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

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Contents

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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.

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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: Workflow and activity model

— Part 4: Exchange and use

Introduction

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

KPIs are defined as quantifiable and strategic measurements that reflects 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 as shown in 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.

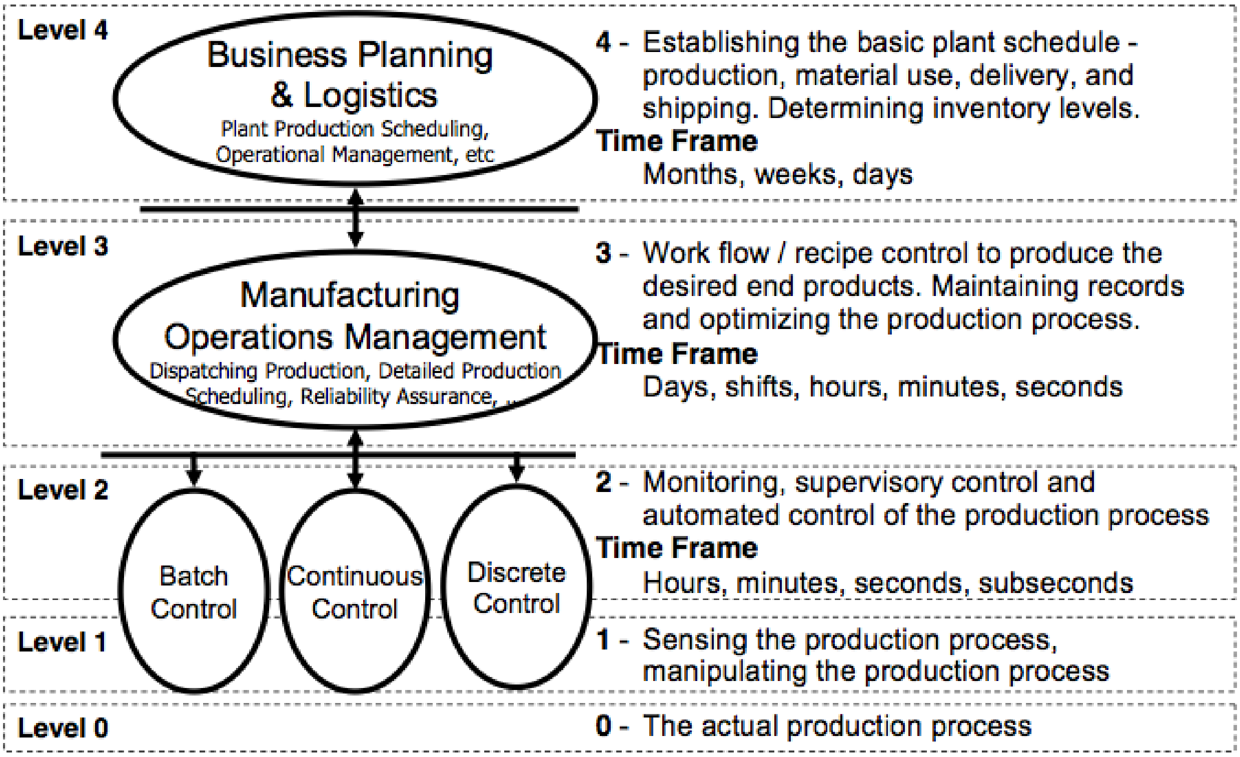


Figure 1 — Functional hierarchy (from Figure 2 in IEC 62264-3)

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.

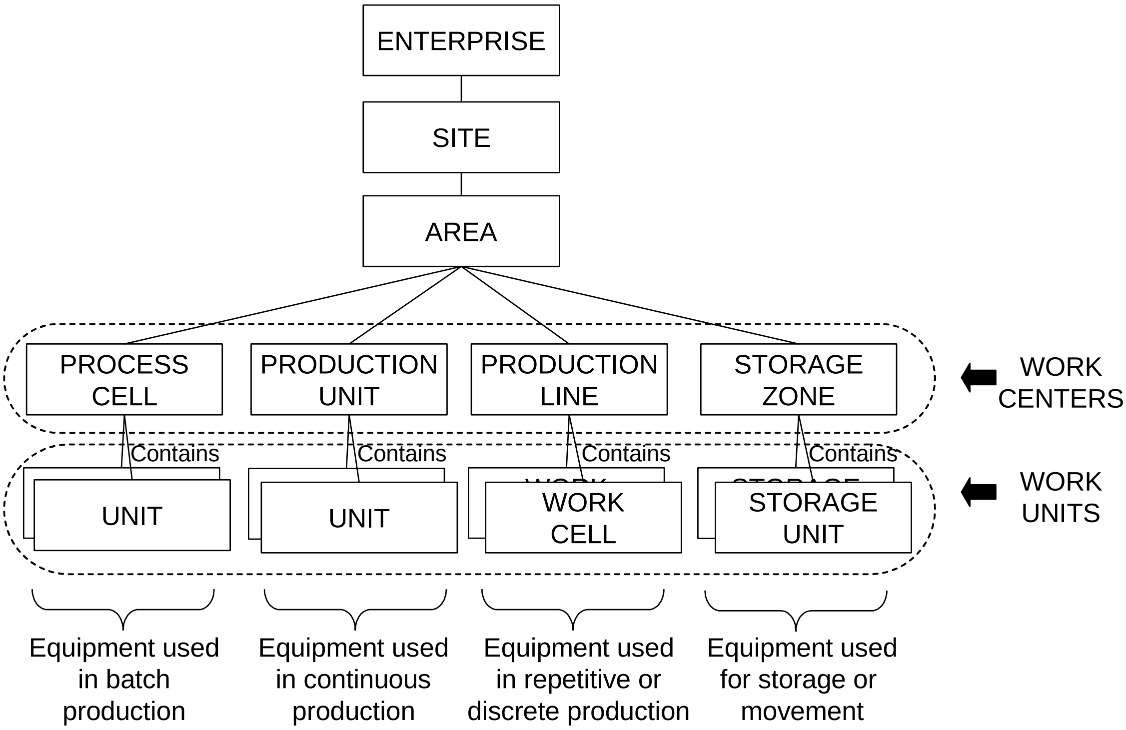


Figure 2 — Operation cluster hierarchy

This 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 level 2 and 1 might be needed.

Manufacturing Operations Management, sometimes referred to as Manufacturing Execution Systems (MES), is modeled using four information categories: production operations management, maintenance operations management, quality operations management, and inventory operations management. The KPIs in this standard are presented according to these information categories.

The KPIs in this standard use the most generic terms possible, i.e. work centers and work units, instead of industry specific terms.

KPIs also reside at Level 4. i.e., KPIs related to business planning and logistics. 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

Manufacturing Operations Management, sometimes referred to as Manufacturing Execution Systems (MES), is modelled using four categories: 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 of falls below the threshold, actions are initiated 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.

The KPIs gathered in this part of the International Standard have been used in various production situations for many years. Although these KPIs were collected in a simple and readily understandable form, different interpretations of these terms can exist.

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;

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.

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

1 Scope

The scope of ISO 22400 is to give a clear and unique definition of Key Performance Indicators (KPIs) used in Manufacturing Operations Management (MOM).

This part presents 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 type they fit.

2 Conformance

To be compliant with the requirements of ISO 22400-2, KPIs shall conform to the relevant descriptions in clause 8 and clause 9.

3 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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

IEC 62264-3, Industrial-process measurement and control – Enterprise-control system integration – Part 3: Activity models of manufacturing operations

IEC 62264-1, Industrial-process measurement and control – Enterprise-control system integration – Part 1: Models and terminology

4 Terms and definitions

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

4.1
Drill down
Examine the source of the data used to calculate a performance indicator

EXAMPLE
Within the OEE index the quality rate is to be analyzed. The drill down presents a direct indicator with reference to workplace, product and time period as well as possible errors. This is a quick analysis which supports a most rapid efficiency improvement by corrective actions, and thus reduces errors.

4.2
Enterprise Resource Planning
Business process of a company involving the enterprise-wide planning and business support functions, such as, procurement, human resource management, customer support, finance and accounting, master data management, etc.

4.3
Timing
Property of a KPI that shows how often an application can examine the value of the KPI

EXAMPLE
Categories include: Demand-oriented – determined by an operator; Periodic – calculated by system per specified time intervals; Event-driven – updated whenever data changes and displayed immediately

5 Symbols (and abbreviated terms)

$\bar{x}$	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 time
POQ	Order quantity
POS	Production order sequence
POT	Planned operation time
PQ	Produced quantity
PRTU	Planned run time per unit
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 restoration
USL	Upper specification limit
VOT	Valued operating time
WG	Working group
WIP	Work in process inventory
WOP	Work process
WP	Work place
WU	work unit
σ^2	Variance

6 Structure of a KPI record

6.1 Attributes of KPIs

In accordance with ISO 22400-1, the KPI descriptions in this part of ISO 22400 are expressed using the structure in Figure 2.

Name / Title of indicator:	
ID[a]	
Description	
Application:	
Timing	
Definition and calculation	
Formula:	
Unit / Dimension:	
Rating:	
Analysis / Drill down:	
Remarks	
Notes / Explanation:	
User group:	
Effect model	
Manufacturing type:	
[a] ID is not used in this part of ISO 22400, whose scope does not include KPI implementation and exchange of KPIs.	

Figure 3 – KPI structure

Explanations of the attributes (except ID) are provided in the remaining subclauses of clause 6.

6.2 Name / Title of indicator

Expression or designation of the KPI.

6.3 Application

A brief description of the benefits provided by the KPI, including its use and consequences in control applications.

6.4 Timing

A KPI can be calculated either in real-time (i.e., after each new data acquisition event), on demand (i.e., after a specific data selection request), or periodically (i.e., done at a certain interval, e.g., one time per day).

6.5 Formula

The mathematical formula of the KPI based on its elements.

6.6 Unit / Dimension

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

6.7 Rating

The upper and lower logical limits of the KPI and the trend indicating improvement.

6.8 Analysis / Drill down

Description of related KPI elements to drill down and analyze the root cause of KPI results.

6.9 User group:

Description of the user groups that utilize the KPI.

6.10 Effect model

An assessment method used to find root causes of KPI value change and how it relates to other elements and KPIs

6.11 Manufacturing type

The type of manufacturing (continuous, batch, discrete) for which the KPI can be used.

7 Elements used in KPI description

7.1 Time elements

7.1.1 Notations

Many time models for performance indicator data are complete and conclusive for manually performed production, but cannot always be used for automated production processes. To avoid potential misunderstanding, the time elements used in KPI descriptions are explicitly defined below.

In this model, a production order is processed and completed when one or more tasks are performed by a set of production resources, such as, 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.

7.1.2 Planned periods

7.1.2.1 Day

The day is the planned maximum time available for production and maintenance tasks. This depends on the number of shifts being run. For example, a single shift corresponds to 8 hours that are scheduled when a production resource is planned to be used to perform the tasks.

7.1.2.2 Planned order time (POET)

The planned order time is the scheduled time for executing an order based on the work plan.

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

7.1.2.3 Planned operation time (POT)

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

7.1.2.4 Planned setup time (PSUT)

The planned setup time is the scheduled time for the setup of a work unit for an order.

7.1.2.5 Planned busy time (PBT)

The planned busy time is the operating time minus the planned downtime. 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.

7.1.2.6 Planned run time per unit (PRU)

The run time per unit is the scheduled time for producing one unit.

7.1.3 Actual times

7.1.3.1 Actual personnel work time (APWT)

The actual personnel work time is the time that a personnel needs for the execution of a production order.

7.1.3.2 Actual unit processing time (AUPT)

The actual unit processing time is the time needed for setup and for the production

7.1.3.3 Actual unit busy time (AUBT)

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

7.1.3.4 Actual order execution time (AOET)

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

7.1.3.5 Actual personnel attendance time (APAT)

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

7.1.3.6 Actual production time (APT)

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

7.1.3.7 Actual queuing time (AQT)

The actual queuing time is the time in which the material is not in progress of the manufacturing process and also is not on transport.

7.1.3.8 Actual unit down time (ADOT)

The actual unit down time is the time when the work unit is not running with orders, although it is available.

7.1.3.9 Actual unit delay time (ADET)

The actual unit delay times are actual times 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

7.1.3.10 Actual setup time (ASUT)

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

7.1.3.11 Actual transport time (ATT)

The actual transport time is the time required for transport between work units, or to and from inventory storage areas.

7.2 Maintenance terms

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 ‘item’ used in the definitions below applies to the ‘work unit’ in this standard.

7.2.1 Time to failure (TTF)

Total time duration of operating time of an item, from the instant it is first put in an up state, until failure or, from the instant of restoration until next failure (IEC 60050-191)

7.2.2 Operating time between failures (TBF)

Total time duration of operating time between two consecutive failures of a repaired item (IEC 60050-191). It includes setup time and production time related to the order being processed, but no delay times.

7.2.3 Time to restoration (TTR)

Time interval during which an item is in a down state due to a failure (IEC 60050-191).

7.2.4 Failure event (FE)

The termination of the ability of an item to perform a required function (IEC 60050-191).

7.2.5 Corrective maintenance time (CMT)

That part of the maintenance time, during which corrective maintenance is performed on an item, including technical delays and logistic delays inherent in corrective maintenance (IEC 60050-191).

7.2.6 Preventive maintenance time (PMT)

That part of the maintenance time during which preventive maintenance is performed on an item, including technical delays and logistic delays inherent in preventive maintenance (IEC 60050-191).

7.3 Time model for production units

This model applies to time considerations for the use of production units. Figure 2 shows the relationship of the defined periods. It is important to note that in figure 2 the difference between time elements constitutes a specific loss.

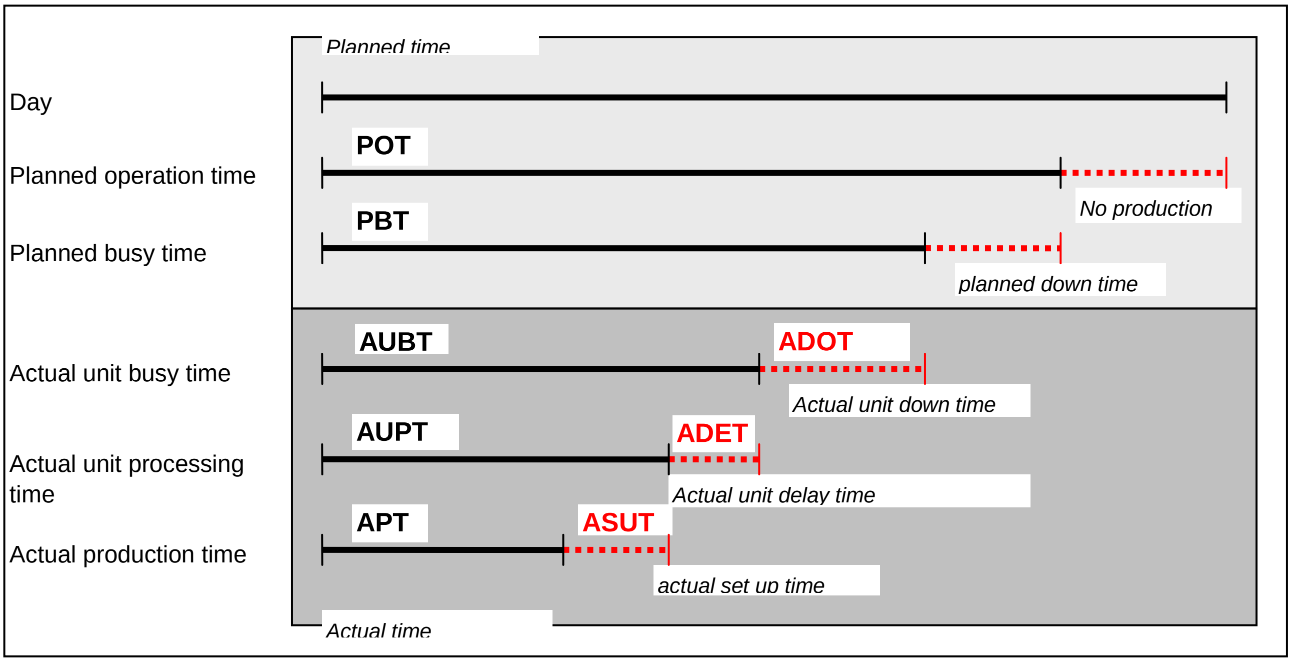


Figure 4 – Time lines for production units

There is a different time model based on partitioning of the total time such as amount of loss time for operation as shown in Annex B. KPIs such as OEE, availability and others that are generated using this type of time model are different from those defined in clause 8 of this part.

7.4 Time model for manufacturing order

This time model is valid for executing the order. Figure 3 shows the manufacturing order processing time line consisting of multiple occurrences of production unit time lines (see Figure 2). It should be noted that the production unit time lines for a production order may be carried out in separate operations at several production units.

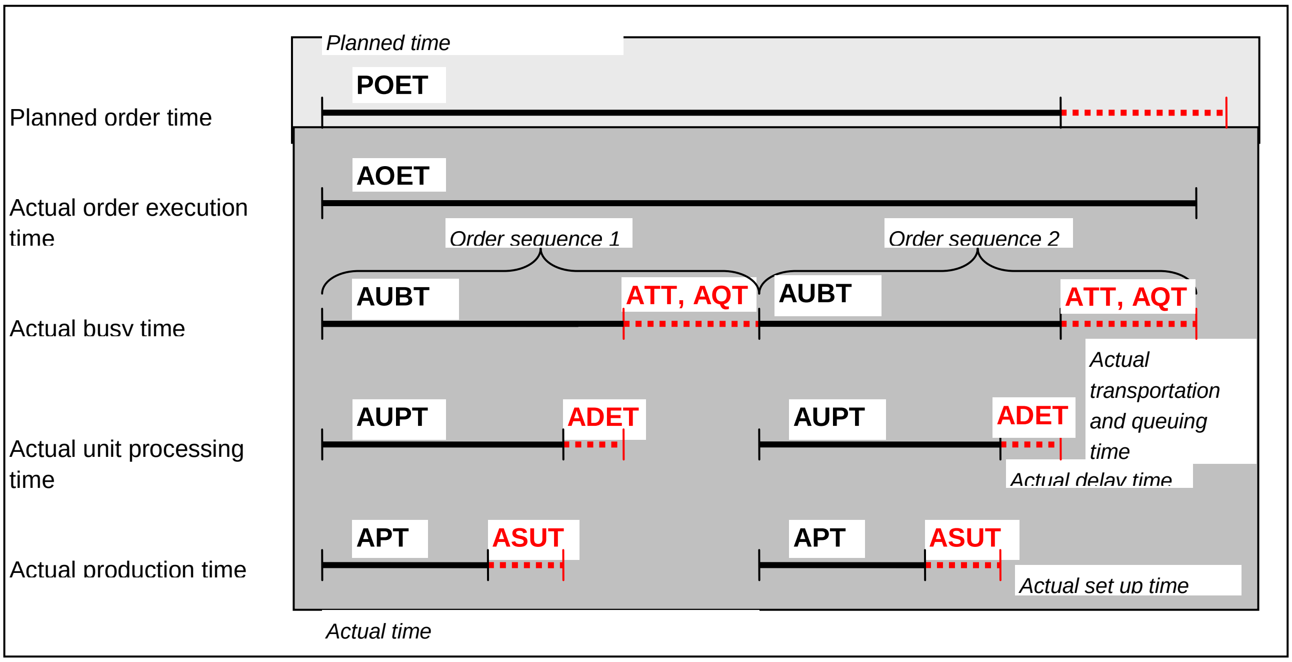


Figure 5 – Time lines for production order processing

7.5 Time model for employment

This model applies to time considerations for the employment of staff.

Figure 6 – Time lines for employment

7.6 Logistical tems

7.6.1 Order quantity (POQ)

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

7.6.2 Scrap quantity (SQ)

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

7.6.3 Planned scrap quantity (PSQ)

The planned scrap quantity is 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).

7.6.4 Good quantity (GQ)

The good quantity is the produced quantity that meets quality requirements.

7.6.5 Rework quantity (RQ)

The rework quantity is the produced quantity that missed the quality requirements. However, these requirements can be met by subsequent work.

7.6.6 Produced quantity (PQ)

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

7.6.7 Raw materials inventory (RMI)

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

7.6.8 Consumables inventory (CI)

The materials of which the quantity or quality are changed during the production such as a catalyst. (Consumables have been defined in detail in IEC 62264-1.)

7.6.9 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.

7.6.10 Work in process inventory (WIP)

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.

7.6.11 Consumed material (CM)

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.

7.6.12 Integrated good quantity (IGQ)

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” raises as the ratio of products of level “A” declines. Therefore, KPIs are calculated from the view of all related products, such as the level “A” and level “B” products mentioned above.

In this case, the KPI “Integrated Goods Ratio” is used instead of “Finished Goods Ratio” and “Integrated good quantity (IGQ)” is used instead of “Good quantity (GQ)”

Since IGQ 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.

7.6.13 Loss

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

7.6.14 Production loss (PL)

The quantity lost during production, calculate as output minus input.

7.6.15 Storage and transportation loss (STL)

The quantity lost during storage and transportation, such as inventory lost during an inventory calculation or material lost during movement from one place to another.

7.6.16 Other loss (OL)

The quantity lost due to extraordinary incidents such as natural disasters.

7.6.17 Equipment production capacity (EPC)

Equipment production capacity is an important indicator in a manufacturing enterprise, which can be used to calculate the KPI” Equipment Load Rate”. Equipment production capacity is either “rated” or “maximum”, as follows:

7.6.18 Maximum Equipment Production Capacity (MEPC)

The upper limit value of production demarcate before the equipment delivery.

7.6.19 Rated Equipment Production Capacity (REPC)

The upper limit value of production promised the stable operation of the equipment.

7.7 Organizational terms

7.7.1 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).

7.7.2 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.

7.7.3 Working group (WG)

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

7.7.4 Workplace (WP)

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

7.7.5 Production order (PO)

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

7.7.6 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 workcenters up to a site.

7.7.6.1 Work center and work unit

Work centers are elements of the equipment hierarchy under an area.

For manufacturing operations management 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.

A work unit is any element of the equipment hierarchy under a work center.

7.8 Quality terms

7.8.1 Good part (GP)

A good part is an individual identifiable part, e.g. by serialization, which meets the quality requirements.

7.8.2 Inspected part (IP)

An inspected part is an individual identifiable part, e.g. by serialization, which was tested against the quality requirements.

