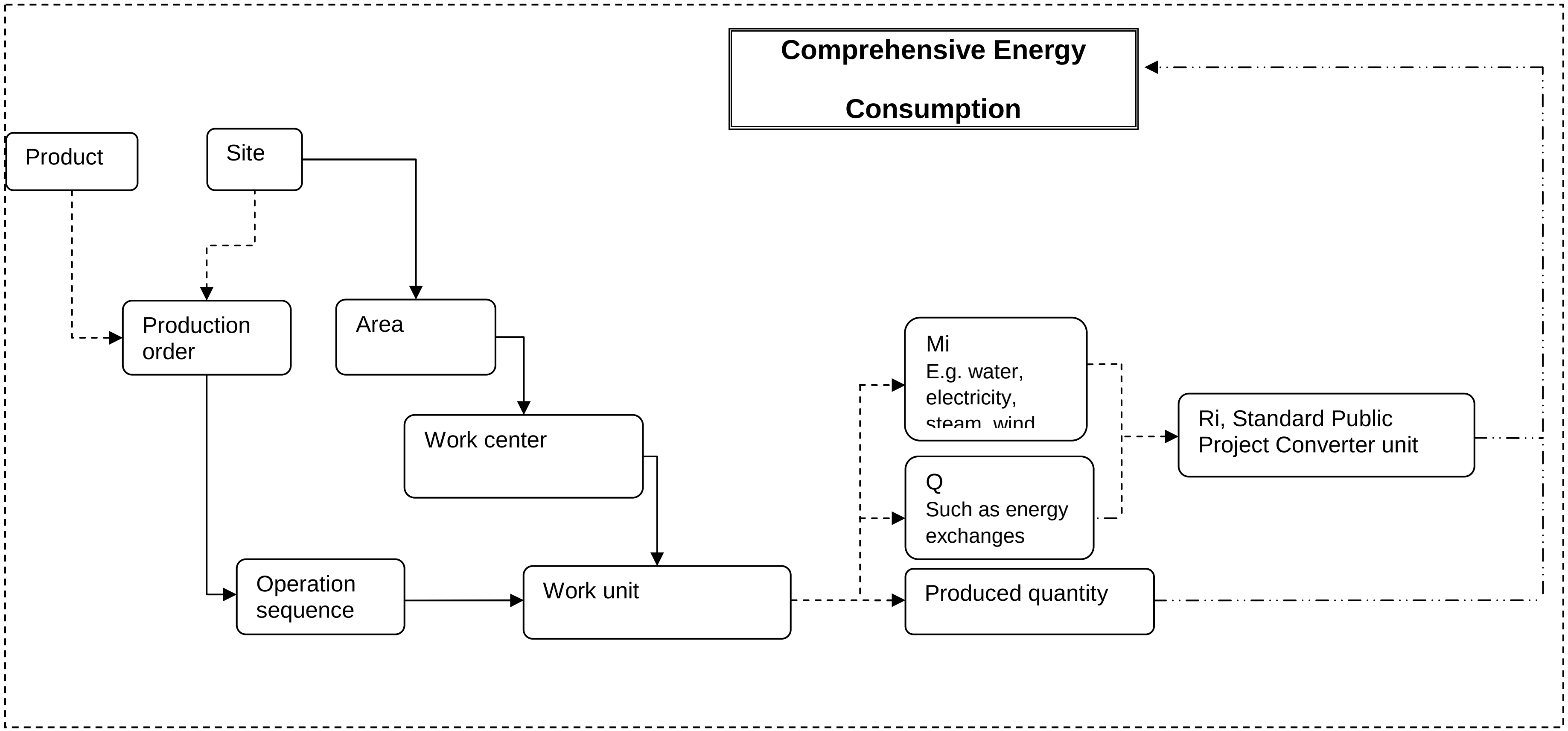
A.22 Machine capability index and critical machine capability index



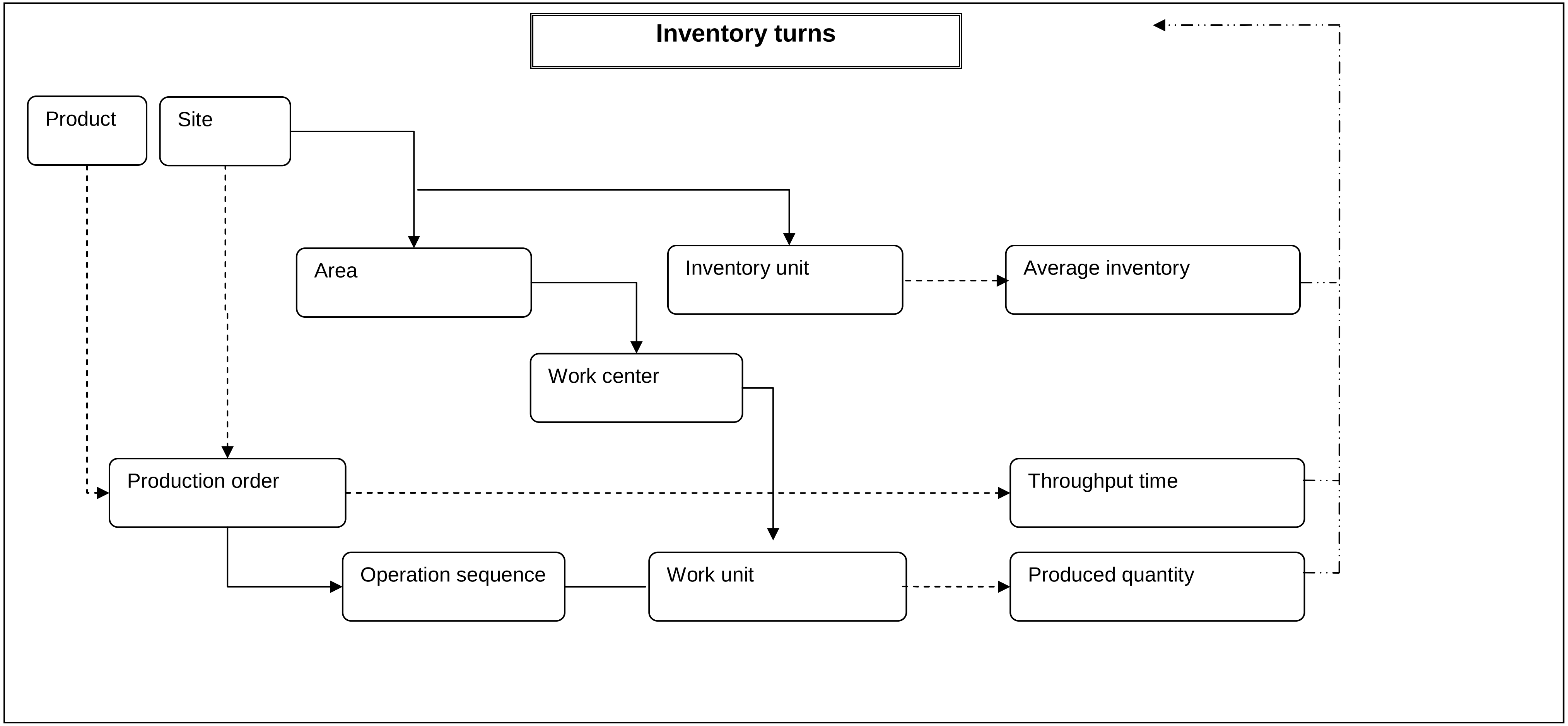
A.23 Process capability index and critical process capability index