7.8.3 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.

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

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

7.8.5 Upper specification limit (USL)

The upper specification limit corresponds to the upper specification border related to the characteristic of a product.

7.8.6 Standard deviation (s)

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.

7.8.7 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.

7.8.8 Lower specification limit (LSL)

The lower specification limit corresponds to the lower specification border related to the characteristic of a product.

7.8.9 Variance (σ^2)

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.

8 Description of KPIs

The Manufacturing Operation Management is divided into four information categories; production operations, maintenance operations, quality operations, and inventory operations. The KPIs in this standard relate to these categories as presented in the following table.

KPI	Production	Maintenance	Inventory	Quality
Worker efficiency	X			
Allocation ratio	X			
Throughput rate	X			
Allocation efficiency	X			
Utilisation efficiency	X			
Overall equipment effectiveness index	X			
Net equipment effectiveness index	X			
Availability	X			
Effectiveness	X			
Quality ratio				X
Set up rate	X			
Technical efficieny	X			
Production process rate	X			
Actual tp planned scrap ratio				X
First pass yield				X
Scrap ratio				X
Rework ratio				X
Fall off ratio				X
Machine capability index	X			
Critical machine capability index	X			
Process capability index	X			
Critical process capability index	X			

KPI	Production	Maintenance	Inventory	Quality
Comprehensive energy consumption	X			
Inventory turns			X	
Finished goods ratio	X			
Integrated goods ratio	X			
Production loss ratio	X			
Storage and transportation loss ratio			X	
Other loss ratio			X	
Equipment load rate	X			
Meanoperation time between failures		X		
Mean time to failure		X		
Mean time to restoration		X		
Corrective maintenance ratio		X		

8.1 Worker efficiency

Name / Title of indicator:	Worker efficiency
Description	
Benefit / Application:	The Worker efficiency considers the relationship between the working hours related to production orders and the total attendance time of the employees.
Timing	Periodic
Definition and Calculation	
Formula:	Worker efficiency = APWT / APAT
Unit/Dimension:	%
Rating:	Min: 0% Max: 100% Trend: the higher the better
Analysis / Drill Down:	Based on working group
Remarks	
Notes / Explanation:	It has to be noted that the work time has to be split if the operation works with several work units at the same time.
User group	Master, Chief, Management
Effect model:	see A.3
Manufacturing type:	continuous, batch, discrete

8.2 Allocation ratio

Name / Title of indicator:	Allocation ratio
Description	
Benefit / Application:	The Allocation ratio is the relationship of the complete busy time over all involved work units and work centres to the throughput time of a production order. The Allocation ratio is an index for the Work in Progress inventory (WIP), the wait times and delay times. To much WIP reduces liquidity and to much wait and down time extend the throughput time
Timing	Periodic
Definition and Calculation	
Formula:	Allocation ratio = AUBT / AOET
Unit/Dimension:	%
Rating:	Min: 0% Max> 100% Trend: the higher the better By overlapping of production operations the rate can be bigger than 100%
Analysis / Drill Down:	Related to product, production order, and plant
Remarks	
Notes / Explanation:	Because the throughput time is related to a complete production order, the smallest entity is a single production order. The allocation time is the summary about all production order sequences which are involved in the order selection.
User group	Master, Chief, Management
Effect model:	see A.4
Manufacturing type:	continuous, batch, discrete

8.3 Throughput rate

Name / Title of indicator:	Throughput rate
Description	
Benefit / Application:	The Throughput rate is an index for the performance of a process. It indicates the produced quantity per unit time. This performance indicator is an important index for the efficiency in production.
Timing	demand-oriented, periodic
Definition and Calculation	
Formula:	Throughput rate = PQ / AOET
Unit/Dimension:	Quantity unit / Time unit
Rating:	Min: 0 Max: depending on product Trend: the higher the better
Analysis / Drill Down:	Related to product, production order, and production unit
Remarks	
Notes / Explanation:	This performance indicator is calculated per order after order closing. The time unit may also be chosen in hours or days to rate the efficiency specific for a product.
User group	Master, Chief, Management
Effect model:	see A.5
Manufacturing type:	continuous, batch, discrete

8.4 Allocation efficiency

Name / Title of indicator:	Allocation efficiency
Description	
Benefit / Application:	The Allocation efficiency is the ratio between the real allocation time of a work unit and planned time for allocating the machine.
Timing	demand-oriented
Definition and Calculation	
Formula:	Allocation efficiency = AUBT / PBT
Unit/Dimension:	%
Rating:	Min: 0% Max: 100% Trend: the higher the better
Analysis / Drill Down:	Related to product, production order, and work unit
Remarks	
Notes / Explanation:	The allocation efficiency indicates how strongly the capacity of the machine is already used and how much capacity is still available.
User group	Worker, Master, Chief, Management
Effect model:	see A.6
Manufacturing type:	continuous, batch, discrete

8.5 Utilization efficiency

Name / Title of indicator:	Utilization efficiency
Description	
Benefit / Application:	The Utilization efficiency is the rate between the production time and the busy time. 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.
Timing	demand-oriented, periodic, online
Definition and Calculation	
Formula:	Utilization efficiency = APT / AUBT
Unit/Dimension:	%
Rating:	Min: 0% Max: 100% Trend: the higher the better
Analysis / Drill Down:	Related to production unit
Remarks	
Notes / Explanation:	This performance indicator is usable as online indicator for the worker level.
User group	Master, Chief, Management
Effect model:	see A.7
Manufacturing type:	continuous, batch, discrete

8.6 Overall equipment effectiveness index

Name / Title of indicator:	Overall Equipment Effectiveness Index
Description	
Benefit / Application:	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 OEE Index represents the used availability, the effectiveness of the work unit, and the quality rate integrated in only one indicator.
Timing	demand-oriented, periodic
Definition and Calculation	
Formula:	OEE index = Availability * Effectiveness * Quality rate
Unit/Dimension:	%
Rating:	Min: 0% Max: 100% Trend: the higher, the better.
Analysis / Drill Down:	Related to work unit, product, period (day), and defect types.
Remarks	
Notes / Explanation:	Before starting a benchmark based on the OEE index, it has to be checked the criteria for a comparability first.
User group	Master, Chief, Management
Effect model:	see A.8
Manufacturing type:	continuous, batch, discrete

8.7 Net equipment effectiveness index

Name / Title of indicator:	Net equipment effectiveness index
Description	
Benefit / Application:	The Net equipment effectiveness (NEE) index is comparable with the OEE index but it includes the setup time within the availability. The NEE index indicates losses by work unit delays, cycle time losses and losses by rework.
Timing	demand-oriented, periodic
Definition and Calculation	
Formula:	NEE index = AUPT / PBT * Effectiveness * Quality rate
Unit/Dimension:	%
Rating:	Min: 0% Max: 100% Trend: the higher, the better.
Analysis / Drill Down:	Related to production unit, product, period (day) and error types.
Remarks	
Notes / Explanation:	Compared to the OEE index, the NEE index is used more rarely. The NEE includes the preparation and set-up time as no losses.
User group	Worker, Master, Chief, Management
Effect model:	see A.9
Manufacturing type:	continuous, batch, discrete

8.8 Availability

Name / Title of indicator:	Availability
Description	
Benefit / Application:	Availability indicates how strongly the capacity of a work unit for the production is used in relation to the available capacity.
Timing	demand-oriented, periodic
Definition and Calculation	
Formula:	Availability = APT / PBT
Unit/Dimension:	%
Rating:	Min: 0% Max: 100% Trend: the higher, the better.
Analysis / Drill Down:	Related to production unit
Remarks	
Notes / Explanation:	The term availability is also called degree of utilisation or capacity factor.
User group	Master, Chief, Management
Effect model:	see A.10
Manufacturing type:	continuous, batch, discrete

8.9 Effectiveness

Name / Title of indicator:	Effectiveness
Description	
Benefit / Application:	Effectiveness is the index for the performance of a work unit. It represents the relationship between the planned target cycle and the actual cycle. The effectiveness can be calculated in short periods and indicates how effective a work unit will be during the production time.
Timing	demand-oriented, periodic, online
Definition and Calculation	
Formula:	Effectiveness = PRU * PQ / APT
Unit/Dimension:	%
Rating:	Min: 0% Max: 100% Trend: the higher, the better. The 100% can be exceeded, if the planned target cycle is bigger than the actual cycle.
Analysis / Drill Down:	Related to product, work unit, and production order
Remarks	
Notes / Explanation:	Effectiveness is also called efficiency factor. This indicator is usable as online indicator for the worker level. .
User group	Master, Chief, Management
Effect model:	see A.11
Manufacturing type:	continuous, batch, discrete

8.10 Quality ratio

Name / Title of indicator:	Quality ratio
Description	
Benefit / Application:	The Quality ratio is the relationship between the good quantity and the produced quantity.
Timing	demand-oriented, periodic, online
Definition and Calculation	
Formula:	Quality ratio = GQ / PQ
Unit/Dimension:	%
Rating:	Min: 0% Max: 100% Trend: the higher, the better.
Analysis / Drill Down:	Related to work unit, product, process, period (day), and error types.
Remarks	
Notes / Explanation:	This indicator is usable as online indicator for the worker level. .
User group	Master, Chief, Management
Effect model:	see A.12
Manufacturing type:	continuous, batch, discrete

8.11 Setup rate

Name / Title of indicator:	Setup rate
Description	
Benefit / Application:	The setup rate is an index for the preparation time in relationship to the processing time at a work unit. As higher the value as higher is the set up part in relation to the processing time of a production order. For an enterprise a high setup rate means a consumption of value added time.
Timing	demand-oriented, periodic
Definition and Calculation	
Formula:	Setup rate = ASUT / AUPT
Unit/Dimension:	%
Rating:	Min: 0% Max: 100% Trend: the lower, the better.
Analysis / Drill Down:	Related to work unit, product, and production order.
Remarks	
Notes / Explanation:	The setup rate has to be considered especially when the order lots will be split in smaller lots.
User group:	Worker, Master, Chief
Effect model:	see A.13
Manufacturing type:	continuous, batch, discrete

8.12 Technical efficiency

Name / Title of indicator:	Technical efficiency
Description	
Benefit / Application:	The technical efficiency of a work unit is the relationship between the production time period and production time period including the delays or malfunction-caused interruptions.
Timing	demand-oriented, periodic, online
Definition and Calculation	
Formula:	Technical efficiency = APT / (APT + ADET)
Unit/Dimension:	%
Rating:	Min: 0% Max: 100% Trend: the higher, the better. 100% corresponds to maximum attainable technical efficiency without malfunction-caused interruptions.
Analysis / Drill Down:	Related to work unit, product, and production order.
Remarks	
Notes / Explanation:	The technical efficiency indicates how much capacity is still available by reduction of the delays and malfunction interrupts. Compared with the utilisation degree, the setup time will not be considered. This indicator is usable as online indicator for the worker level.
User group:	Worker, Master, Chief, Management
Effect model:	see A.14
Manufacturing type:	continuous, batch, discrete

8.13 Production process ratio

Name / Title of indicator:	Production process ratio
Description	
Benefit / Application:	The production process ratio is an index for the efficiency of the production. This indicator defines the relationship between the production time and the whole throughput time of a production order. When the production process ratio is low, then it means that the production orders include a lot of wait-time or idle periods instead of production time.
Timing	demand-oriented, periodic
Definition and Calculation	
Formula:	Production process ratio = APT / AOET
Unit/Dimension:	%
Rating:	Min: 0% Max: > 100% Trend: the higher, the better. By overlapping production order operations it is possible to get a result higher than 100%
Analysis / Drill Down:	Related to product, production order, and plant.
Remarks	
Notes / Explanation:	Because the throughput time is related to production orders, the smallest entity will be a complete production order. The production time is the summary about all production time periods of all production order operations which are included in the selected production orders
User group:	Master, Chief, Management
Effect model:	see A.15
Manufacturing type:	continuous, batch, discrete

8.14 Actual to planned scrap ratio

Name / Title of indicator:	Actual to planned scrap ratio
Description	
Benefit / Application:	The actual to planned scrap ratio is a limitation of the planned scrap. The indicator should be smaller than 100%. In this case the produced scrap will be within the planned limitation.
Timing	demand-oriented, periodic, online
Definition and Calculation	
Formula:	Actual to planned scrap ratio = SQ / PSQ
Unit/Dimension:	%
Rating:	Min: 0% Max: 100% Trend: the lower, the better.
Analysis / Drill Down:	Related to production unit, product, and errors.
Remarks	
Notes / Explanation:	The indicator supports the monitoring of the target value. The planned scrap quantity (which can be expected) is normally already defined in the ERP system in order to ensure also the necessary material allocation. This indicator is usable as online indicator for the worker level.
User group:	Worker, Master, Chief, Management
Effect model:	see A.16
Manufacturing type:	continuous, batch, discrete

8.15 First pass yield

Name / Title of indicator:	First pass yield
Description	
Benefit / Application:	The First pass yield (FPY) is a direct indicator for the process quality related to work place and product. The FPY considers the rate of yield over all production order operations. When the indicator increases then defect costs and material wastage will be reduced and the output improved.
Timing	demand-oriented, periodic, online
Definition and Calculation	
Formula:	FPY = GP / IP
Unit/Dimension:	%
Rating:	Min: 0% Max: 100% Trend: the higher, the better.
Analysis / Drill Down:	Related to workplace, product, production order, and defect types.
Remarks	
Notes / Explanation:	For identifying the first pass it is necessary to label each single product unit with an identification number (serial number). The FPY designates the percentage of products, which fulfil the quality requirements in the first process run without reworks (good parts). The FPY stands in reciprocal relationship to the defect costs. If the FPY increases, then the defect costs will be less. This indicator is usable as online indicator for the worker level. .
User group:	Worker, Master, Chief, Management
Effect model:	see A.17
Manufacturing type:	Batch, discrete

8.16 Scrap ratio

Name / Title of indicator:	Scrap ratio
Description	
Benefit / Application:	The scrap ratio is the relationship between scrap quantity and produced quantity.
Timing	demand-oriented, periodic, online
Definition and Calculation	
Formula:	Scrap ratio = SQ / PQ
Unit/Dimension:	%
Rating:	Min: 0% Max: 100% Trend: the lower, the better.
Analysis / Drill Down:	Related to production unit, product, production order, and error types.
Remarks	
Notes / Explanation:	The Scrap ratio will be also used for the commercial rating. As smaller the value, as better is the productivity. This indicator is usable as online indicator for the worker level.
User group:	Worker, Master, Chief, Management
Effect model:	see A.18
Manufacturing type:	continuous, batch, discrete

8.17 Rework ratio

Name / Title of indicator:	Rework ratio
Description	
Benefit / Application:	The rework ratio is the relationship between rework quantity and produced quantity.
Timing	demand-oriented, periodic, online
Definition and Calculation	
Formula:	Rework ratio = RQ / PQ
Unit/Dimension:	%
Rating:	Min: 0% Max: 100% Trend: the lower, the better.
Analysis / Drill Down:	Related to production unit, product, production order, and error types.
Remarks	
Notes / Explanation:	The Rework ratio will be also used for the commercial rating. As smaller the value, as better is the productivity. This indicator is usable as online indicator for the worker level.
User group:	Worker, Master, Chief, Management
Effect model:	see A.19
Manufacturing type:	continuous, batch, discrete

8.18 Fall off ratio

Name / Title of indicator:	Falloff ratio
Description	
Benefit / Application:	The Fall off ratio indicates the fall off quantity in each production operation step in relation to the produced quantity in the first operation. The KPI can be used in concatenated processes, where are mother products (e.g. motherboard) which will be produced in the first manufacturing step and will have scrap in the further operation steps. 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.
Timing	demand-oriented, periodic, online
Definition and Calculation	
Formula:	Fall off ratio = SQ / PQ $_{\text{of the first production order sequence}}$
Unit/Dimension:	%
Rating:	Min: 0% Max: 100% Trend: the lower, the better.
Analysis / Drill Down:	Related to product, production order, and operation.
Remarks	
Notes / Explanation:	This indicator is usable as online indicator for the worker level. In process industry, such as 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.
User group:	Worker, Master, Chief, Management
Effect model:	see A.20
Manufacturing type:	batch, discrete

8.19 Machine capability index

Name / Title of indicator:	Machine capability index
Description	
Benefit / Application:	The Machine capability index (C_m) indicates the ability of a machine or a work mechanism to produce the specified quality. The evaluation should be executed if possible by exclusion of other process influences. The method will be used mainly with the approval from machines in combination with products
Timing	demand-oriented, periodic, online
Definition and Calculation	
Formula:	Cm = (USL - LSL) / (6 * s)
Unit/Dimension:	---
Rating:	Min: → 0, if s is very big Max: infinite, if s → 0 Trend: the higher, the better
Analysis / Drill Down:	Related to product, machine, characteristic, and measurement.
Remarks	
Notes / Explanation:	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 only for characteristic with upper and lower specification limits.
User group:	Worker, Master, Chief
Effect model:	see A.21
Manufacturing type:	continuous, batch, discrete

8.20 Critical machine capability index

Name / Title of indicator:	Critical machine capability index
Description	
Benefit / Application:	The Critical machine capability index (C_{mk}) indicates the ability of a machine or a work mechanism to produce the specified quality. The evaluation should be executed if possible by exclusion of other process influences. The method will be used mainly with the approval from machines in combination with products
Timing	demand-oriented, periodic, online
Definition and Calculation	
Formula:	$C_{mko} = (USL - \bar{x}) / (3 * s)$; $C_{mku} = (\bar{x} - LSL) / (3 * s)$
Unit/Dimension:	---
Rating:	Min: < 0, if $\bar{x}$ is out of the specification limits Max: infinite, if s → 0 Trend: the higher, the better
Analysis / Drill Down:	Related to product, machine, characteristic, and measurement.
Remarks	
Notes / Explanation:	C_{mk} is a critical 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 an upper and a lower specification limits. The C_{mk} can be calculated as (C_{mku}) index based on the lower specification limit and as the (C_{mko}) index based on the upper specification limit. The lower C_{mk} will be the relevant value of both calculations.
User group:	Worker, Master, Chief
Effect model:	see A.21
Manufacturing type:	continuous, batch, discrete

8.21 Process capability index

Name / Title of indicator:	Process capability index (C_p)
Description	
Benefit / Application:	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 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 and the 6-sigma process dispersion. A process is usually called capable if the process capability index is > 1,33.
Timing	demand-oriented, online
Definition and Calculation	
Formula:	$C_p = (USL - LSL) / (6 * \hat{\sigma})$
Unit/Dimension:	--
Rating:	Min: → 0, if $\hat{\sigma}$ is very big Max: infinite, if $\hat{\sigma}$ → 0 Trend: the higher, the better
Analysis / Drill Down:	Related to product, machine, characteristic, and measurement.
Remarks	
Notes / Explanation:	The measurement has to be done in regular time steps or after defined quantity intervals with small samples (1-25). $\hat{\sigma}$ will be calculated based on a confidence factor from the standard deviation, depending on the sample inspection size.
User group:	Worker, Master, Chief
Effect model:	see A.22
Manufacturing type:	continuous, batch, discrete

8.22 Critical process capability index

Name / Title of indicator:	Critical process capability index
Description	
Benefit / Application:	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 Critical process capability index ($C_{pk)}$ is the relationship between the dispersion of a process and the upper or lower specification limit and its averages. The method compares the range between the upper or lower specification limit and its averages and the 3-sigma process dispersion. A process is usually called capable if the process capability index is > 1,33.
Timing	demand-oriented, online
Definition and Calculation	
Formula:	$C_{pko} = (USL - \bar{\bar{x}}) / (3 * \hat{\sigma})$; $C_{pku} = (\bar{\bar{x}} - LSL) / (3 * \hat{\sigma})$
Unit/Dimension:	---
Rating:	Min: → 0, if $\hat{\sigma}$ is very big Max: infinite, if $\hat{\sigma}$ → 0 Trend: the higher, the better
Analysis / Drill Down:	Related to product, machine, characteristic, and measurement.
Remarks	
Notes / Explanation:	The measurement has to be done in regular time steps or after defined quantity intervals with small samples (1-25). $\hat{\sigma}$ will be calculated based on a confidence factor from the standard deviation, depending on the sample inspection size. The $\bar{\bar{x}}$ will be calculated as the average of the averages of all small samples. The C_{pk} can be calculated as (C_{pku}) index based on the lower specification limit and as the (C_{pko}) index based on the upper specification limit. The lower Cp_k will be the relevant value of both calculations.
User group: Effect model: Manufacturing type:	Worker, Master, Chief See A.22 continuous, batch, discrete

8.23 Comprehensive energy consumption

Name / Title of indicator:	Comprehensive energy consumption
Description	
Benefit / Application:	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. Comprehensive energy consumption is the ratio between all the energy consumed in a production cycle and produced quantity.
Timing	demand-oriented, periodic
Definition and Calculation	
Formula:	$e = E/PQ = (\sum Mi*Ri + Q) / PQ$ where e: unit energy consumption of statistical object, standard quantity / ton E: comprehensive energy consumption, standard quantity Mi: actual consumption of certain kind of energy, ton (kilowatt hour) Ri[a]: conversion coefficient of certain kind of energy, standard quantity / ton Q: algebraic sum of effective energy exchanges with environment, standard quantity PQ is expressed in tons
Unit/Dimension:	Joule / quantity unit
Rating:	Min: 0 Max: related to product Trend: the lower, the better.
Analysis / Drill Down:	Related to product and statistics unit
Remarks	
Notes / Explanation:	Energy consumption is an important factor impacting the production costs and final profits.
User group	Worker, Master, Chief, Management
Effect model:	A.23
Manufacturing type:	Continuous, batch
[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.	

8.24 Inventory turns

Name / Title of indicator:	Inventory turns
Description	
Benefit / Application:	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 though the production. 2) Consumables (CI): The materials of which the quantity or quality is changed during the production, such as 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): 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. 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.
Timing	demand-oriented, periodic
Definition and Calculation	
Formula:	Inventory turns = Throughput / average inventory
Unit/Dimension:	Time unit
Rating:	Min: 0 Max: related to product Trend: the higher, the better.
Analysis / Drill Down:	Related to product, production order, production unit, and inventory unit.
Remarks	
Notes / Explanation:	Exactly which inventory is included depends on what is being measured. For instance, in a warehouse, all inventory is FGI, so turns are given by TH / FGI. In a plant, generally both WIP and FGI are considered, so turns are given by TH / (WIP+FGI). There are also other inventory turns in different departments, such as Raw Material Inventory Turns (TH/RMI), Consumables Inventory Turns (TH/CI), and so on.