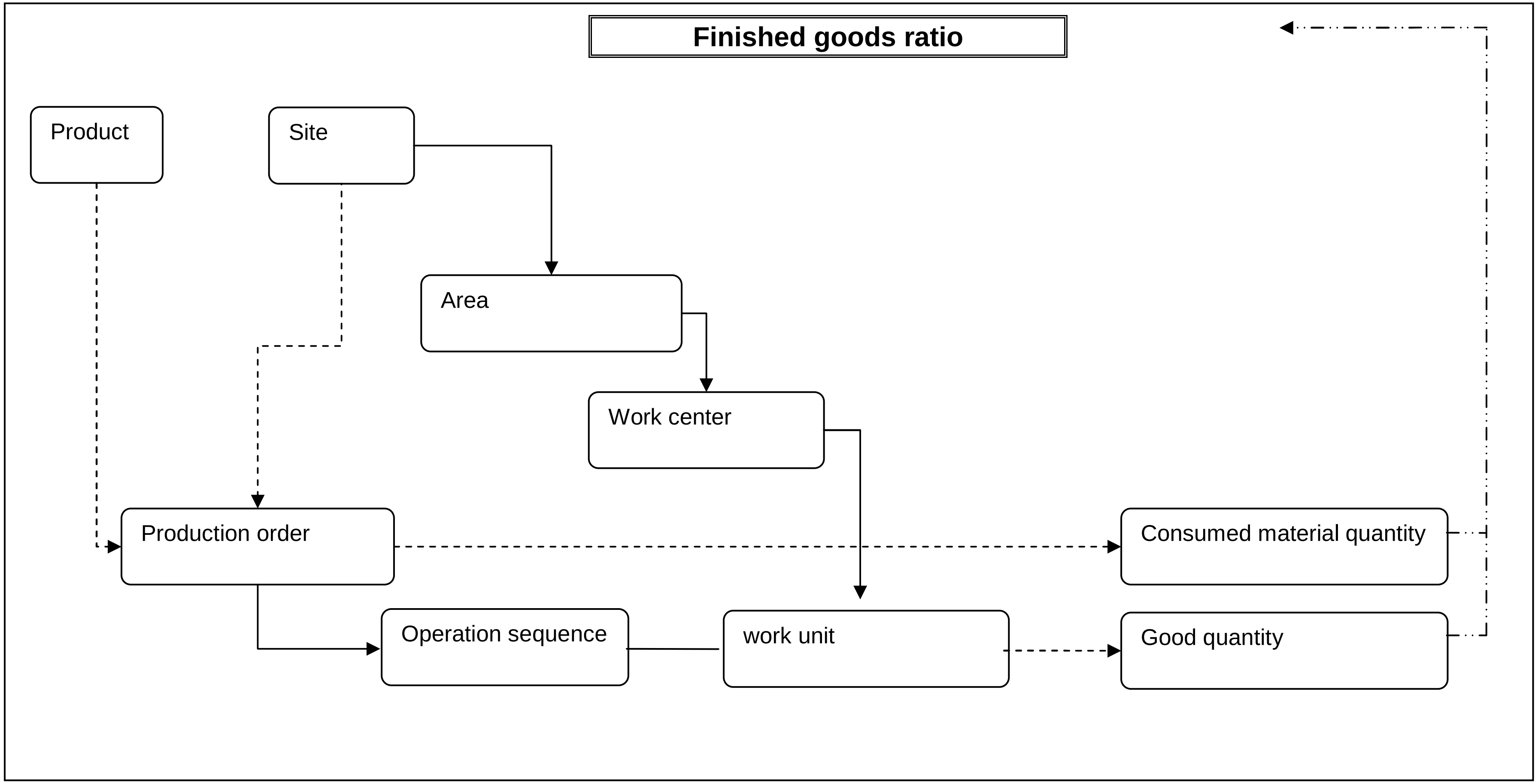
A.24 Comprehensive energy consumption



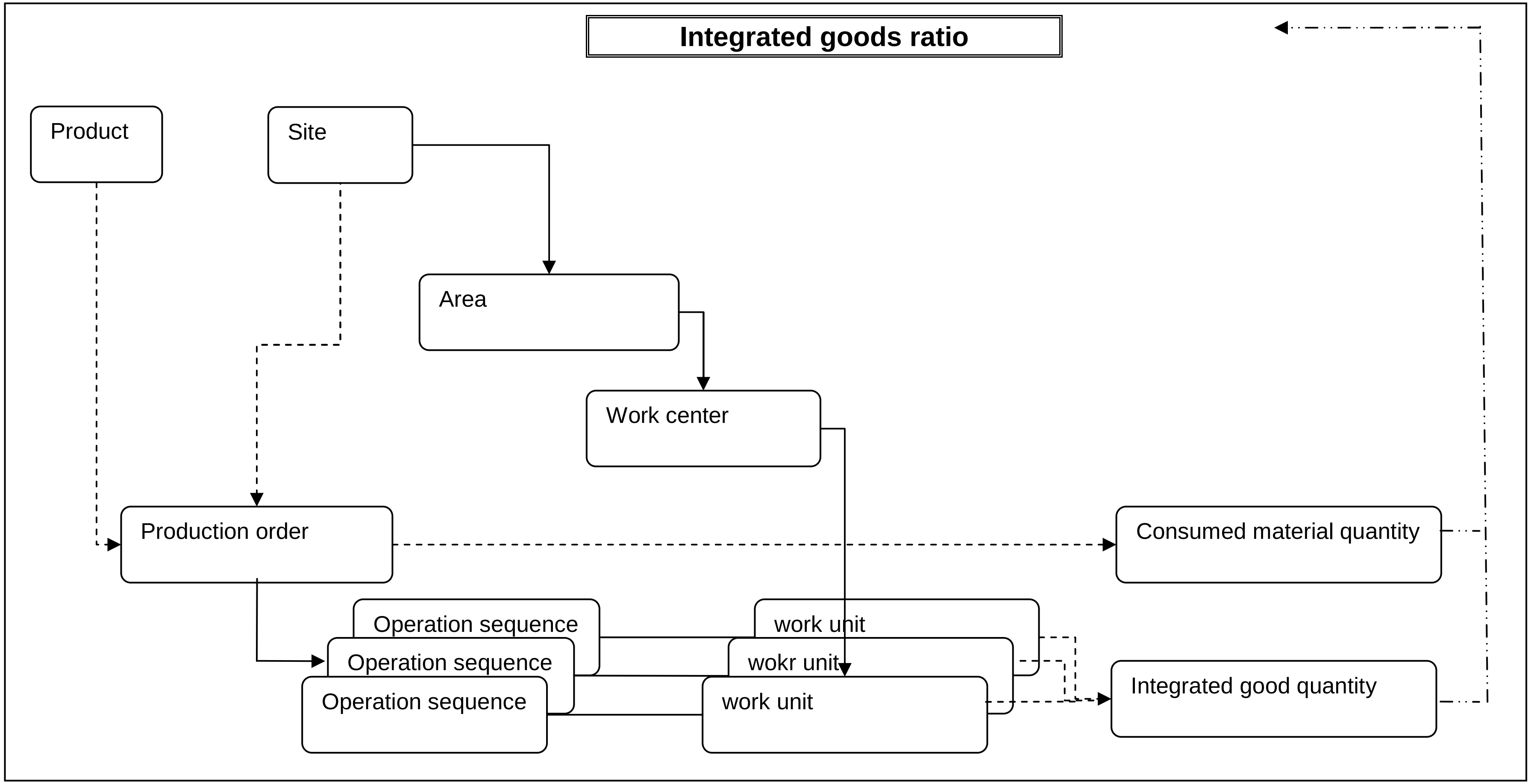
A.25 Inventory turns



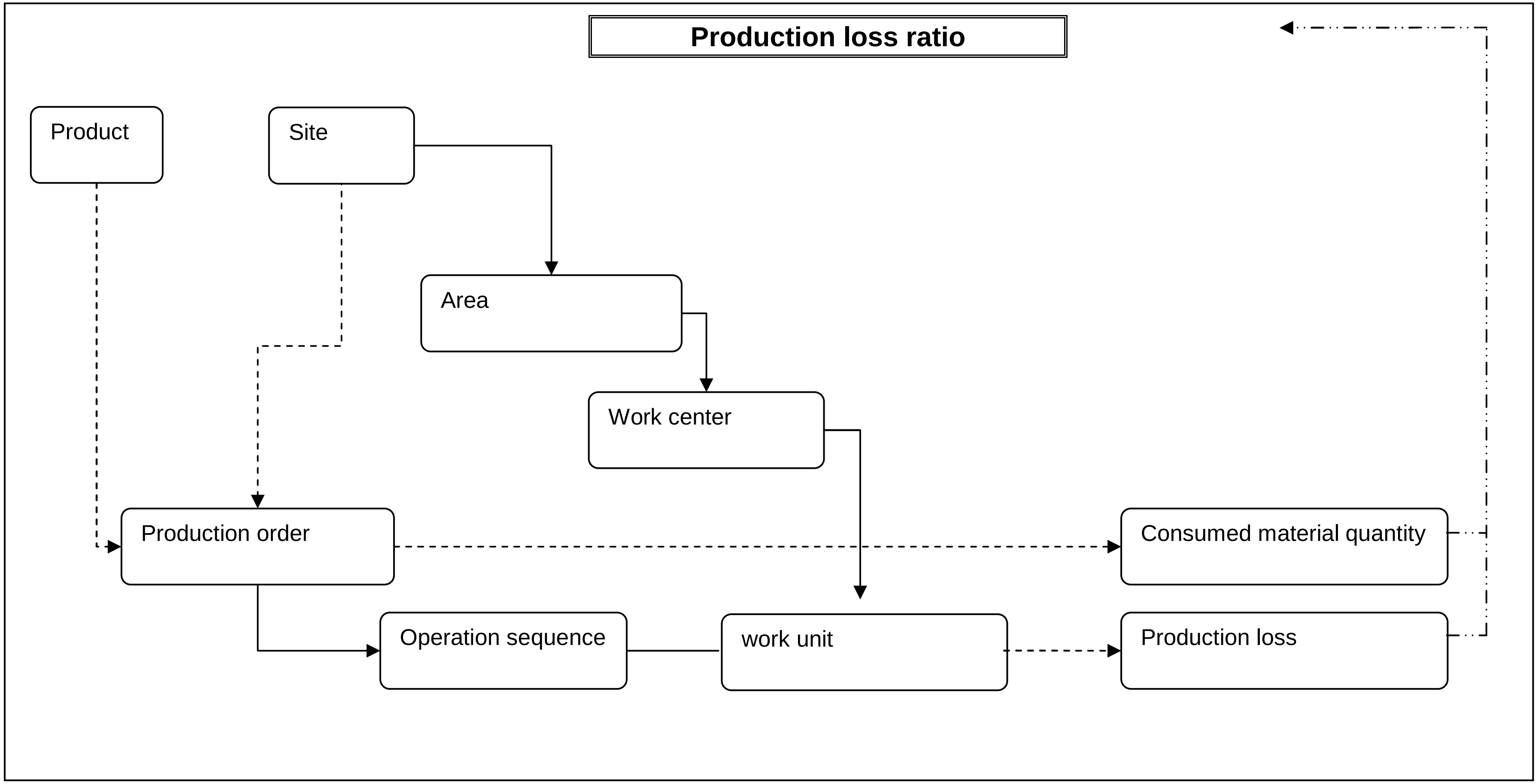
A.26 Finished goods ratio