	Attention needs to be paid to the boundary of the Inventory Turns in a Manufacturing Execution System. Usually, Inventory Turns in a Manufacturing Execution System only focuses on the inventory of WIP, while the Inventory Turns of RMI and FGI are usually the focus of an Enterprise Resource Planning system. It is essential to make sure that throughput and inventory are measured in the same unit.
User group	Master, Chief, Management
Effect model:	A.24
Manufacturing type:	continuous (Inventory Turns is typically a Level 4 KPI in discrete manufacturing)

8.25 Finished goods ratio

Name / Title of indicator:	Finished goods ratio
Description	
Benefit / Application:	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. The Finished Goods Ratio is the ratio of the good quantity produced (GQ) to the consumed material.
Timing	demand-oriented, periodic, online
Definition and Calculation	
Formula:	Finished goods ratio = GQ / CM
Unit/Dimension:	%
Rating:	Min: 0% Max: 100% Trend: the higher, the better.
Analysis / Drill Down:	Related to production unit, product, period (day) and error types.
Remarks	
Notes / Explanation:	This indicator is suitable as on-line characteristic number for the worker level.
User group	Master, Chief, Management
Effect model:	A.25
Manufacturing type:	continuous, batch

8.26 Integrated goods ratio

Name / Title of indicator:	Integrated goods ratio
Description	
Benefit / Application:	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, such as 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. The Integrated Goods Ratio is the relationship of the produced quantity to the consumed material.
Timing	demand-oriented, periodic, online
Definition and Calculation	
Formula:	Finished goods ratio = IGQ / CM
Unit/Dimension:	%
Rating:	Min: 0% Max: 100% Trend: the higher, the better.
Analysis / Drill Down:	Related to production unit, product, period (day), and error types.
Remarks	
Notes / Explanation:	This indicator is suitable as on-line characteristic number for the worker level.
User group	Master, Chief, Management
Effect model:	A.26
Manufacturing type:	continuous, batch

8.27 Production loss ratio

Name / Title of indicator:	Production Loss Ratio
Description	
Benefit / Application:	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, such as 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 such as natural disasters. The Production Loss Ratio is the relationship of quantity lost during production to the consumed material.
Timing	demand-oriented, periodic, online
Definition and Calculation	
Formula:	Production loss ration = PL / CM
Unit/Dimension:	%
Rating:	Min: 0% Max: 100% Trend: the lower, the better.
Analysis / Drill Down:	Related to production unit, product, period (day), and error types.
Remarks	
Notes / Explanation:	This indicator is suitable as on-line characteristic number for the worker level.
User group	Master, Chief, Management
Effect model:	A.27
Manufacturing type:	continuous, batch

8.28 Storage and transportation loss ratio

Name / Title of indicator:	Storage and Transportation Loss Ratio
Description	
Benefit / Application:	The Storage and Transportation Loss Ratio is the relationship of the quantity of loss during storage and transportation to the consumed material.
Timing	demand-oriented, periodic, online
Definition and Calculation	
Formula:	Storage and transportation loss ratio = STL / CM
Unit/Dimension:	%
Rating:	Min: 0% Max: 100% Trend: the lower, the better.
Analysis / Drill Down:	Related to production unit, product, period (day), and error types.
Remarks	
Notes / Explanation:	This indicator is suitable as on-line characteristic number for the worker level.
User group	Master, Chief, Management
Effect model:	A.28
Manufacturing type:	continuous, batch

8.29 Other loss ratio

Name / Title of indicator:	Other Loss Ratio
Description	
Benefit / Application:	The Other Loss Ratio evaluates loss that is not during production, storage, or transportation.
Timing	demand-oriented, periodic, online
Definition and Calculation	
Formula:	Other loss ratio = OL / CM
Unit/Dimension:	%
Rating:	Min: 0% Max: 100% Trend: the lower, the better.
Analysis / Drill Down:	Related to production unit, to product, to period (day) and to error types.
Remarks	
Notes / Explanation:	This indicator is suitable as on-line characteristic number for the worker level.
User group	Master, Chief, Management
Effect model:	A.29
Manufacturing type:	continuous, batch

8.30 Equipment load ratio

Name / Title of indicator:	Equipment Load Ratio
Description	
Benefit / Application:	Production capacity and the load rate of equipment are important indicators in a manufacturing enterprise. The Equipment Load Rate KPI is calculated as: Equipment Load Rate = Produced Quantity (PQ) / Equipment Production Capacity Equipment production capacity is either “rated” or “maximum”, as follows: a) Maximum Equipment Production Capacity: the upper limit value of production demarcated before the equipment delivery. b) Rated Equipment Production Capacity: the upper limit value of production promised the stable operation of the equipment. The Equipment Load Rate KPI provides information about the ratio of produced quantity (PQ) in relation to the maximum equipment production capacity. It 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.
Timing	demand-oriented, periodic, online
Definition and Calculation	
Formula:	Equipment load ratio = PQ / EPC
Unit/Dimension:	%
Rating:	Min: 0% Max: 100% Trend: If the produced quantity is below the Rated Equipment Production Capacity, the higher, the better. It 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 to some equipment, below which it cannot be produced.
Analysis / Drill Down:	Related to production unit.
Remarks	
Notes / Explanation:	The value of Equipment Load Rate impacts the production costs and, ultimately, profits.
User group	Master, Chief, Management
Effect model:	A.30
Manufacturing type:	continuous, batch

8.31 Mean operating time between failures

Name / Title of indicator:	Mean operating time between failures
Description	
Benefit / Application:	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.
Timing	demand-oriented, periodic
Definition and Calculation	
Formula:	$MTBF = \frac{\sum_{i=1}^{i=n} TBF_i}{FE+1}$
Unit/Dimension:	Time unit
Rating:	Min: 0 Max: infinite Trend: the higher the better
Analysis / Drill Down:	Related to work unit.
Remarks	
Notes / Explanation:	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.
User groups	Master, Chief, Management
Effect model	See A.31
Manufacturing type	batch, continuous, discrete

8.32 Mean time to failure

Name / Title of indicator:	Mean Time To Failure
Description	
Benefit / Application:	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 repairable items.
Timing	demand-oriented, periodic
Definition and Calculation	
Formula:	$MTTF = \frac{\sum_{i=1}^{i=n} TTF_i}{FE+1}$
Unit/Dimension:	Time unit
Rating:	Min: 0 Max: infinite Trend: the higher the better
Analysis / Drill Down:	Related to work unit.
Remarks	
Notes / Explanation:	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.
User groups	Master, Chief, Management
Effect model	See A.32
Manufacturing types	batch, continuous, discrete

8.33 Mean time to restoration

Name / Title of indicator:	Mean Time To Restoration
Description	
Benefit / Application:	Mean Time To Restoration (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 restoration (IEC 60050-191).
Timing	demand-oriented, periodic
Definition and Calculation	
Formula:	$MTTR = \frac{\sum_{i=1}^{i=n} TTR_i}{FE+1}$
Unit/Dimension:	Time unit
Rating:	Min: 0 Max: infinite Trend: the lower the better
Analysis / Drill Down:	Related to work unit.
Remarks	
Notes / Explanation:	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.
User groups	Master, Chief, Management
Effect model	See A.33
Manufacturing type	batch, continuous, discrete

8.34 Corrective maintenance ratio

Name / Title of indicator:	Corrective maintenance ratio
Description	
Benefit / Application:	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.
Timing	demand-oriented, periodic
Definition and Calculation	
Formula:	Corrective maintenance ratio = CMT / (CMT + PMT)
Unit/Dimension:	%
Rating:	Min: 0 Max: 100 Trend: the lower the better
Analysis / Drill Down:	Related to work unit.
Remarks	
Notes / Explanation:	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.
User groups	Master, Chief, Management
Effect model	See A.34
Manufacturing types	batch, continuous, discrete

Annex A
(normative)

Effect models

A.1 Parameter-indicator matrix

Parameters		Worker efficiency	Allocation rate	Throughput rate	Allocation efficiency	Utilisation efficiency	OEE-Index	NEE-Index	Availability	Effectiveness	Quality rate	Setup rate	Technical efficiency	Production process rate	Actual to planned scrap ratio	First pass yield	Scrap ratio	Rework rate	Fall off Ratio	Machine capability index (C_m)	Critical machine capability index (C_{mk})	Process capability index (C_p)	Critical process capability index (C_{pk})
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 ($\bar{\bar{x}}$)																				●		●
	Upper specification limit (USL)																			●	●	●	●
	Standard deviation (s)																			●	●		
	Lower specification limit (LSL																			●	●	●	●
	Estimated deviation ($\hat{\sigma}$)																					●	●
Performance indicators*	Availability						●																
	Effectiveness						●	●															
	Quality rate						●	●															

* these performance indicators were defined separately to map the OEE- and NEE-indicators

			Mean time to failure	Mean operating time between failures	Mean time to restoration	Corrective maintenance ratio	…
Maintenance terms	Time to failure		•				
	Operating time between failures			•			
	Time to restoration				•		
	Failure event		•	•	•		
	Corrective maintenance time					•	
	Preventive maintenance time					•	

A.2 Effect model diagram key

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

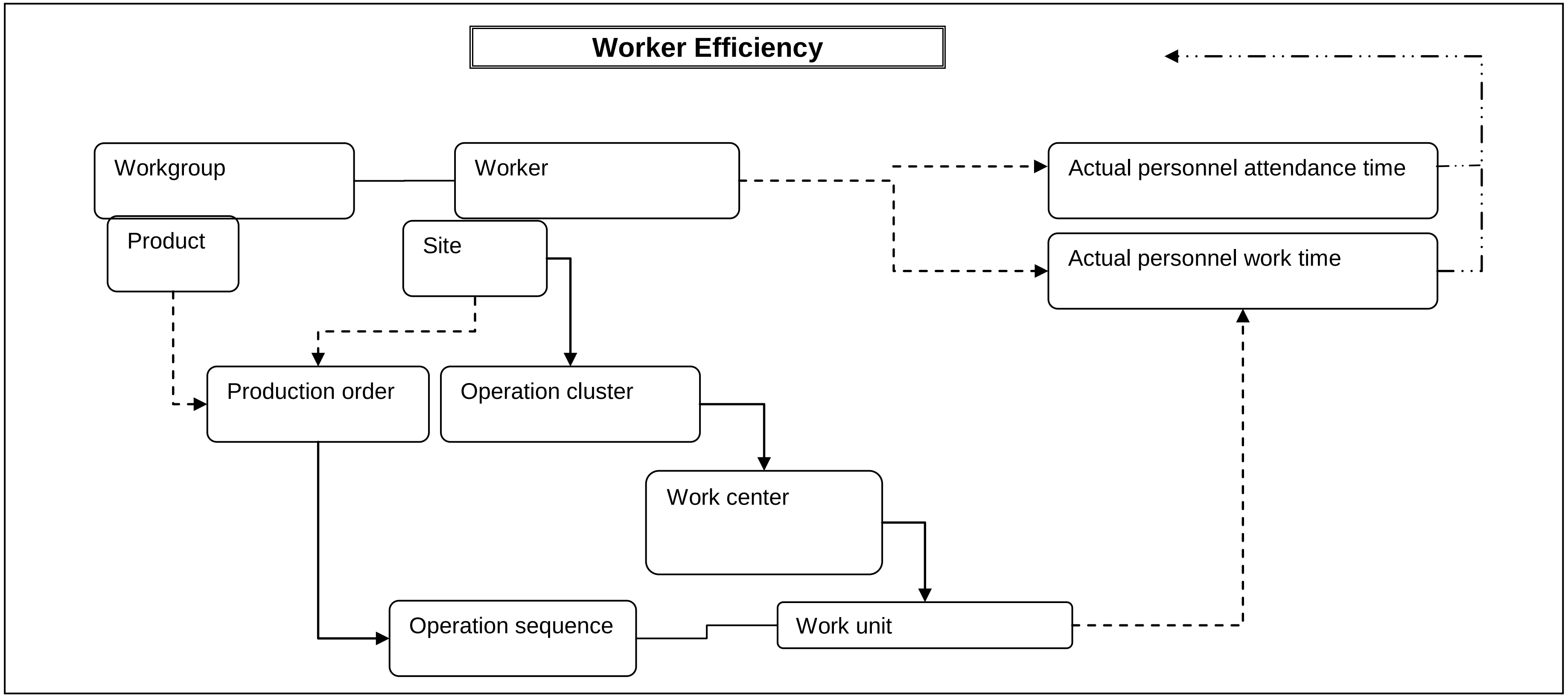
results, through use of a formula, in a KPI

includes (a 1:1 relationship)

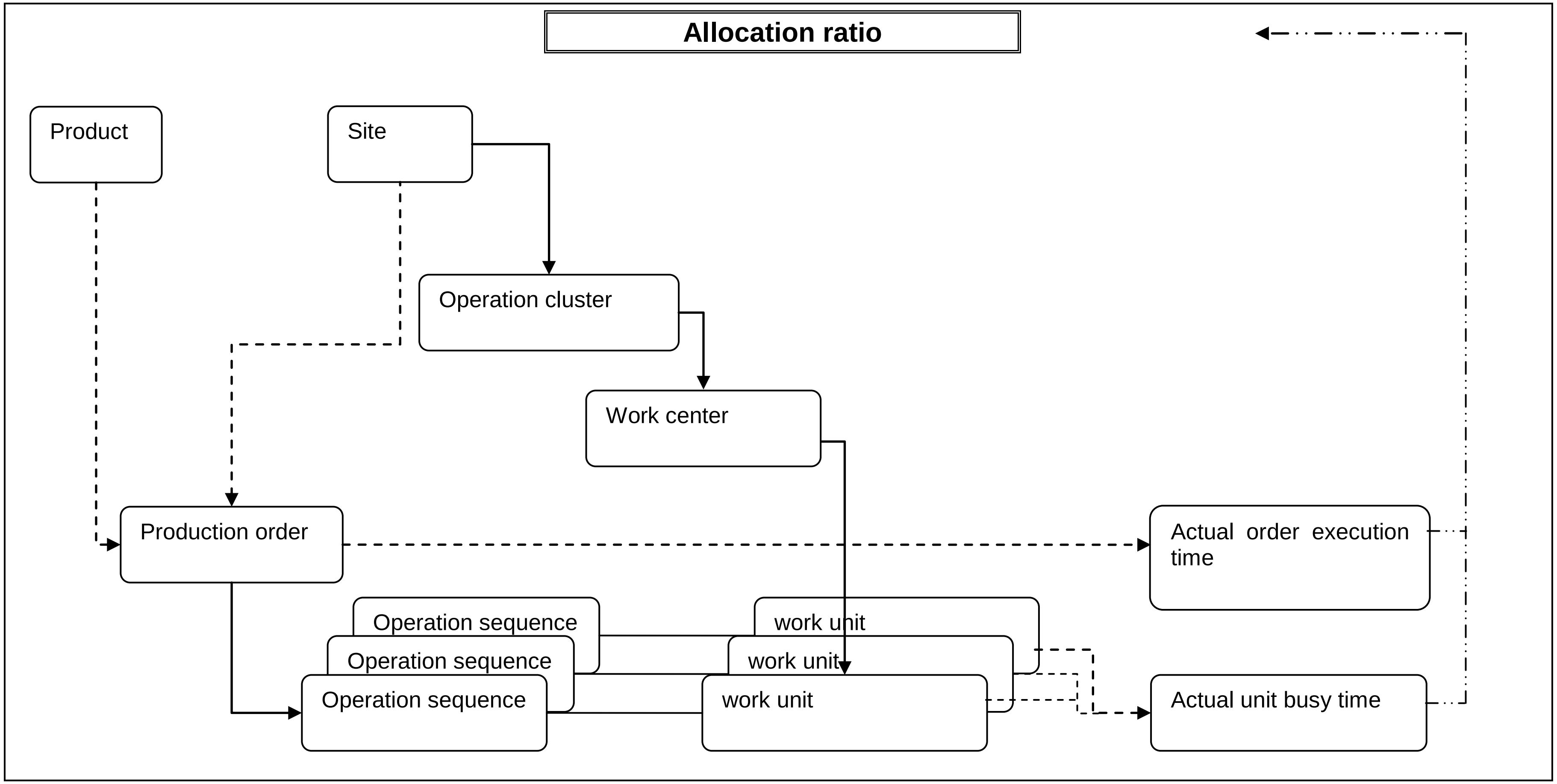
has (i.e. is booked or entered)

consists of (a 1:n relationship)