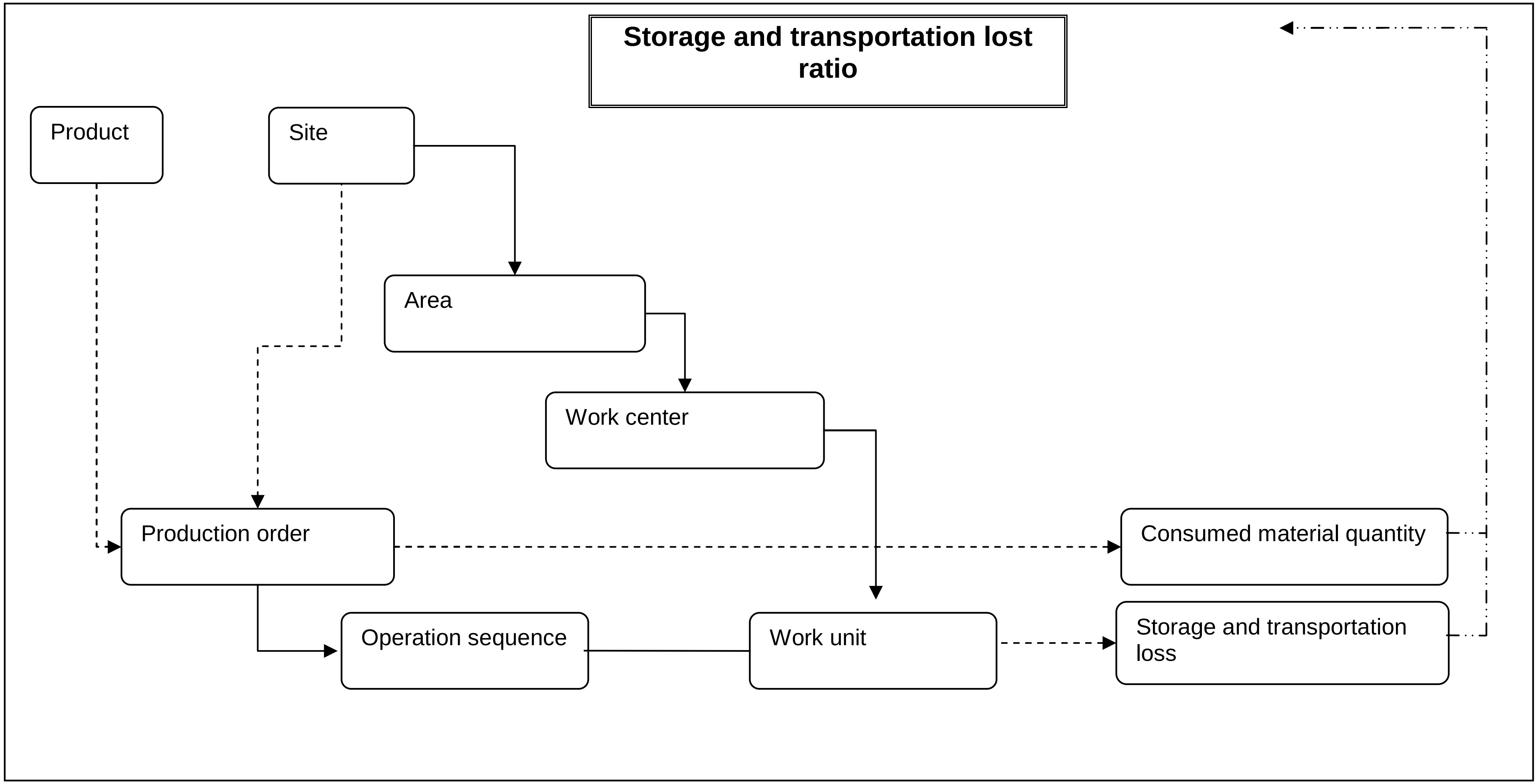
A.27 Integrated goods ratio



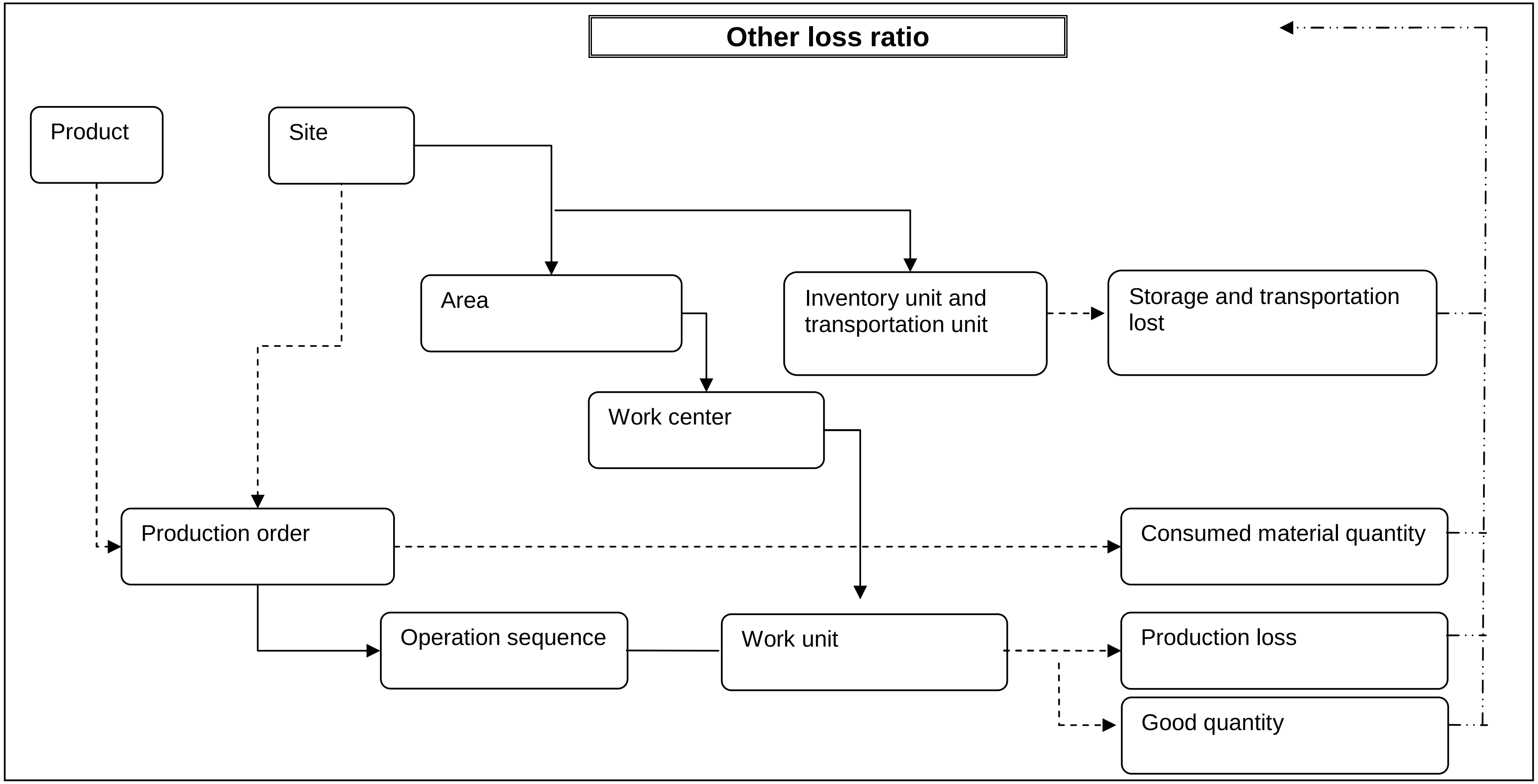