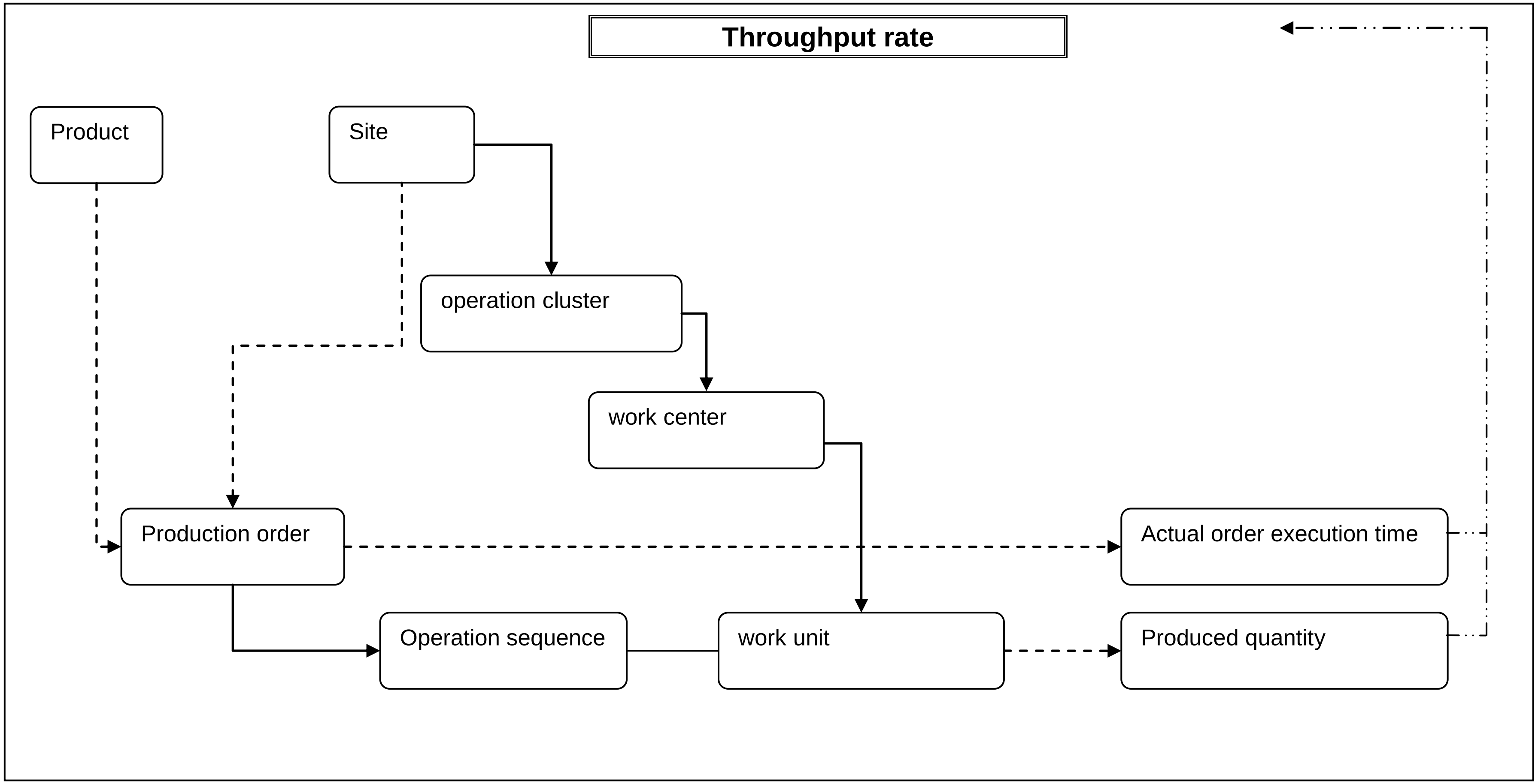
A.3 Worker efficiency



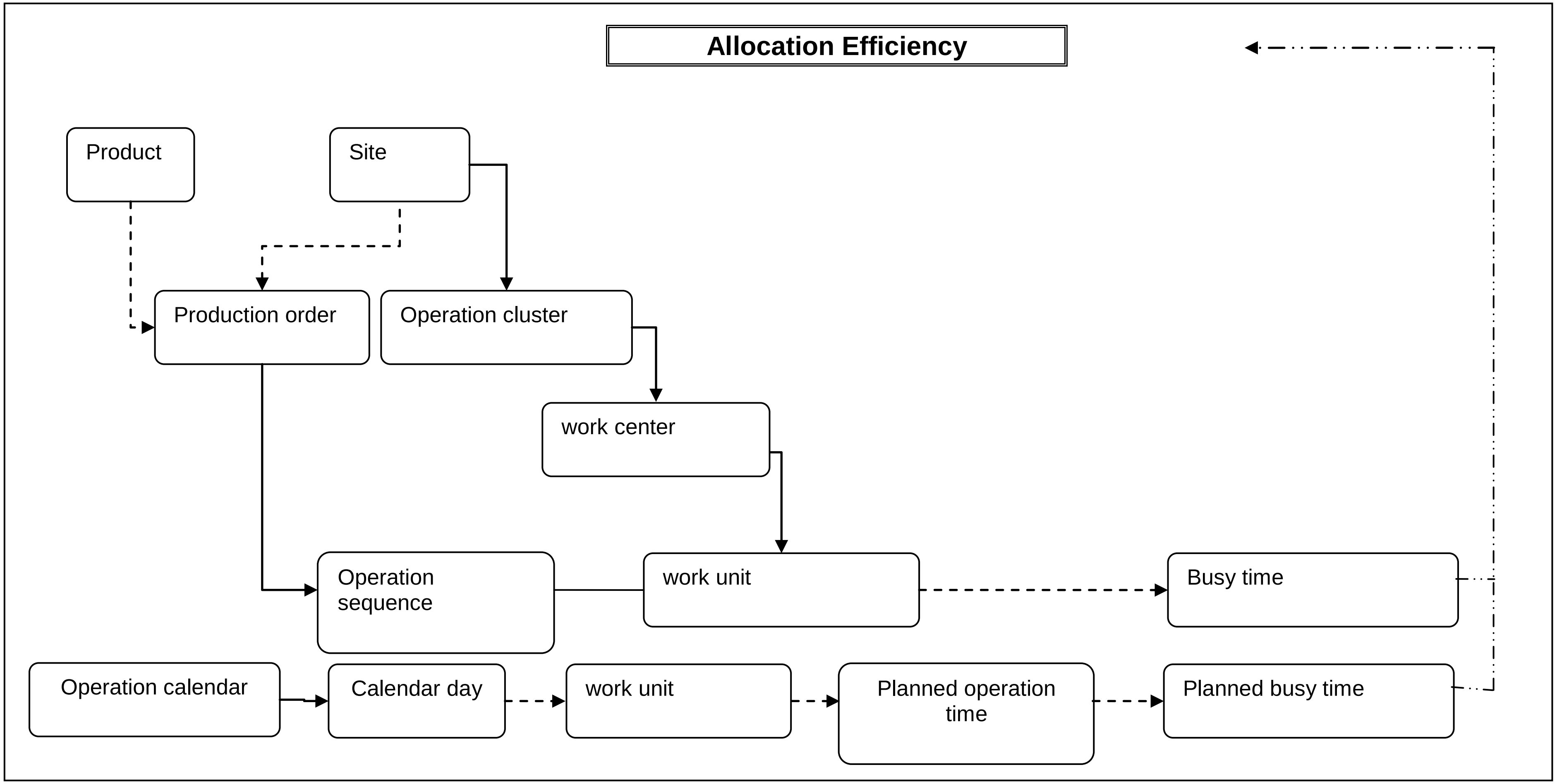
A.4 Allocation ratio



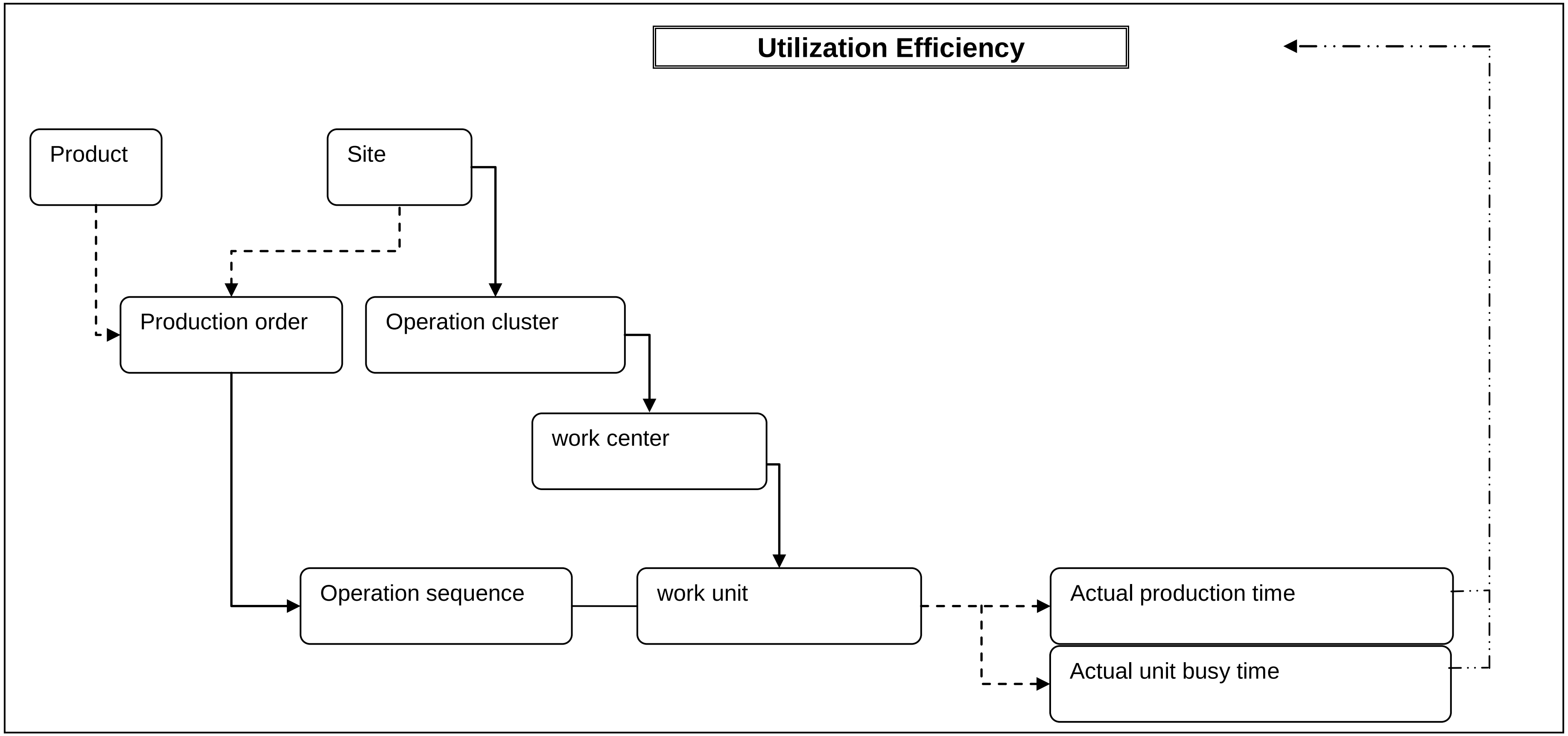
A.5 Throughput rate



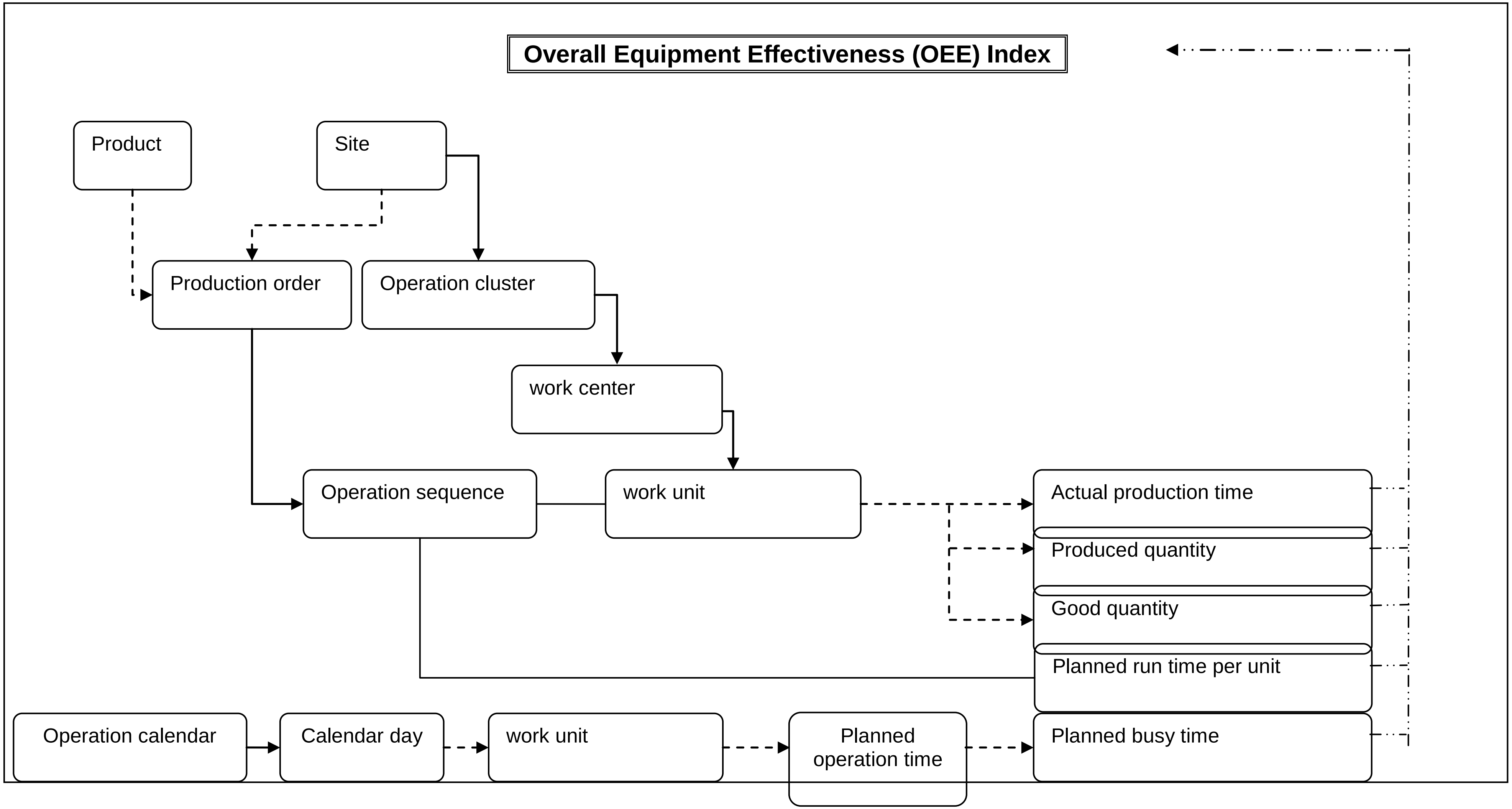
A.6 Allocation efficiency



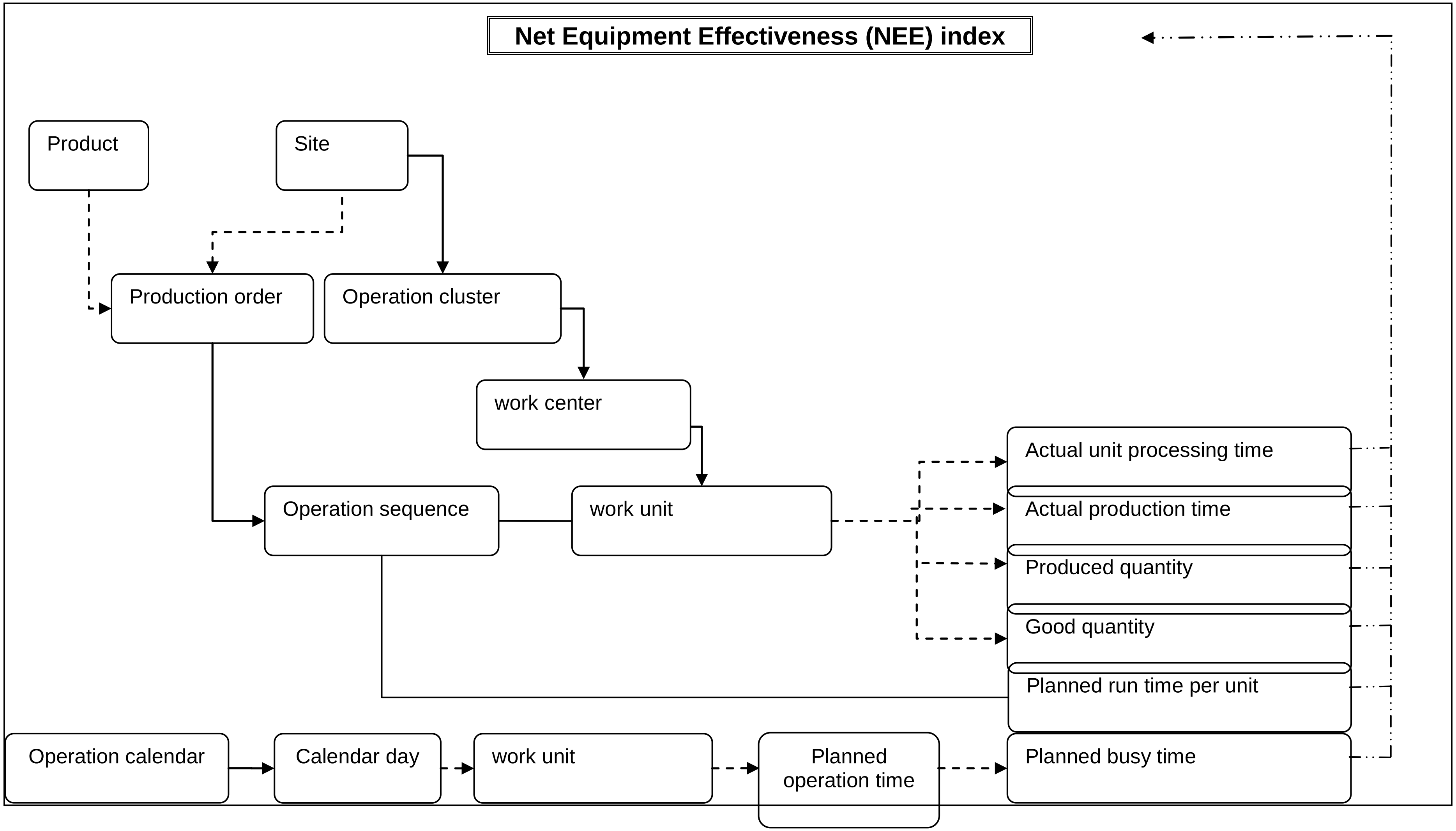
A.7 Utilization efficiency



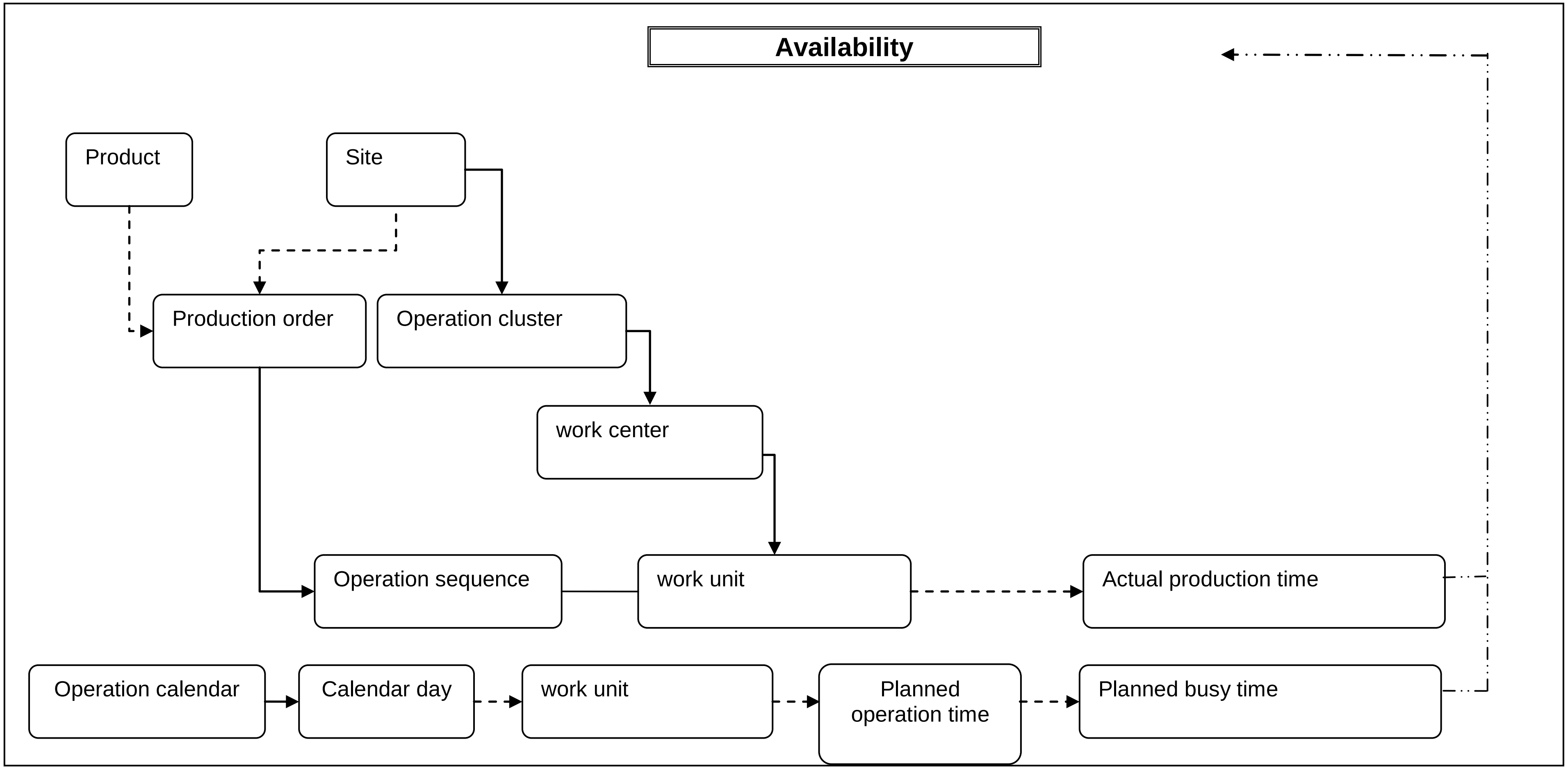
A.8 Overall equipment effectiveness index



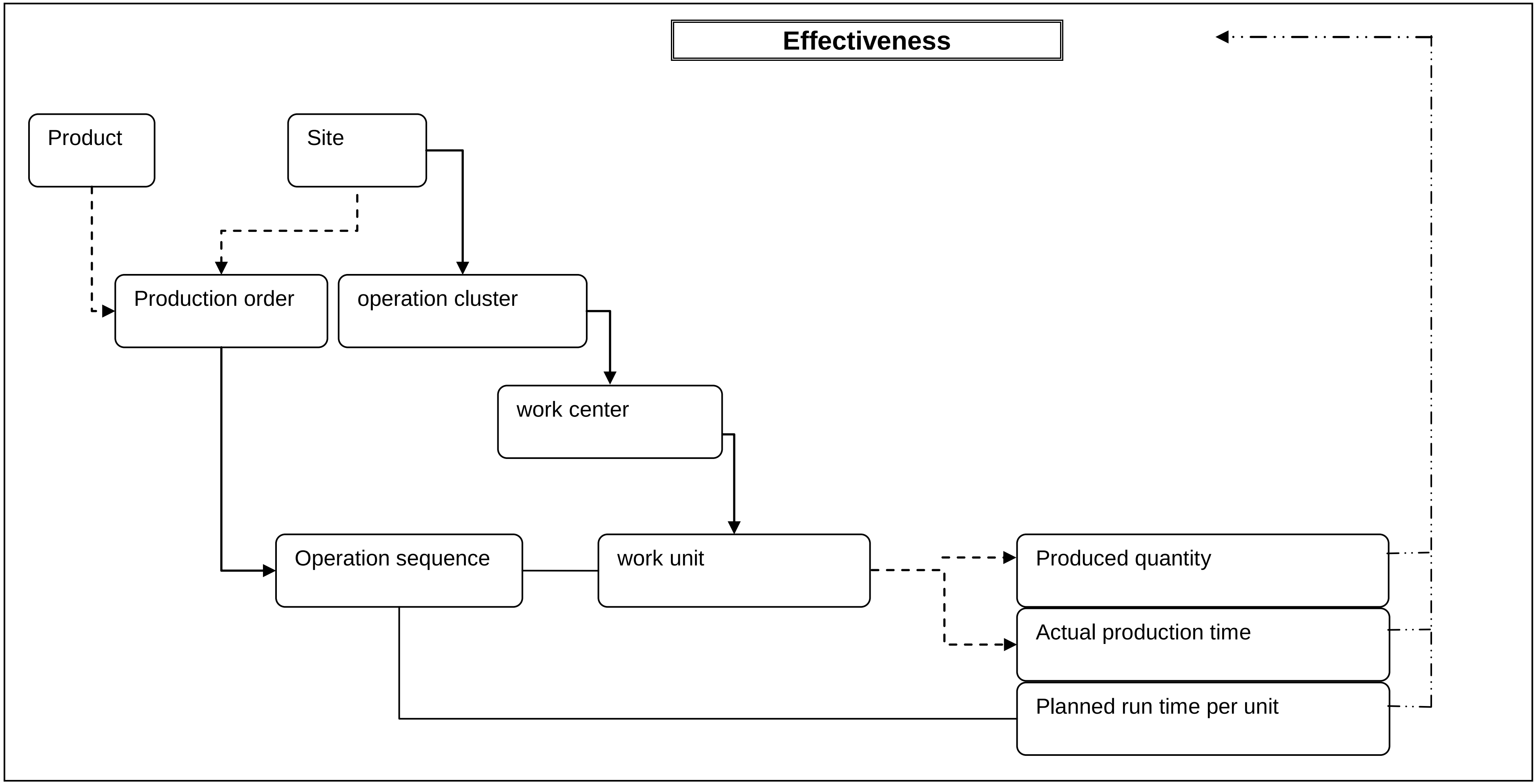
A.9 Net equipment effectiveness index



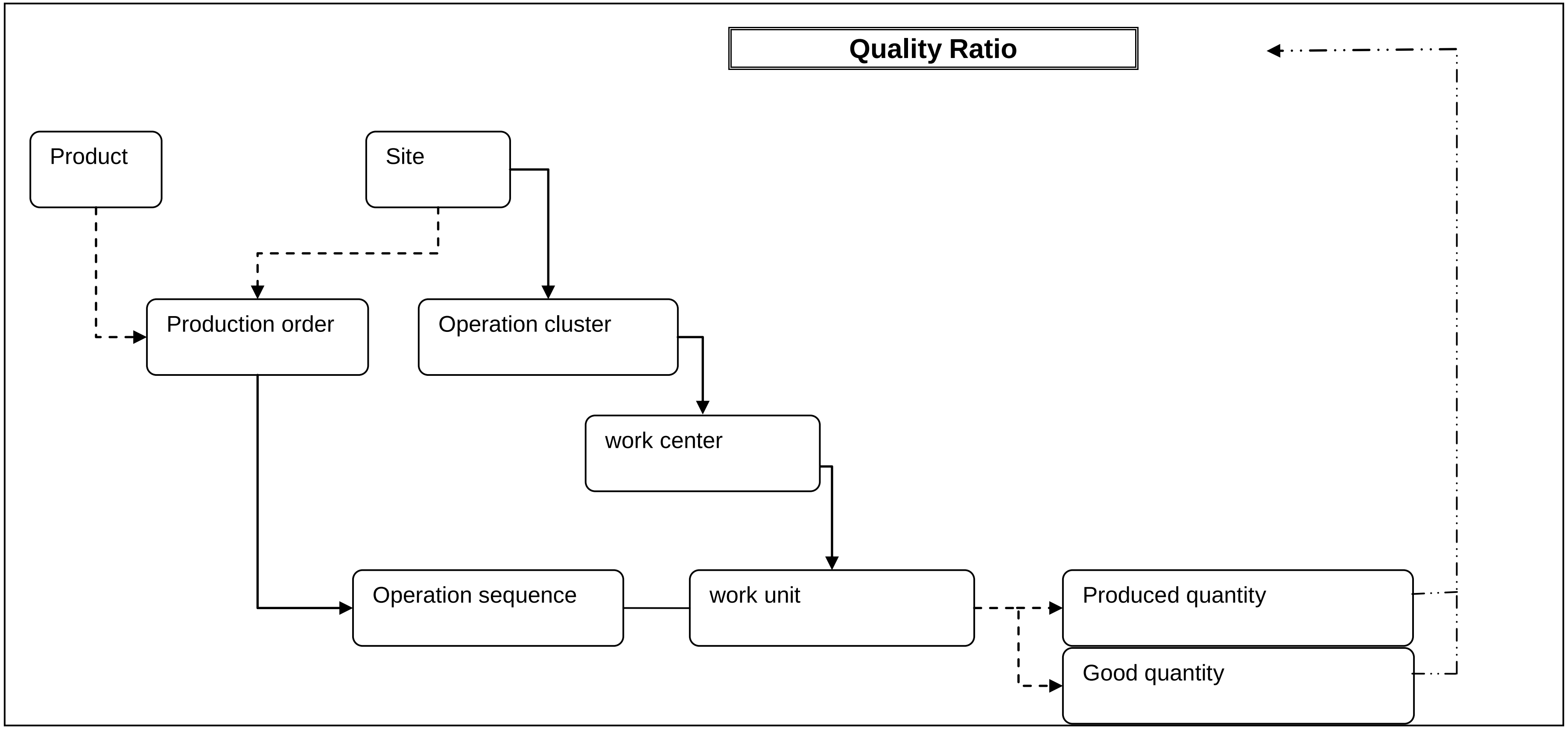
A.10 Availability



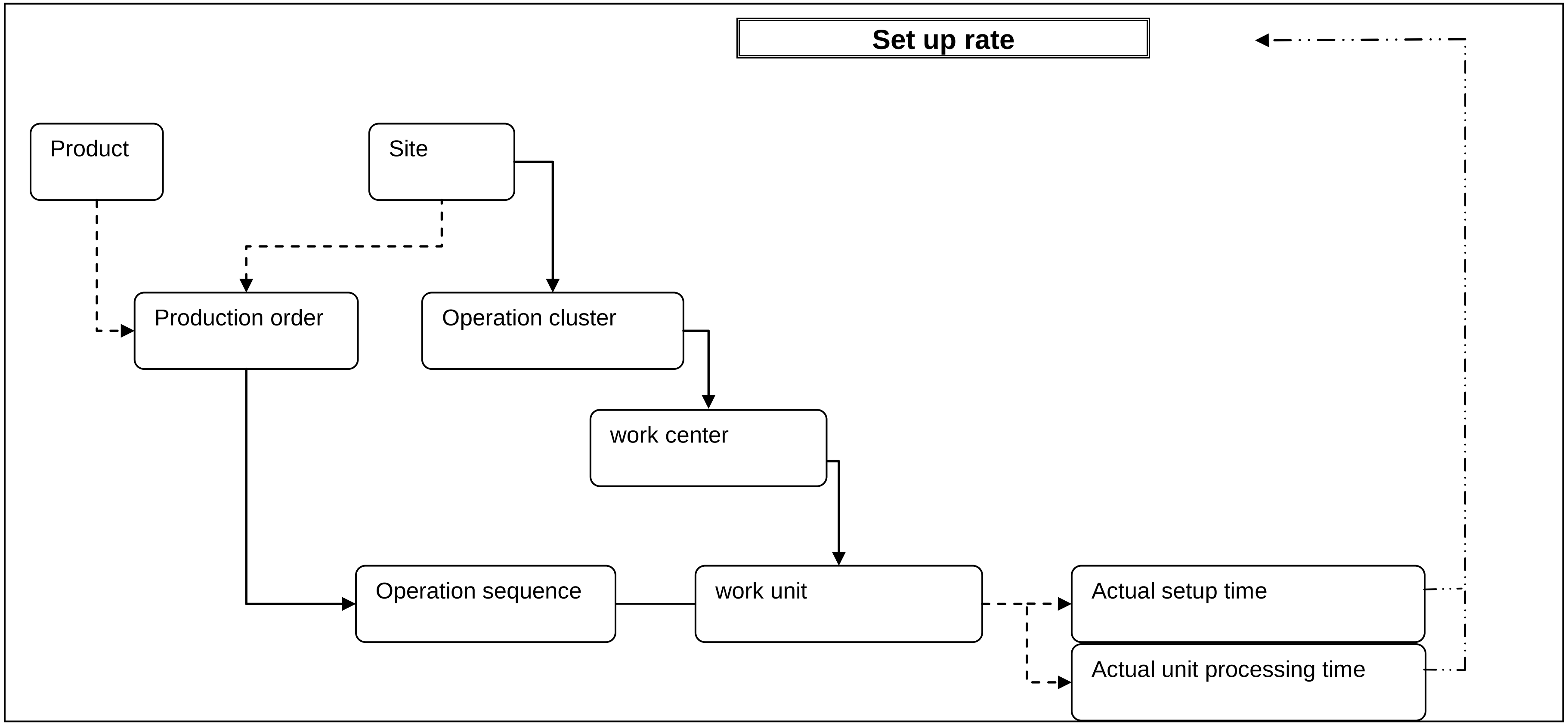
A.11 Effectiveness



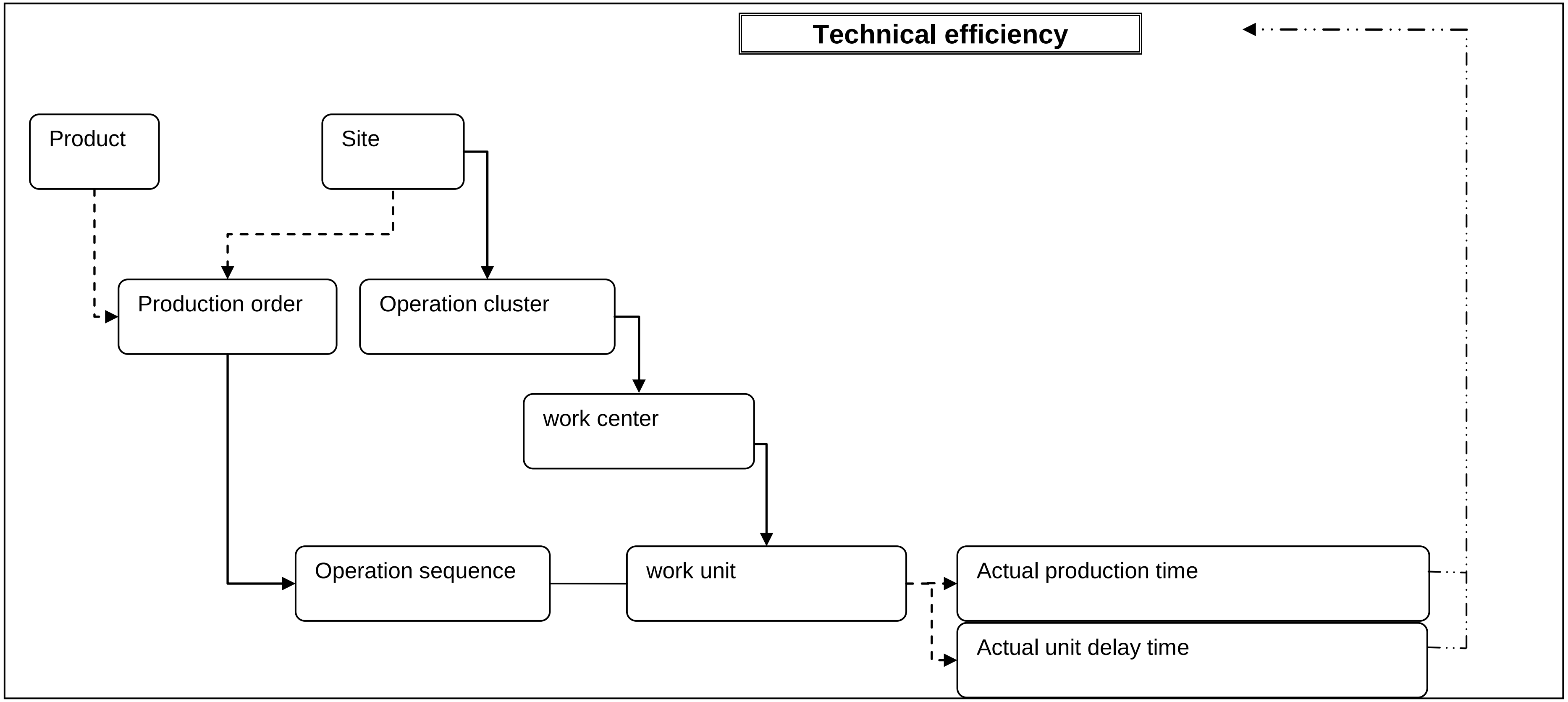
A.12 Quality ratio



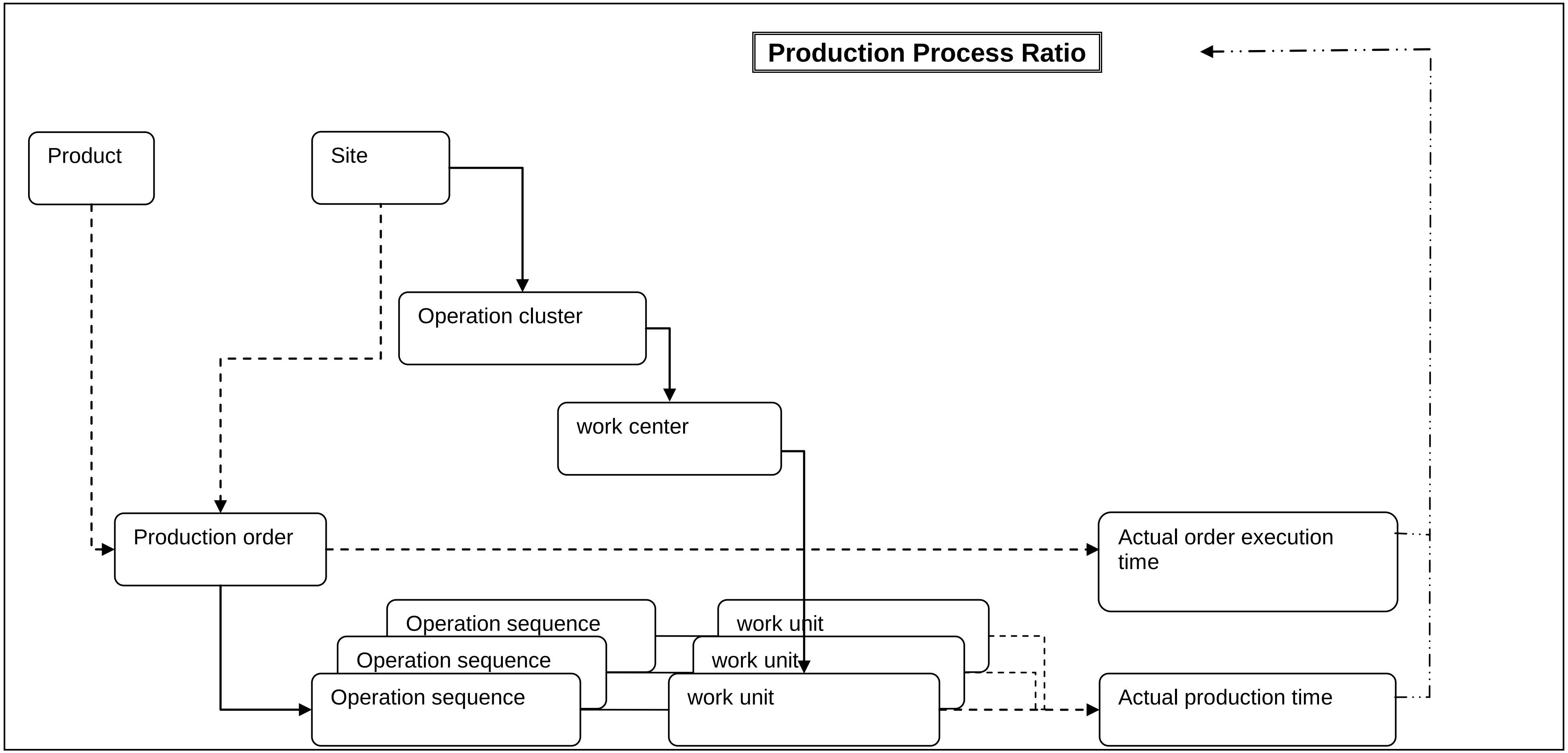
A.13 Set up rate



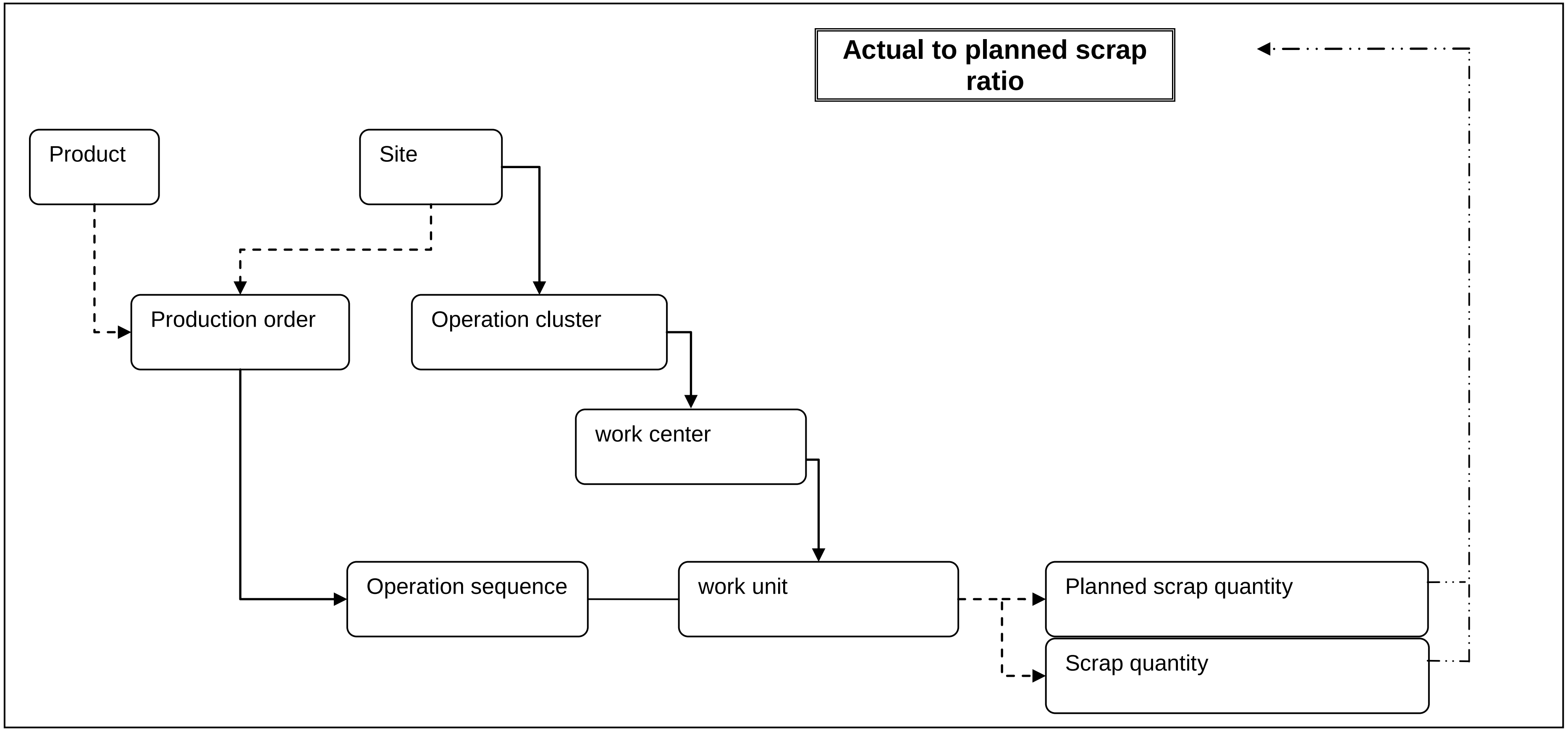
A.14 Technical efficiency



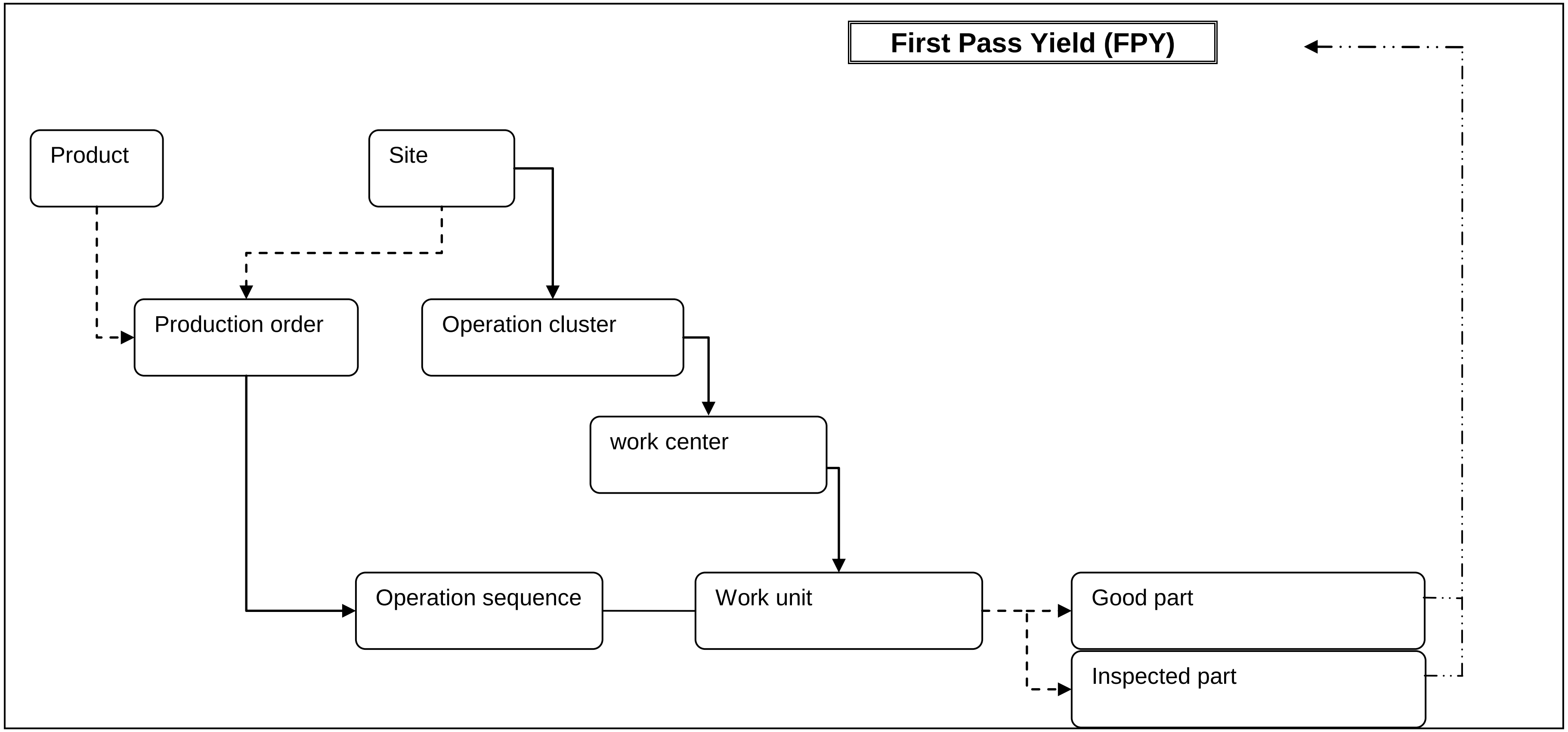
A.15 Production process ratio



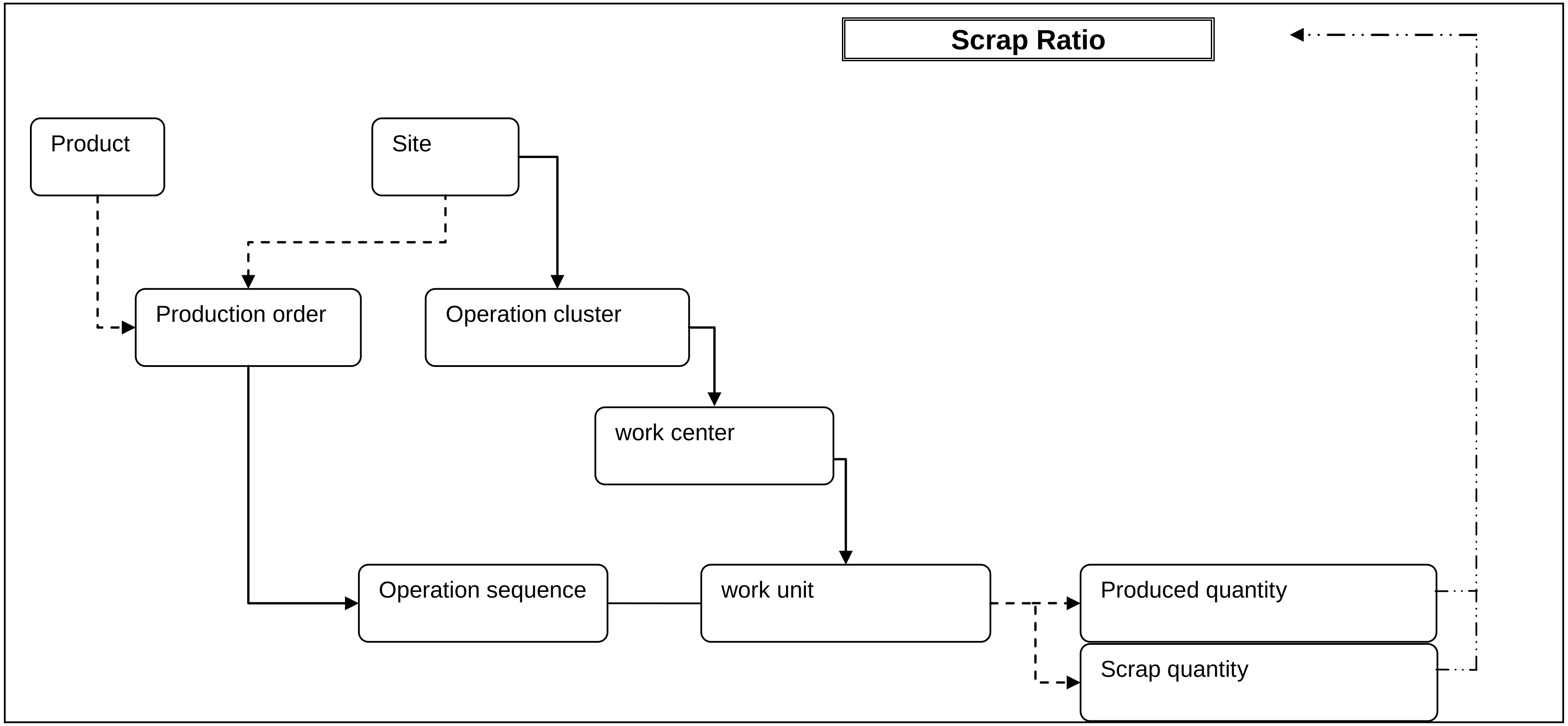