A.28 Production loss ratio



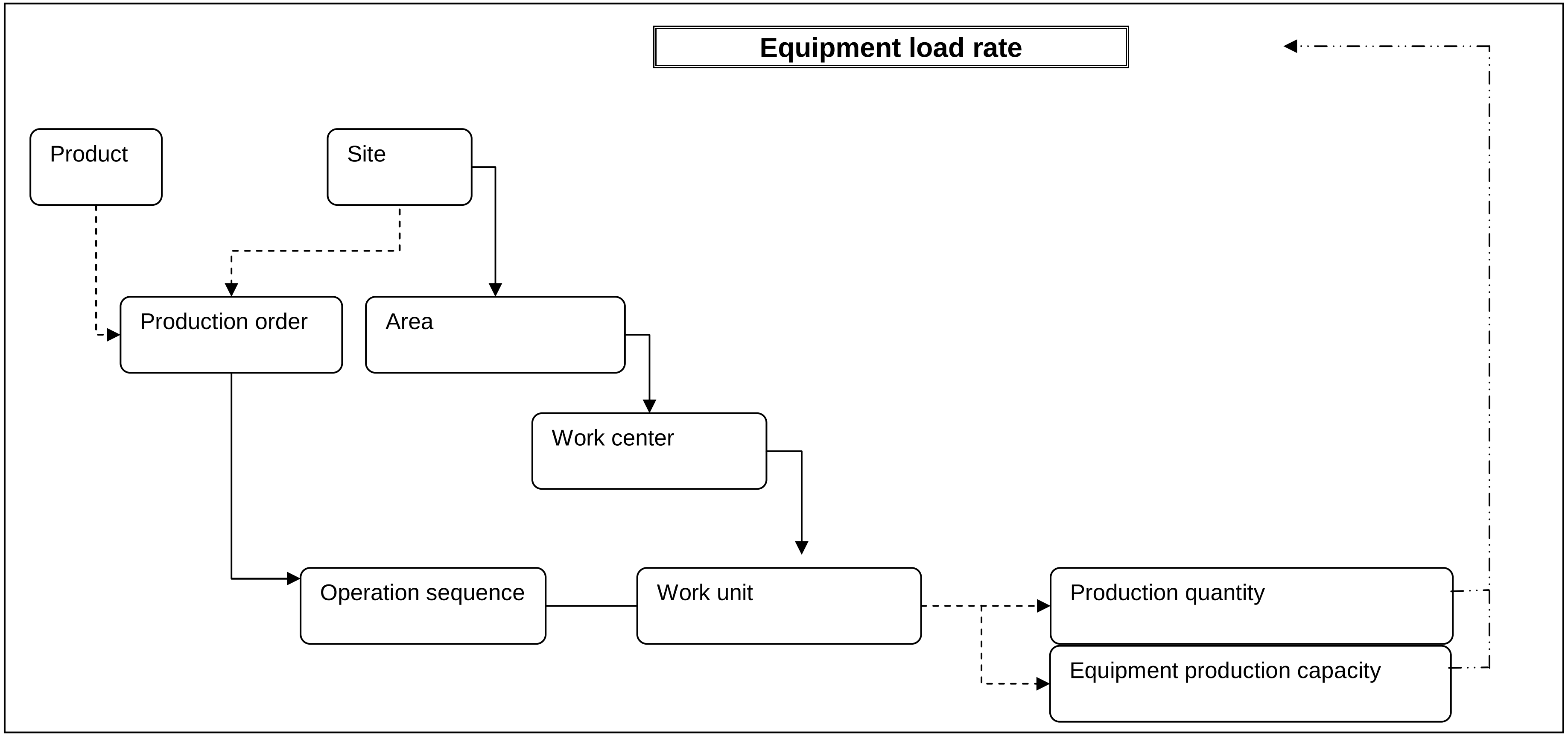
A.29 Storage and transportation loss ratio