A.16 Actual to planned scrap ratio



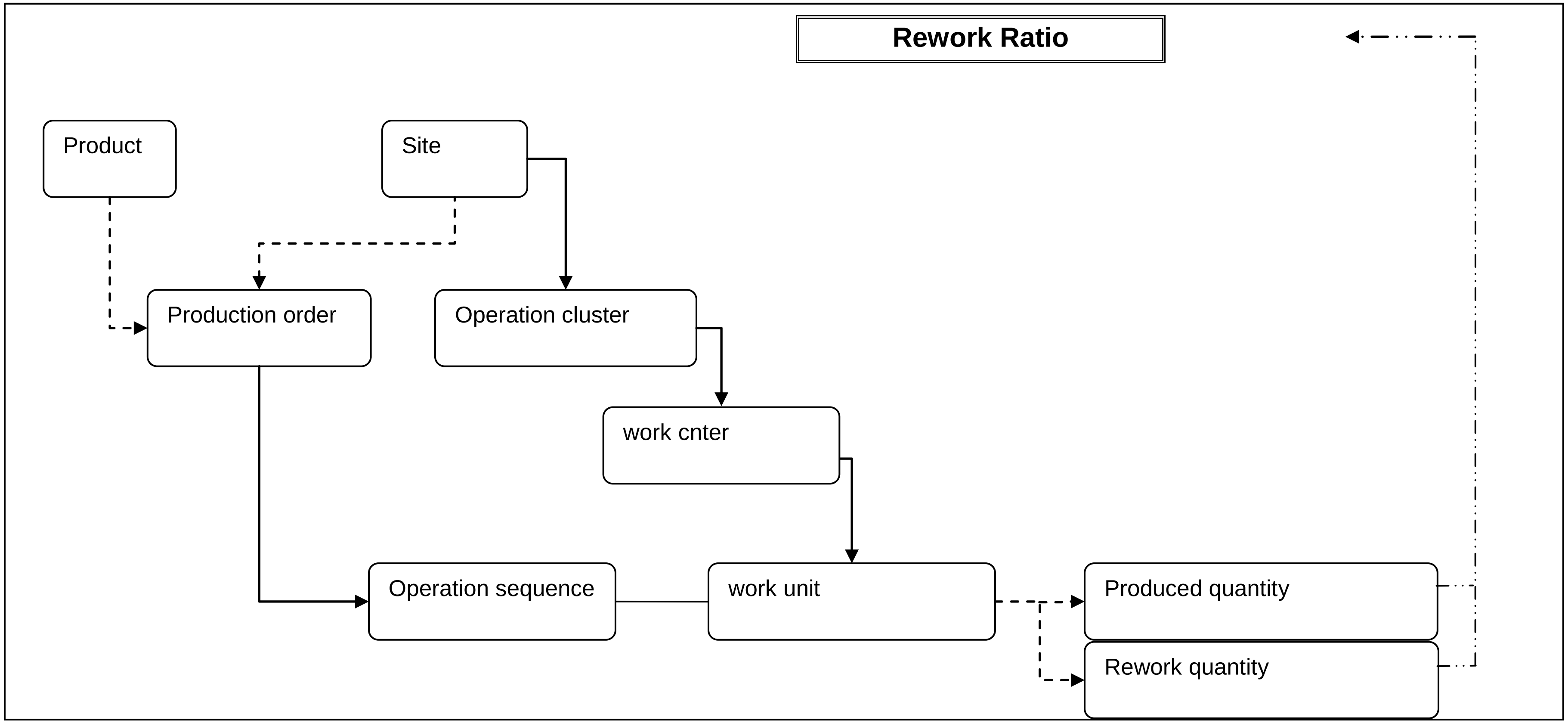
A.17 First pass yield



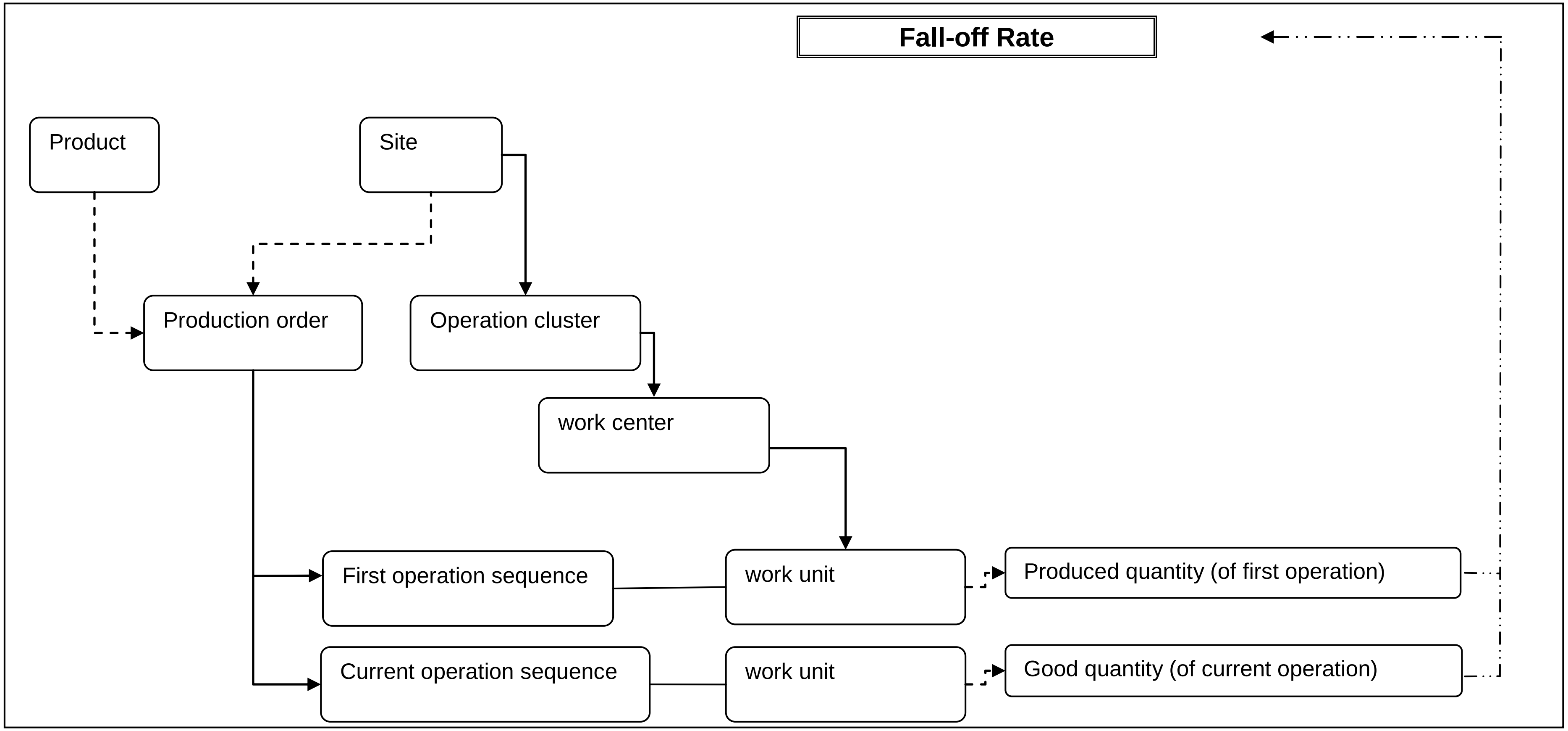
A.18 Scrap ratio



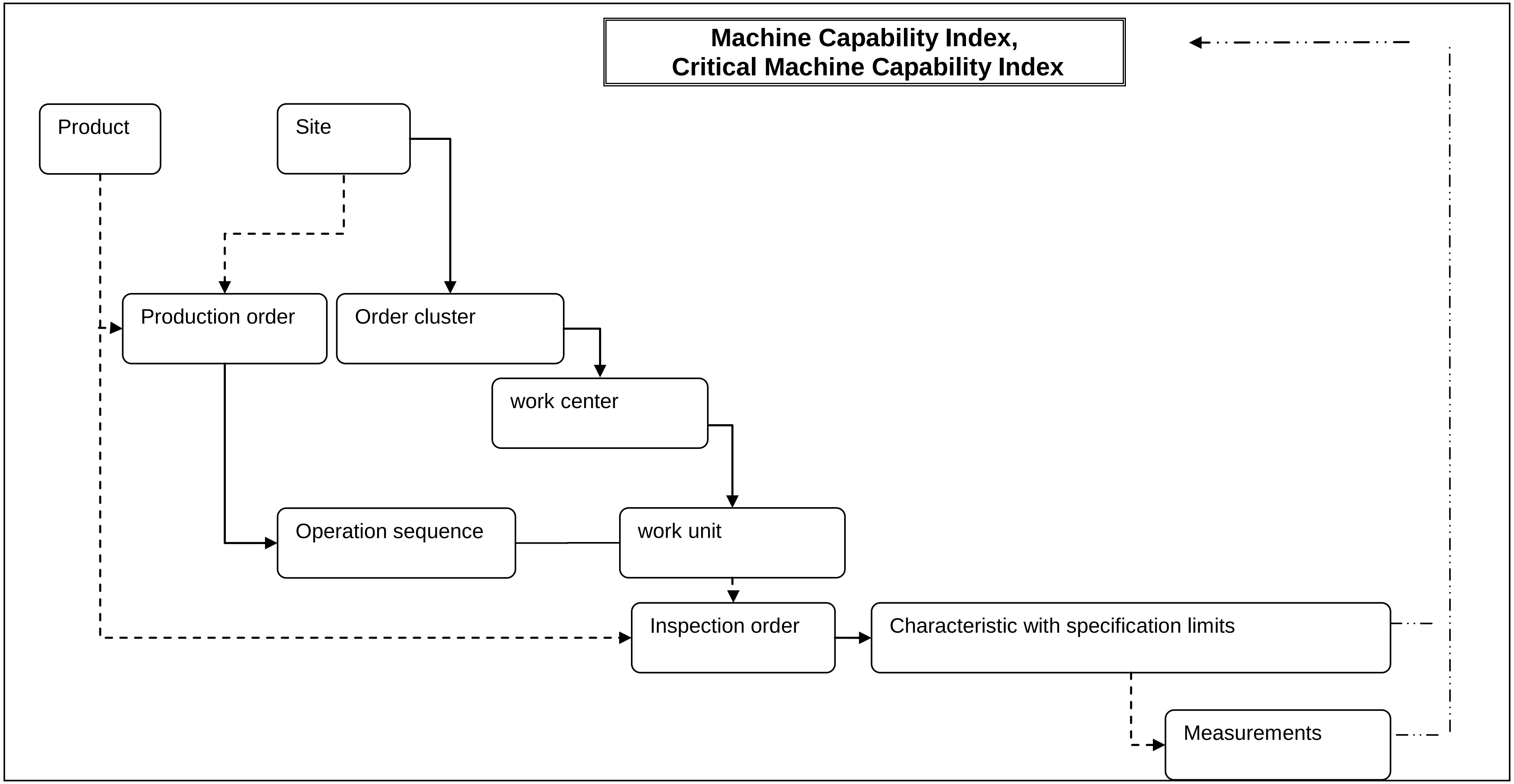
A.19 Rework ratio



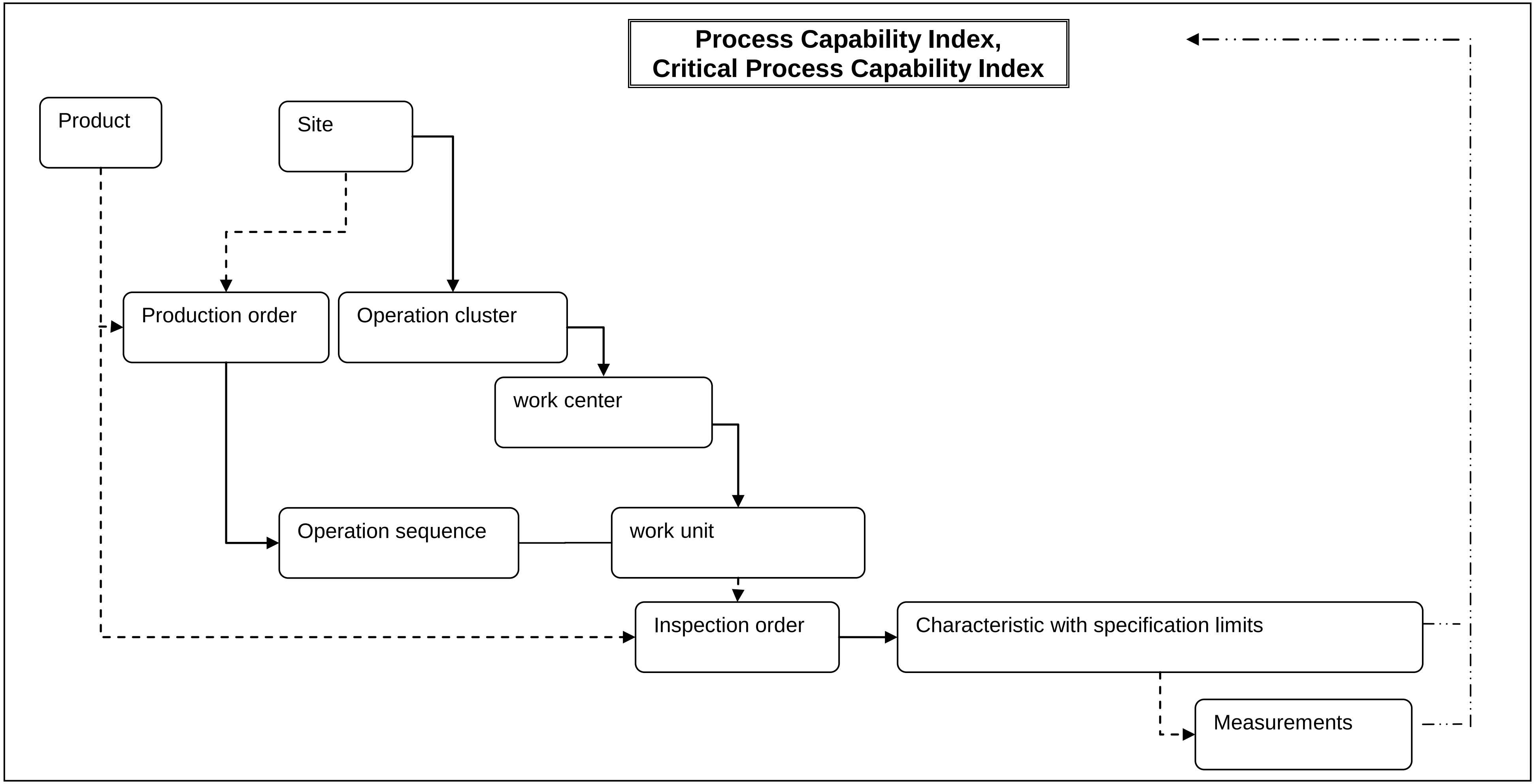
A.20 Fall-off rate



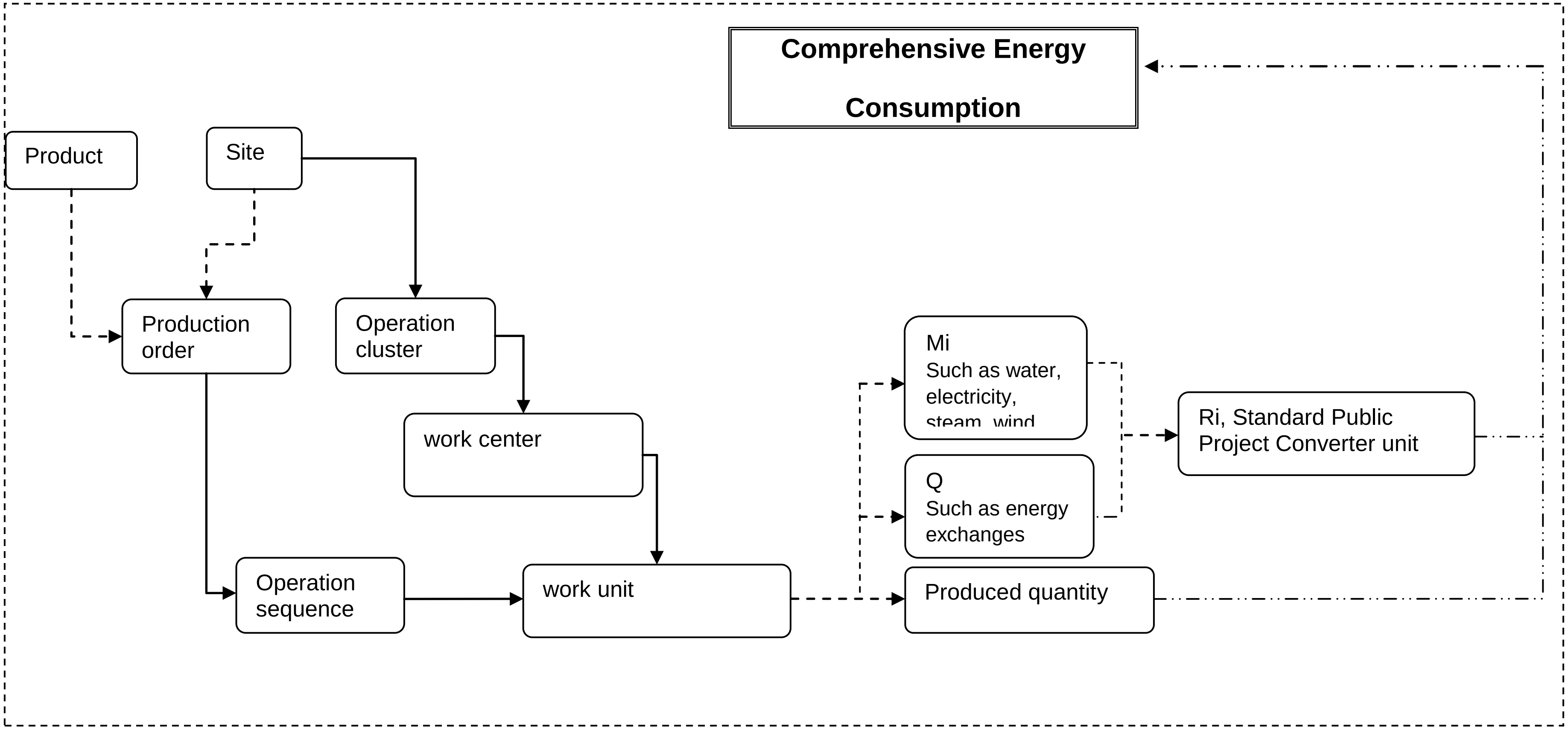
A.21 Machine capability index and critical machine capability index



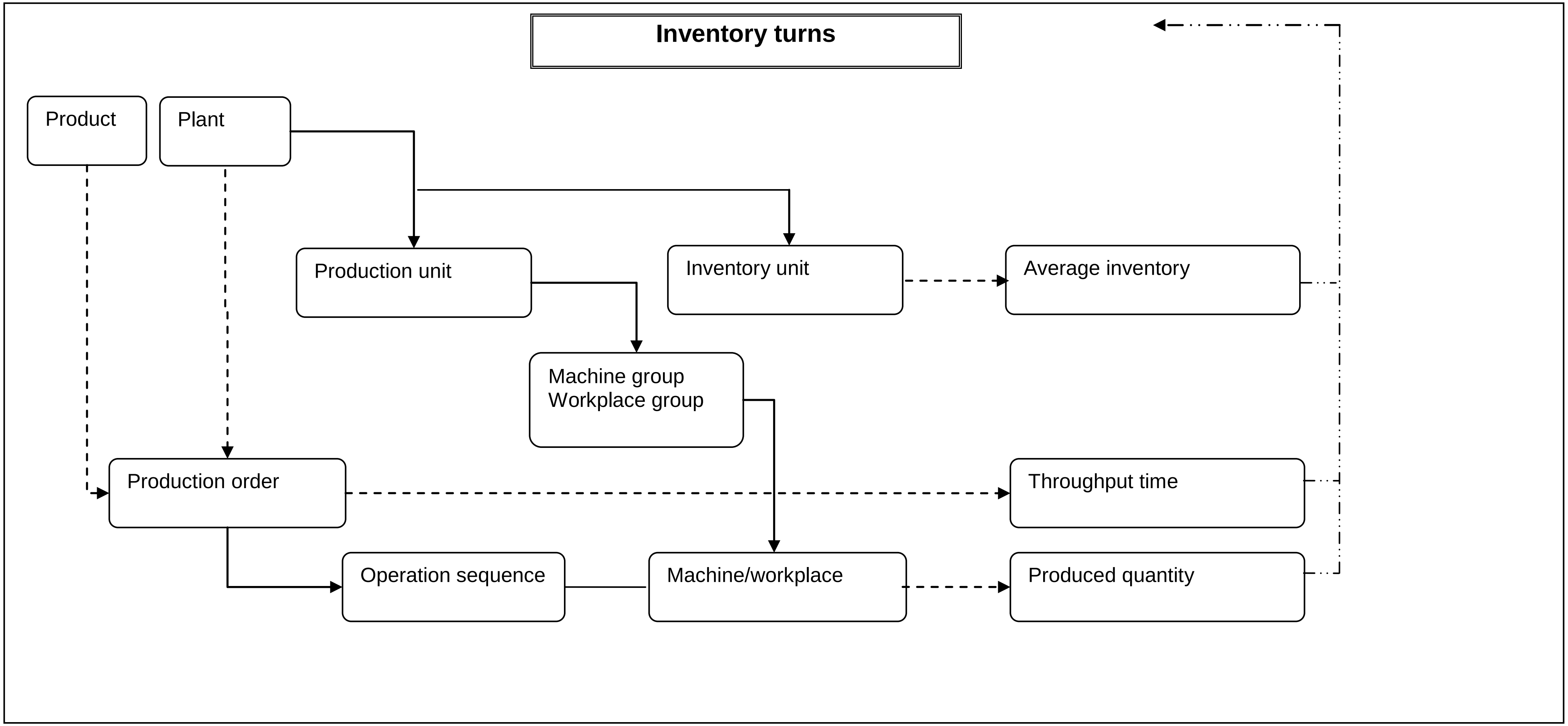
A.22 Process capability index and critical process capability index



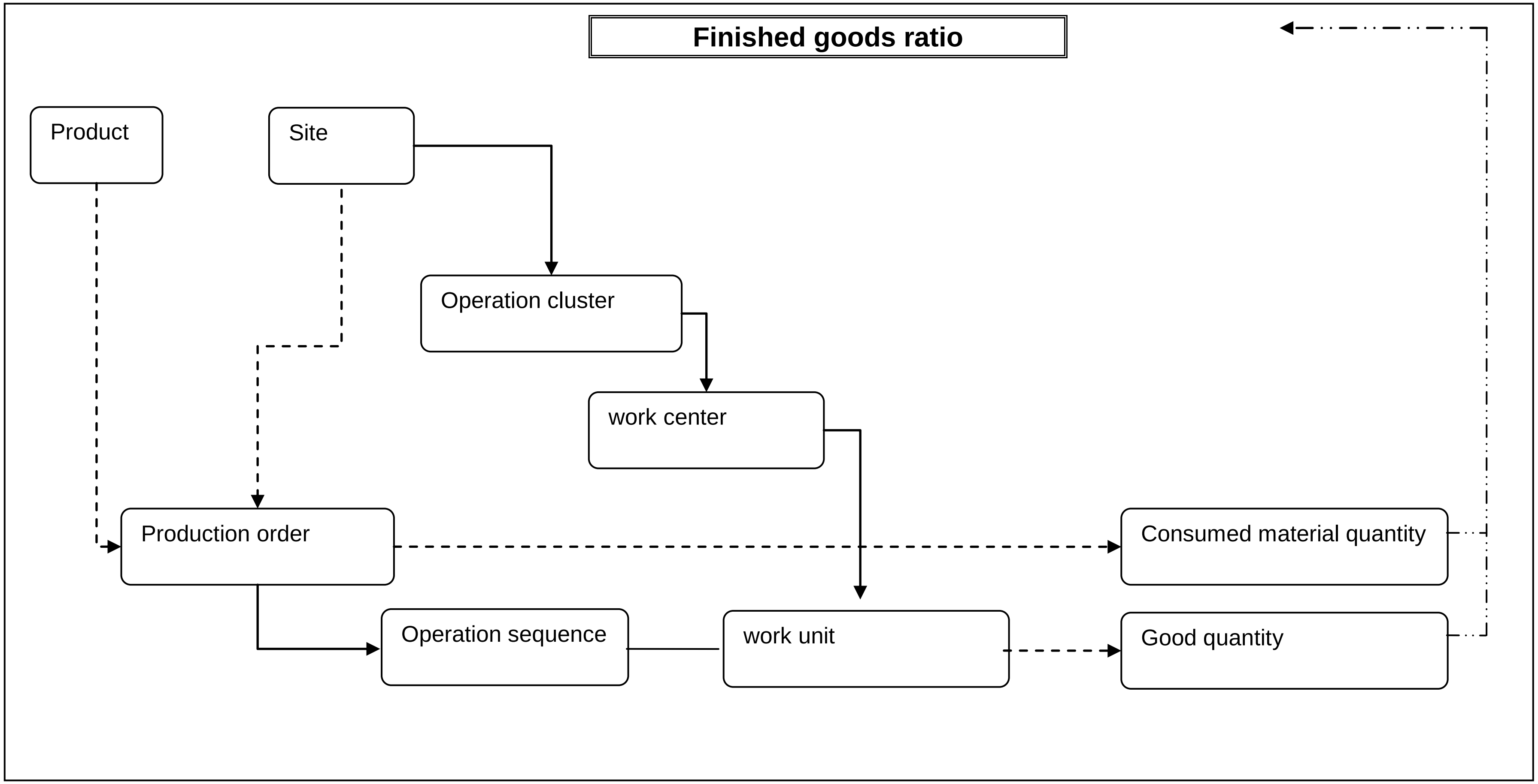
A.23 Comprehensive energy consumption



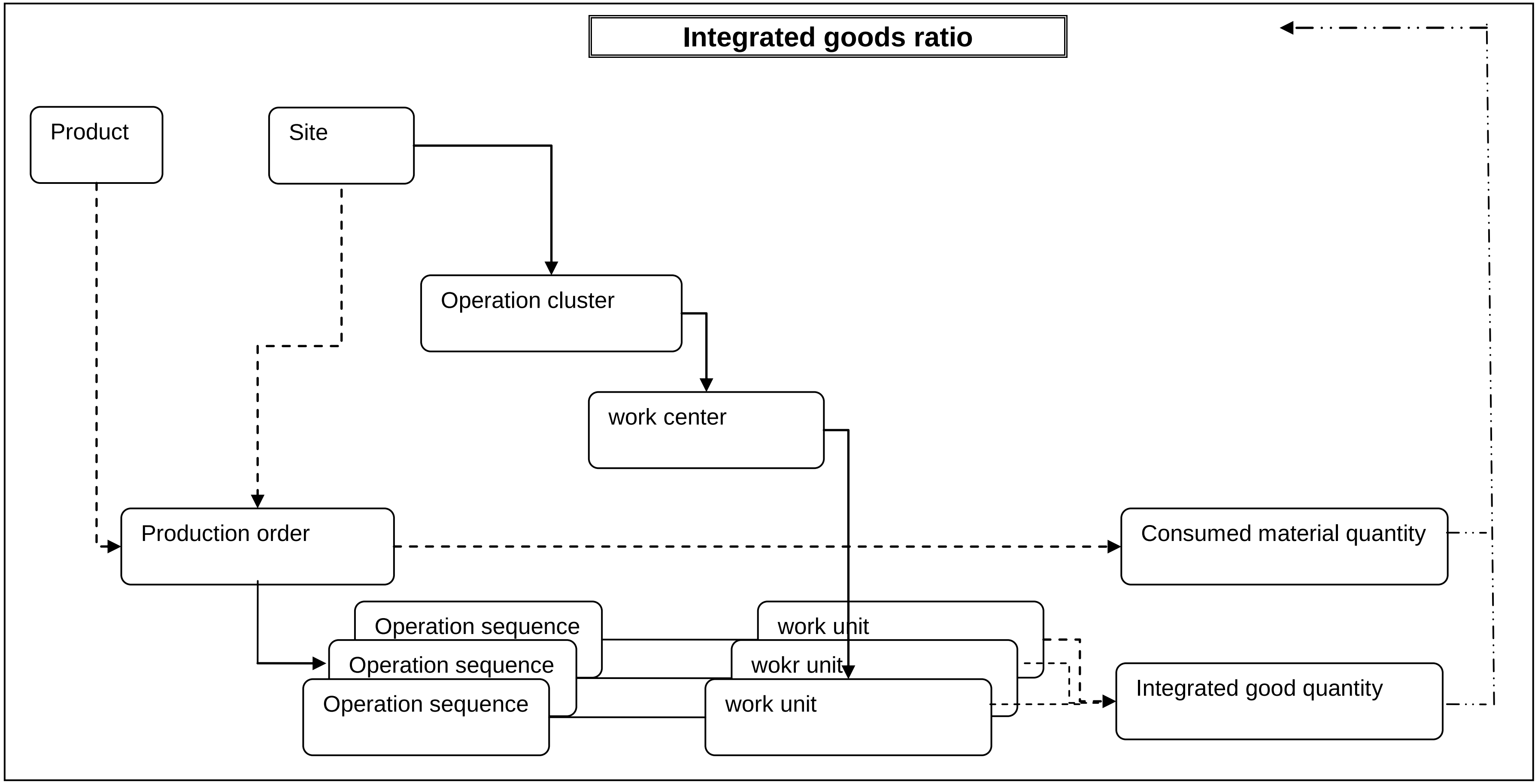
A.24 Inventory turns



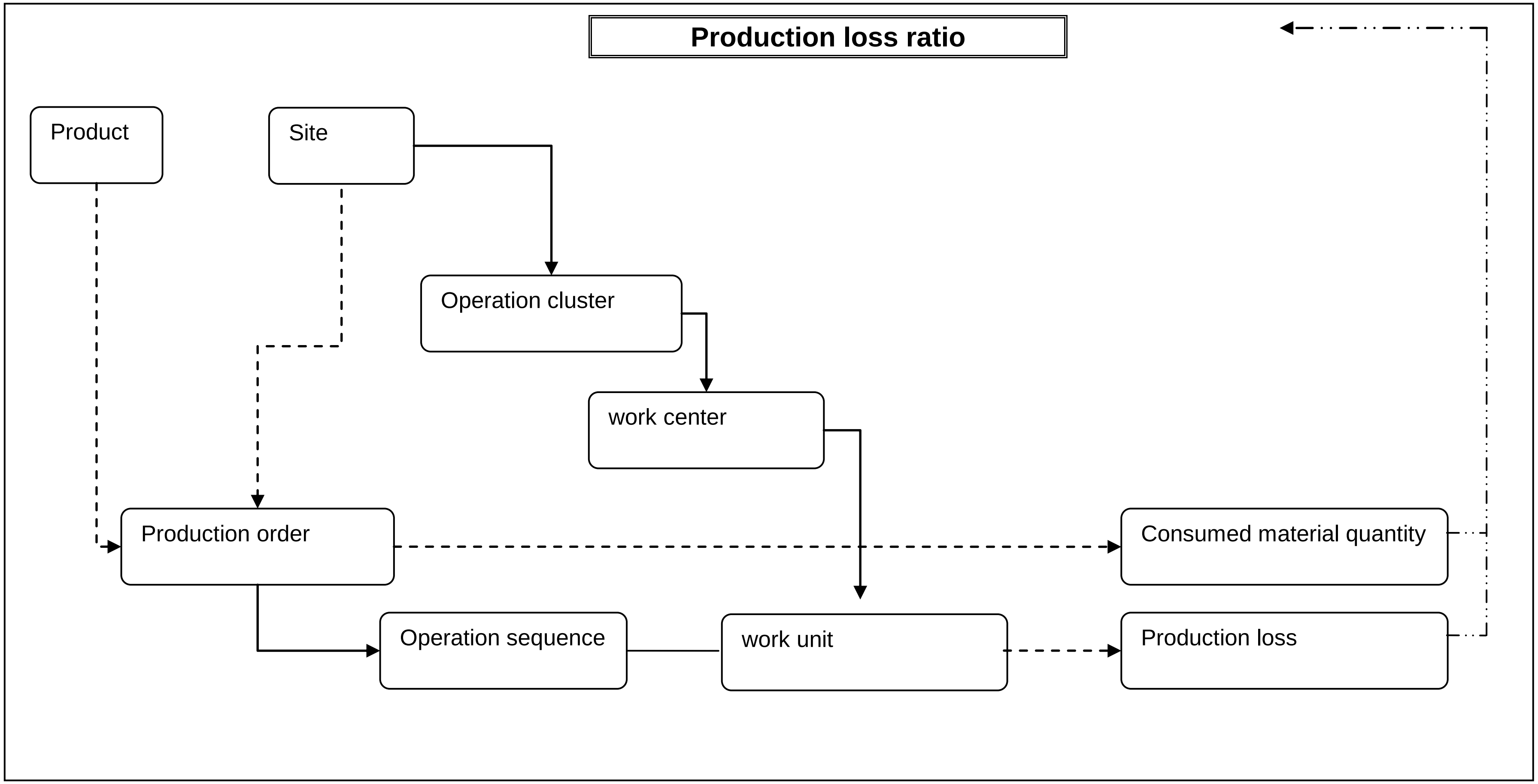
A.25 Finished goods ratio



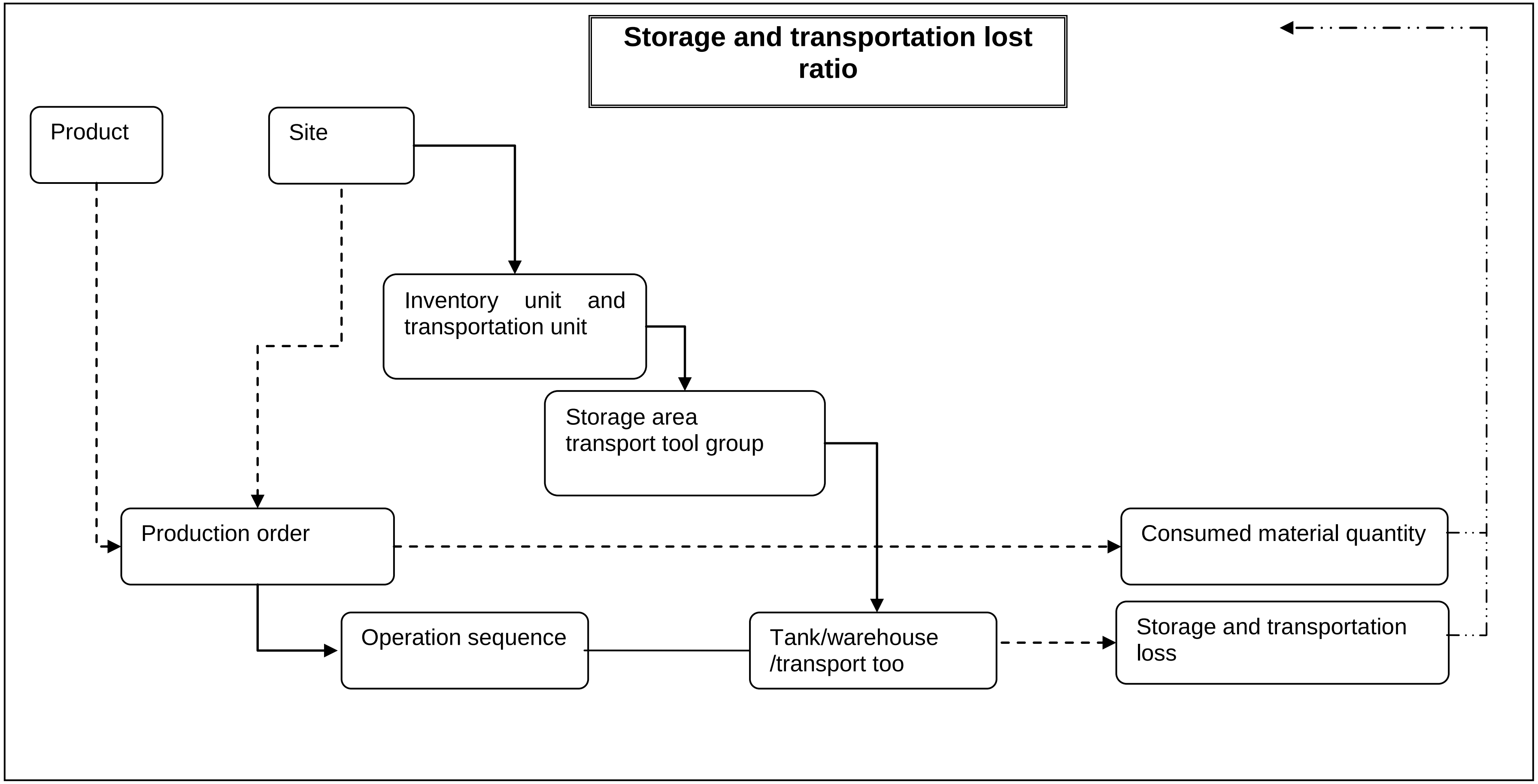
A.26 Integrated goods ratio



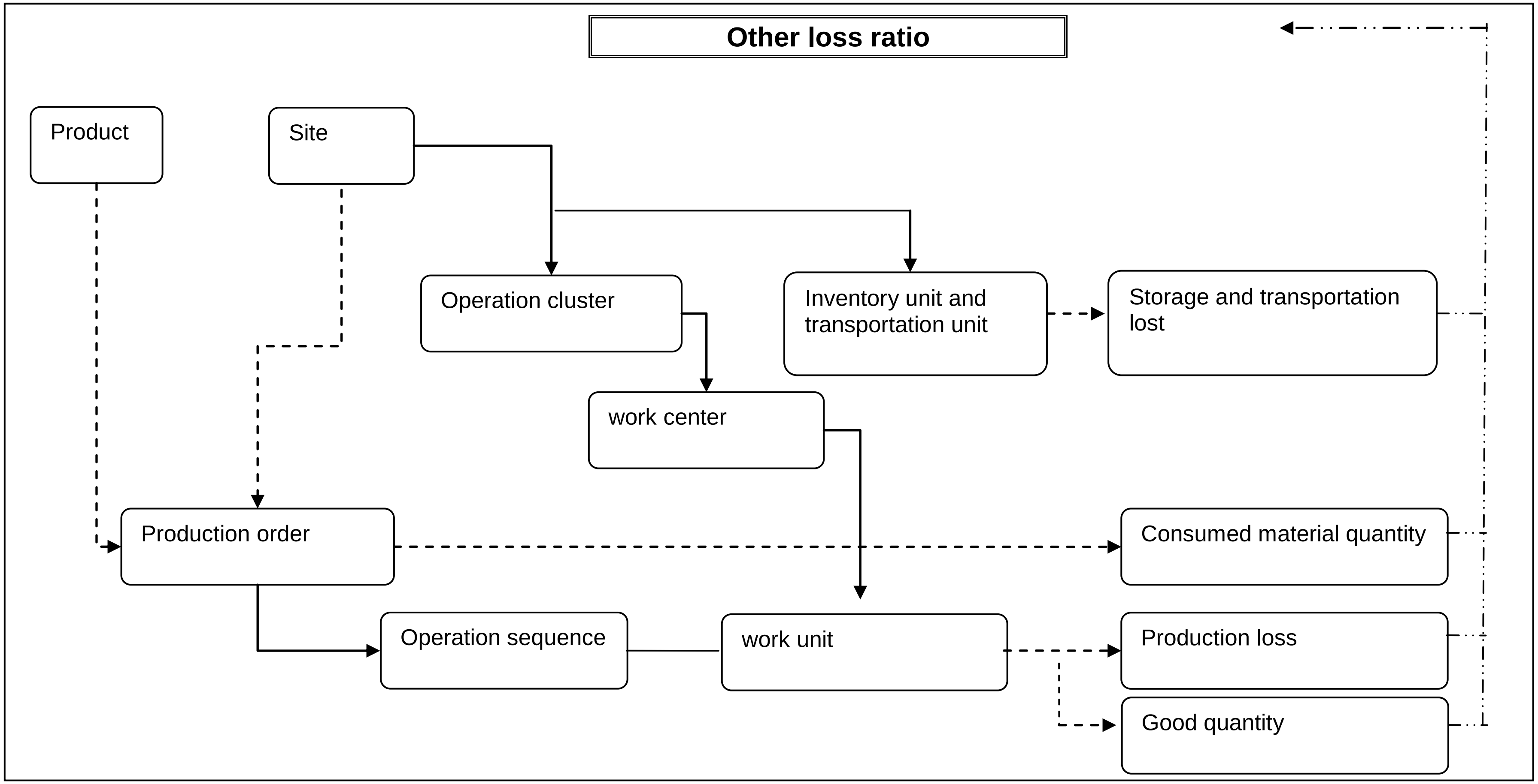
A.27 Production loss ratio



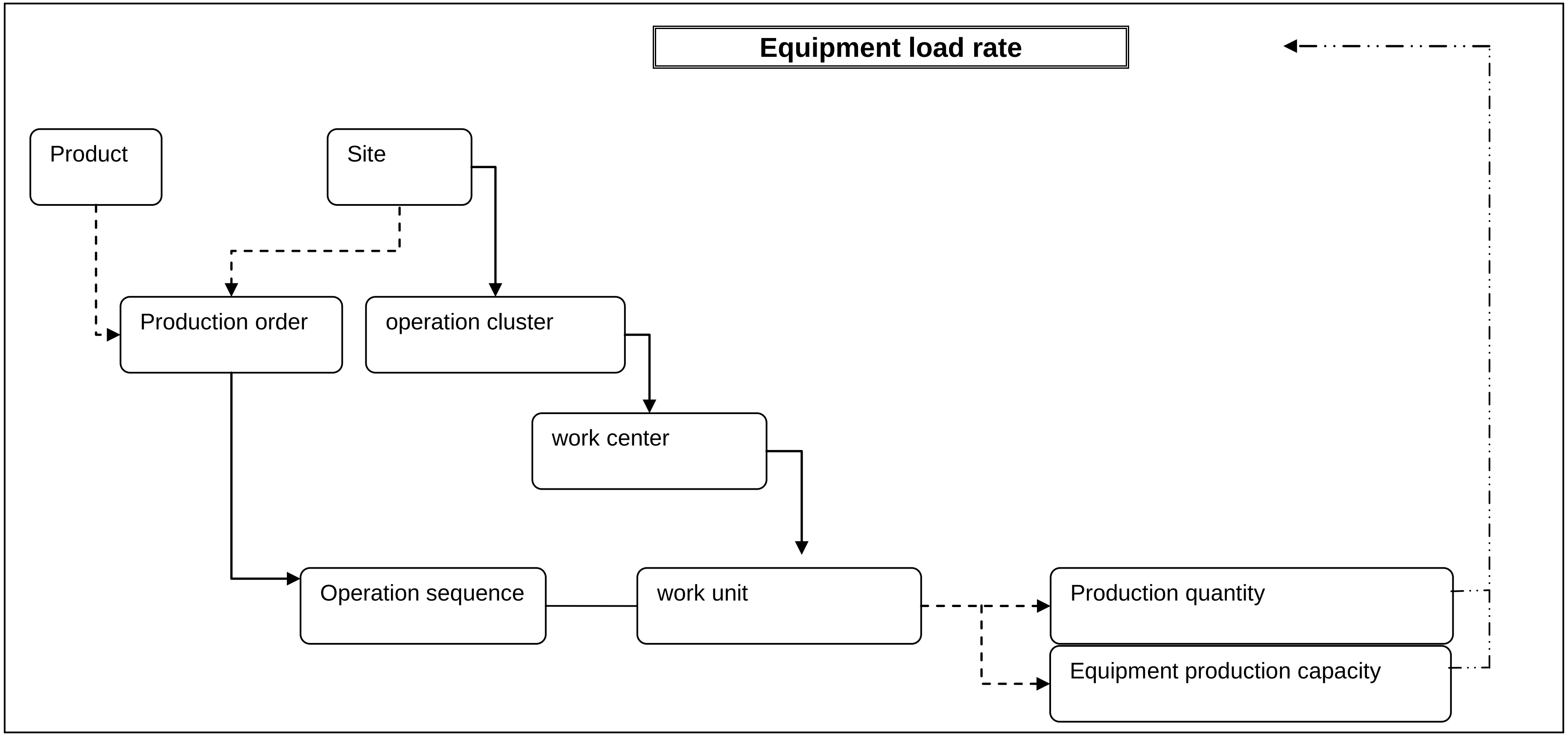
A.28 Storage and transportation loss ratio