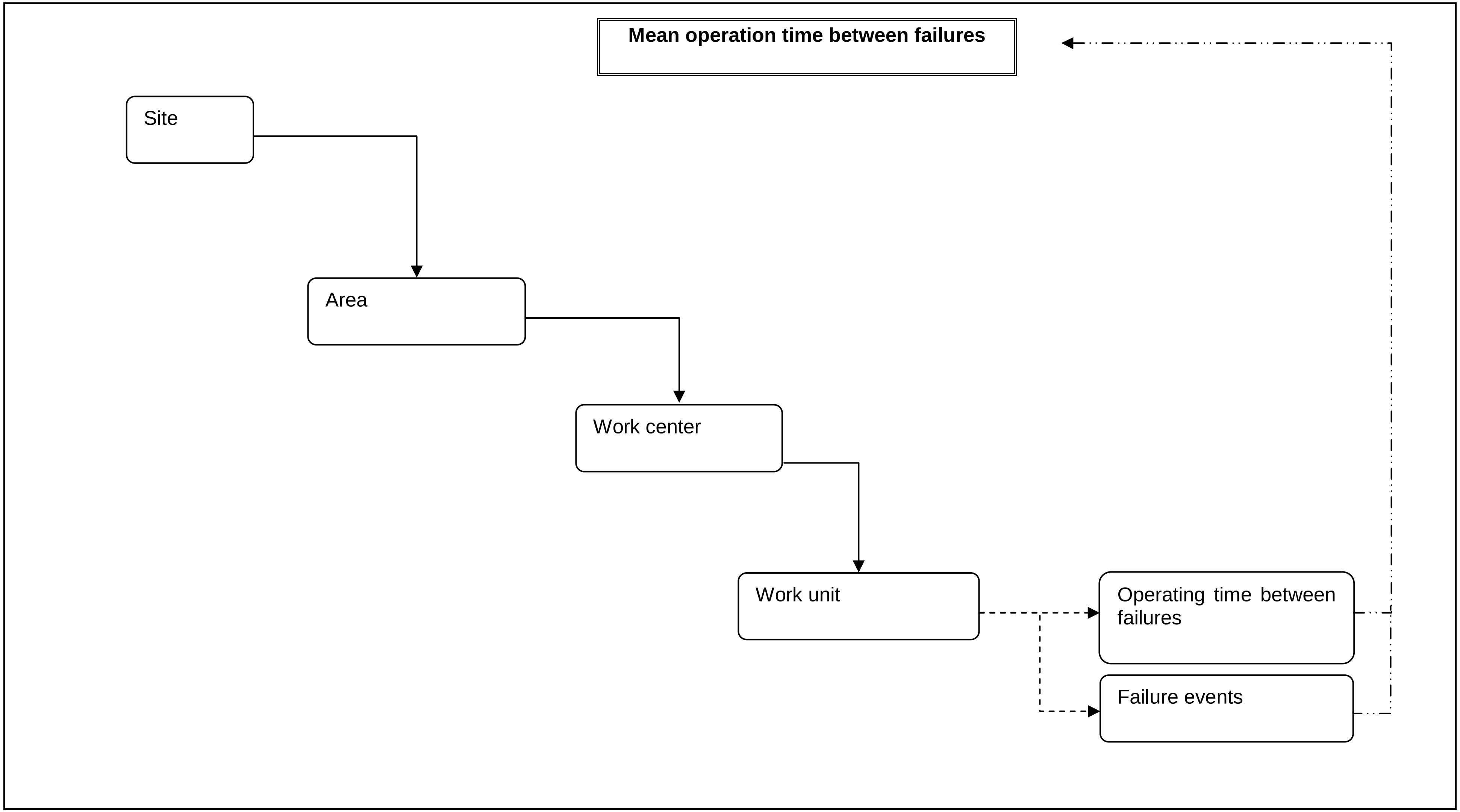
A.30 Other loss ratio



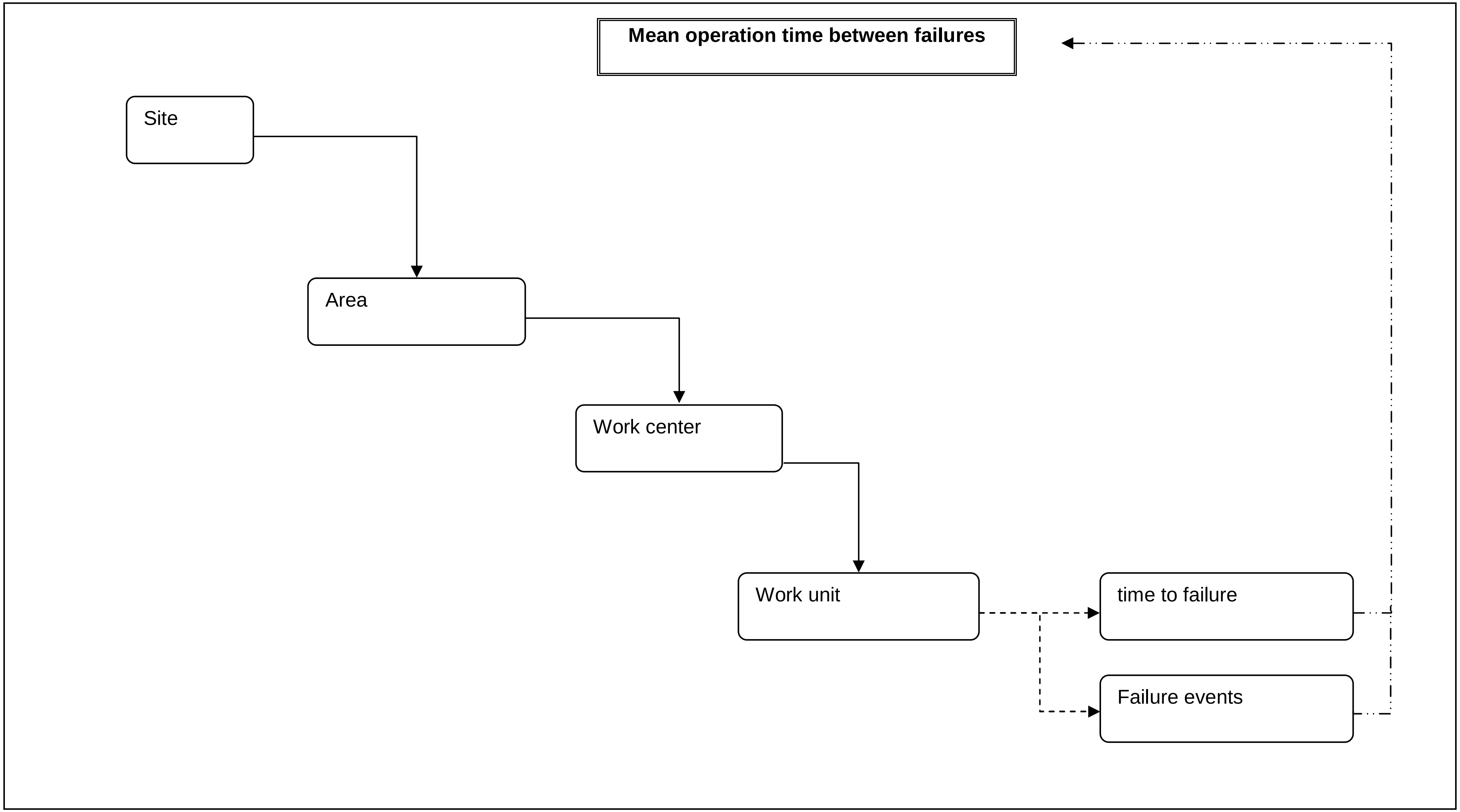