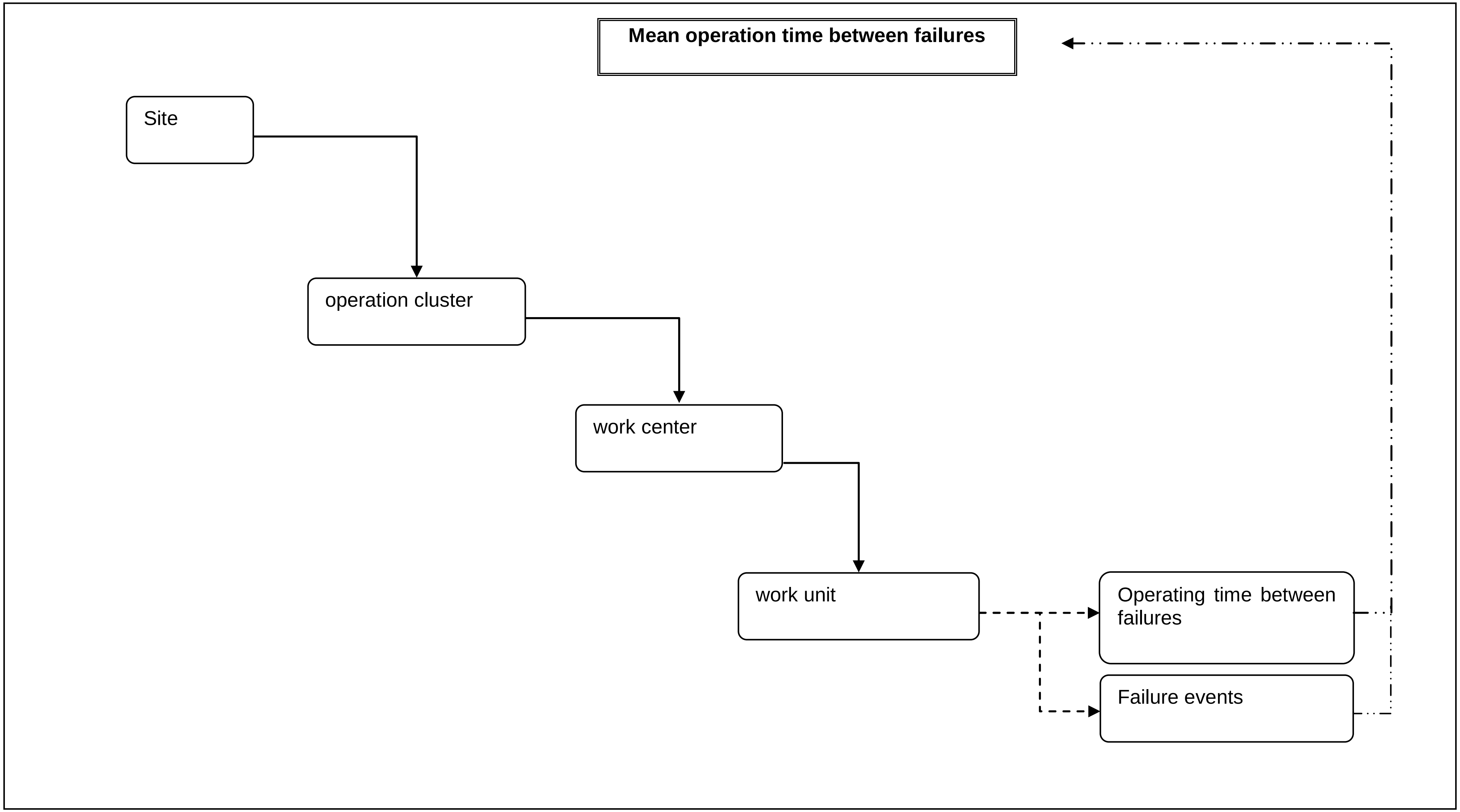
A.29 Other loss ratio



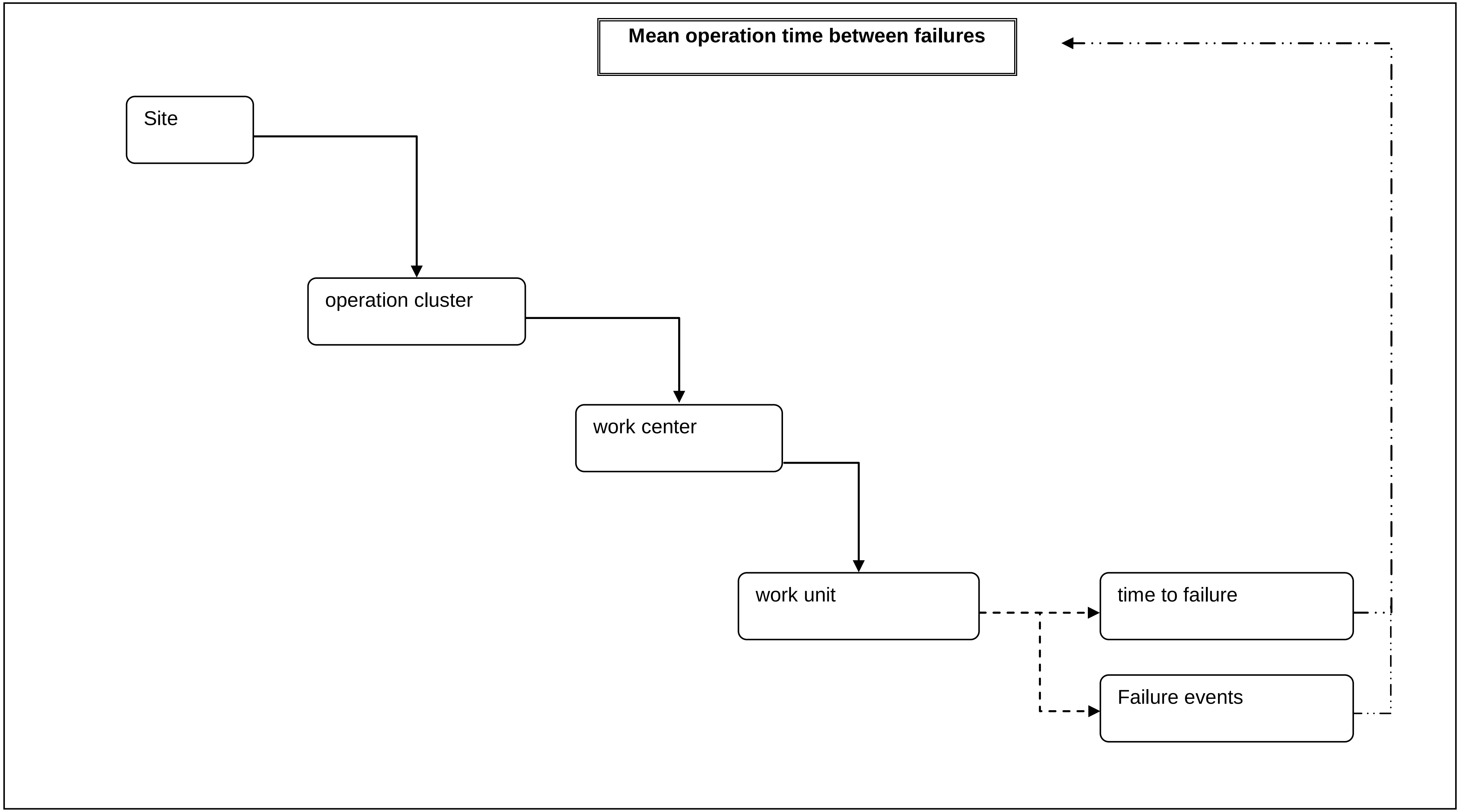
A.30 Equipment load rate



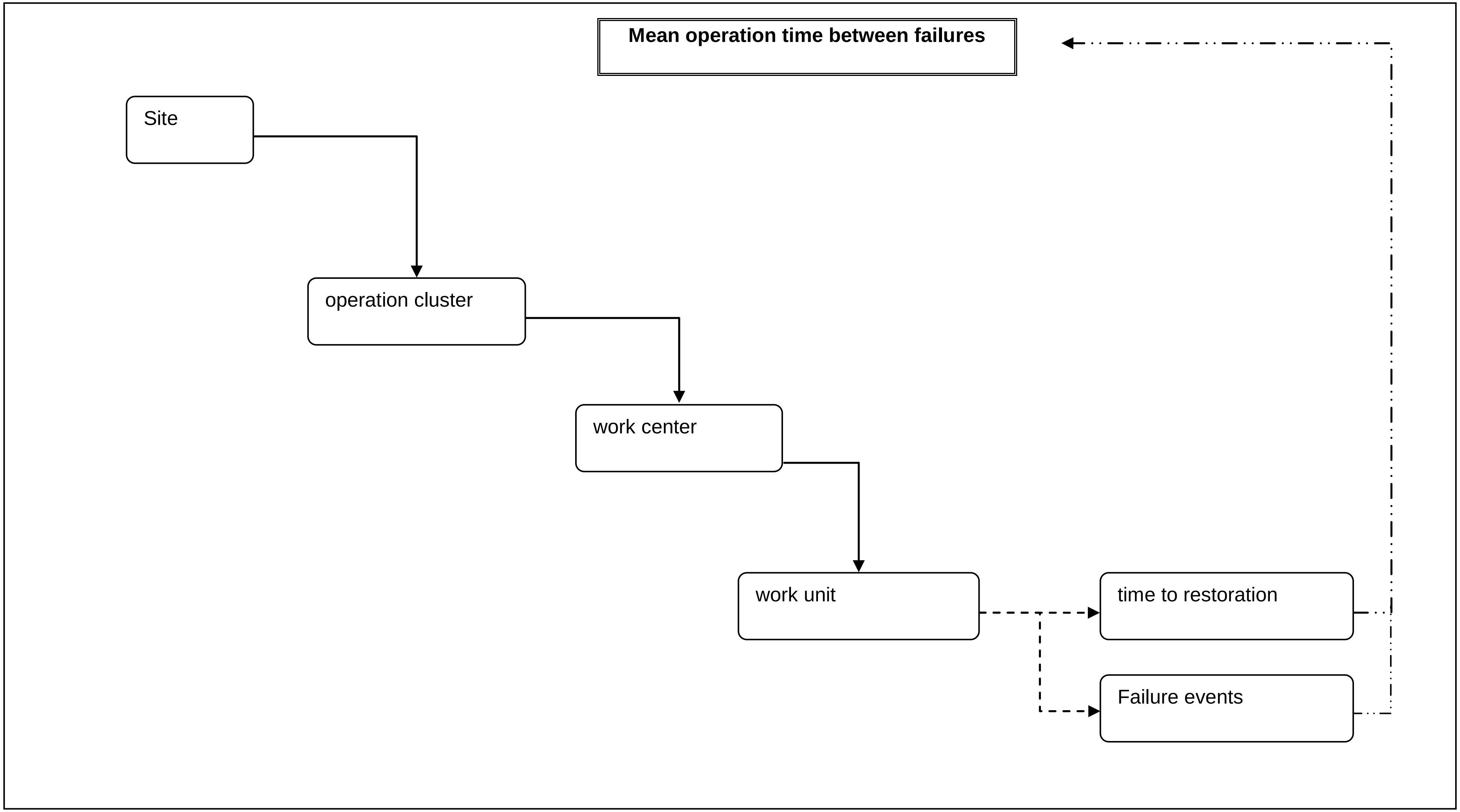
A.31 Mean operation time between failures



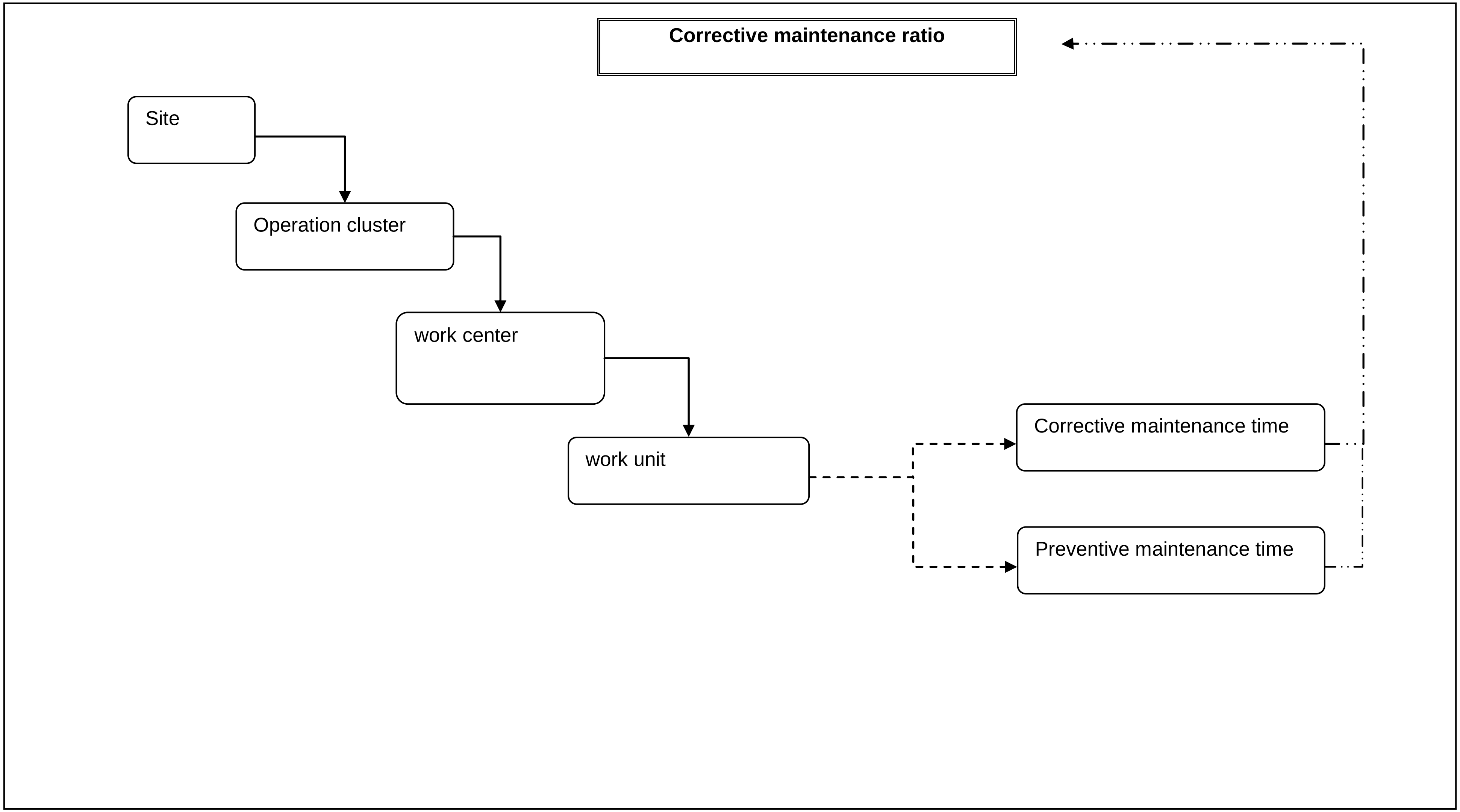
A.32 Mean time to failures



A.33 Mean time to restoration



A.34 Corrective maintenance ratio



Annex B

(Normative)

Alternative OEE calculation based on loss time model

B.1 Introduction

This annex could use to calculate the OEE (Overall Equipment Efficiency) based on partitioning of the total time such as amount of loss time for operation

B.2 Time Model for Production Units

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

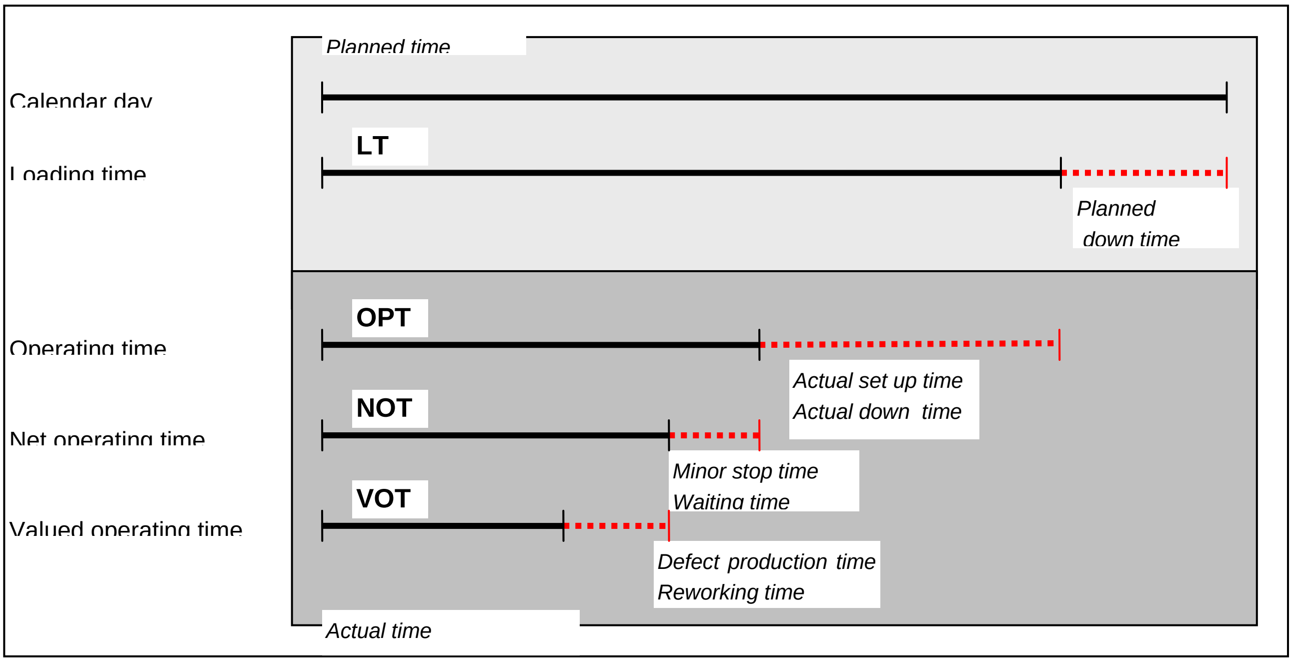


Fig B.1 Time Model for calculation the OEE

B.3 KPI

B.3.1 Overall equipment effectiveness index

Name / Title of indicator:	Overall Equipment Effectiveness Index
Description	
Benefit / Application:	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 production unit, and their finished goods rate summarized in a characteristic number.
Timing	demand-oriented, periodic
Definition and Calculation	
Formula:	OEE Index = Availability * Performance Rate * Finished Goods Ratio
Unit/Dimension:	%
Rating:	Min: 0% Max: 100% Trend: the higher, the better.
Analysis / Drill Down:	Related to production unit, product, period (day), and error types.
Remarks	
Notes / Explanation:	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 8.25
User group	Master, Chief, Management
Effect model:	
Manufacturing type:	continuous, batch

B 3.2 Availability

Name / Title of indicator:	Availability
Description	
Benefit / Application:	Availability indicates the proportion of time the equipment is actually utilized against the loading time. The availability represents the magnitude of equipment stoppage loss.
Timing	demand-oriented, periodic
Definition and Calculation	
Formula:	Availability = OPT / LT
Unit/Dimension:	%
Rating:	Min: 0% Max: 100% Trend: the higher, the better.
Analysis / Drill Down:	Related to production unit
Remarks	
Notes / Explanation:	The term availability is also called usage grade.
User group	Master, Chief, Management
Effect model:	
Manufacturing type:	continuous, batch

B 3.3 Performance Rate

Name / Title of indicator:	Performance Rate
Description	
Benefit / Application:	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.
Timing	demand-oriented, periodic, online
Definition and Calculation	
Formula:	Effectiveness = NOT / OPT
Unit/Dimension:	%
Rating:	Min: 0% Max: 100% Trend: the higher, the better. The 100% can be exceeded, if the planned production time for each production unit is larger than the actual production time.
Analysis / Drill Down:	Related to product, production unit, and production order
Remarks	
Notes / Explanation:	Performance Rate is also called efficiency factor or performance. This indicator is suitable as on-line characteristic number for the worker level.
User group	Master, Chief, Management
Effect model:	
Manufacturing type:	continuous, batch

Bibliography

[1] IEC 62264-3, *Industrial-process measurement and control—Enterprise-control system integration – Part 3: Activity models of manufacturing operations*

[2] KPI standard sheets from VDMA, Association of German Machinery and Equipment Manufacturers.

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

[4] ISO 31 (all parts), *Quantities and units*

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