A.31 Equipment load rate



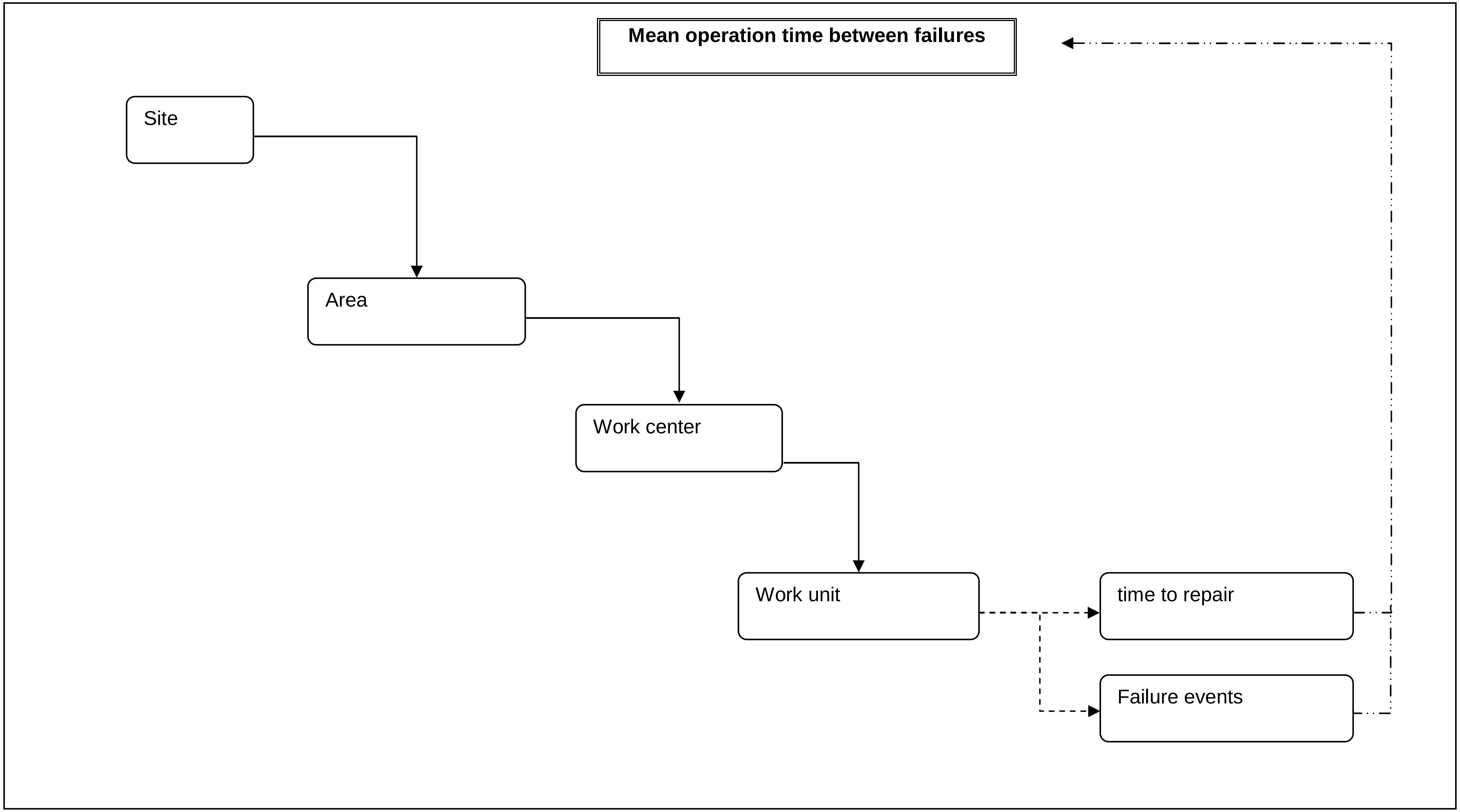
A.32 Mean operation time between failures



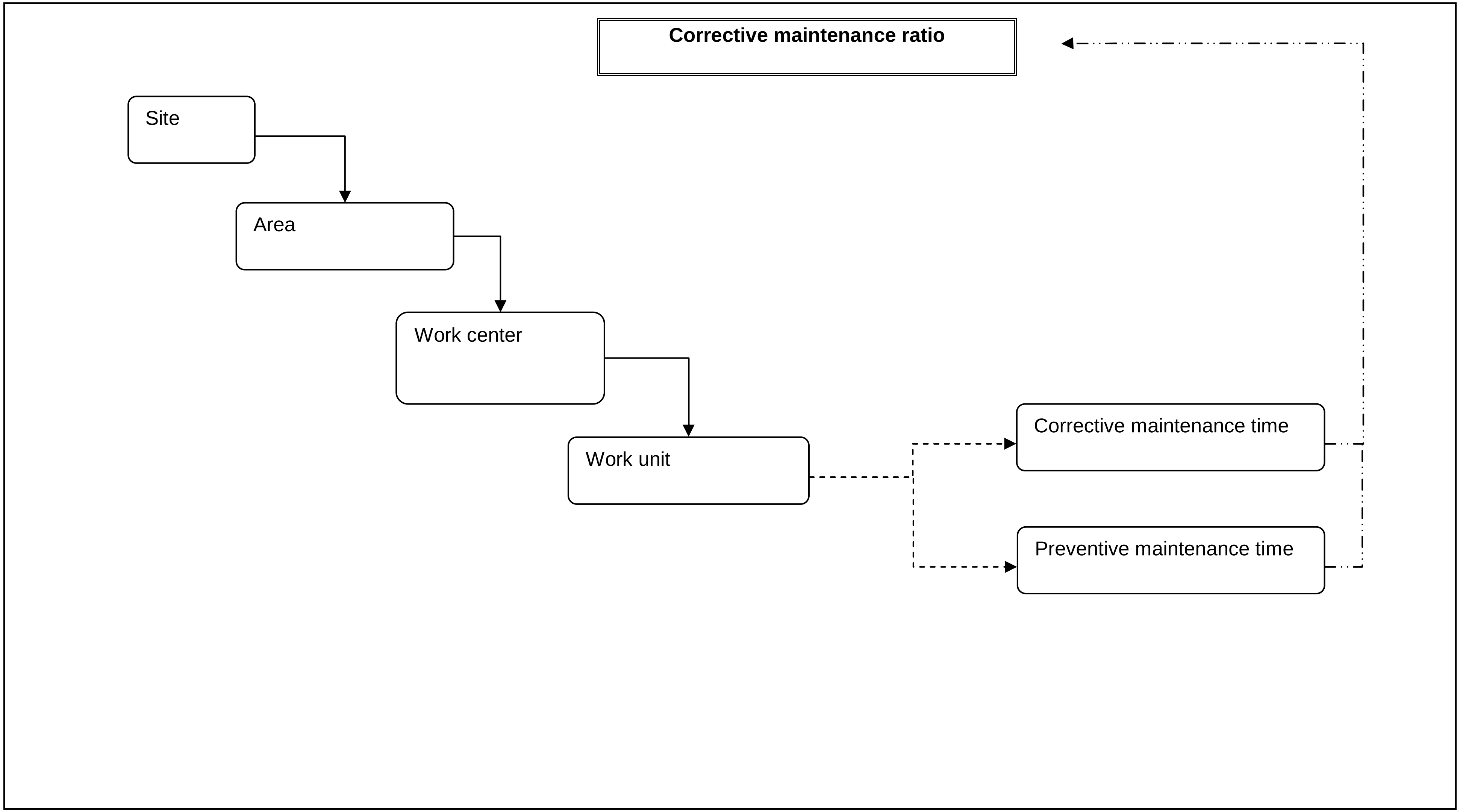
A.33 Mean time to failures



A.34 Mean time to repair



A.35 Corrective maintenance ratio



Annex B

Alternative OEE calculation based on loss time model (Normative)

B.1 Introduction

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 8 of this part of ISO 22400

B.2 Time Model for Work units

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

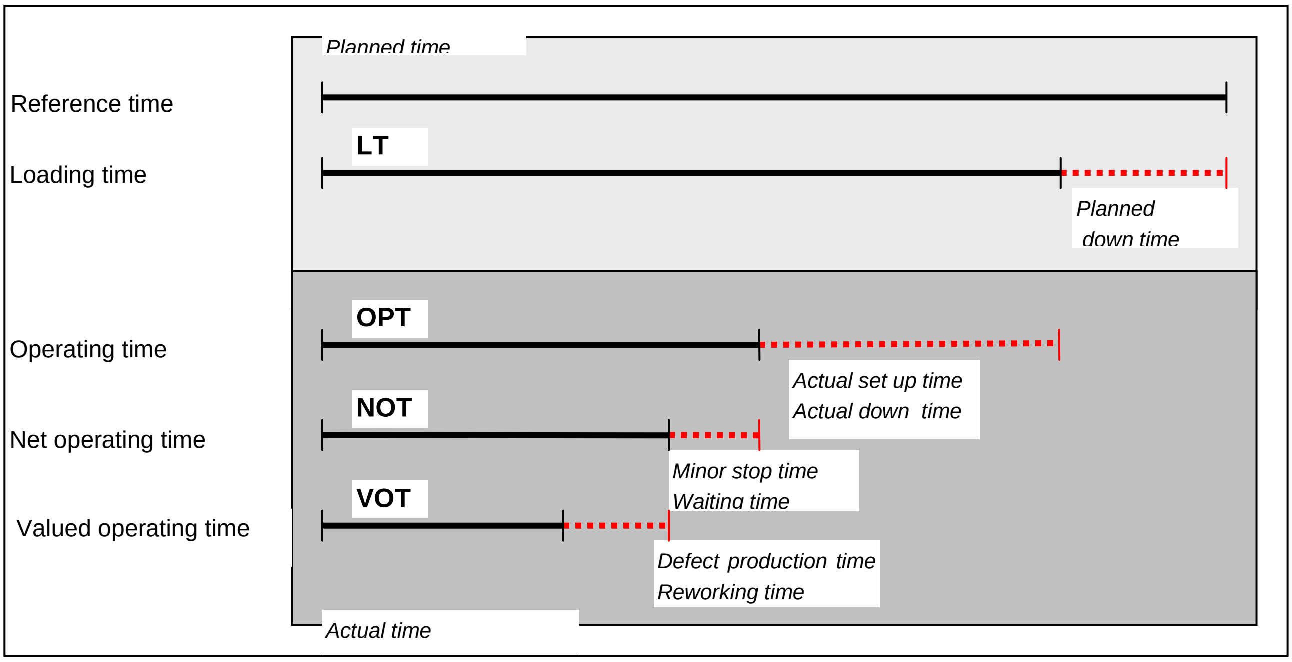


Figure B.1 Time Model for calculation of the OEE

B.3 KPI

B.3.1 Overall equipment effectiveness index

KPI definition	
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 defined in chapter 5.25

B.3.2 Availability

KPI definition	
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

B.3.3 Performance ratio

KPI definition	
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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[3] ISO 1000, *SI units and recommendations for the use of their multiples and of certain other units*

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[5] ISO 13053-2:2011 - Quantitative methods in process improvement -- Six Sigma -- Part 2: Tools and techniques

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[7] DIN NA 060-30-05-03 "Definition of MES and Quality Management Requirements on MES"

[8] IEC 60050-191 ed1.0 International Electrotechnical Vocabulary. Chapter 191: Dependability and quality of service