TECHNICAL REPORT

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

Part 10: Operational sequence description of data acquisition

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

Partie 10: Description de l'acquisition des données relatives aux séquences opérationnelles

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Foreword

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

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This document was prepared by Technical Committee ISO/TC 184, *Automation systems and integration*, Subcommittee SC 5, *Interoperability, integration, and architectures for enterprise systems and automation applications*.

A list of all parts in the ISO 22400 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

This document describes the procedure for the determination of key performance indicators (KPIs) by means of examples. The KPIs that are used are given in ISO 22400-2.

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

Part 10: Operational sequence description of data acquisition

1 Scope

This document contains descriptions for the practical use for applying formulae as specified in ISO 22400-2 for key performance indicators for production control and monitoring. This document is intended to be applied in conjunction with the content of ISO 22400-2.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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.

ISO 22400-2:2014, *Automation systems and integration — Key performance indicators (KPIs) for manufacturing operations management — Part 2: Definitions and descriptions*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 22400-2 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1
planned shut down time
PSDT
time in which the work unit is planned to be out of operation

Note 1 to entry: Corresponds to “no production” as defined in ISO 22400-2.

3.2
planned down time
PDOT
time, included in the planned operation time, in which the work unit is planned for no operations within the operation time period

Note 1 to entry: ISO 22400-2:2014, Figure 3, gives a detailed overview of the used time lines for work units as used for the ISO 22400 series.

3.3
work unit log
data recording of work unit events along with their time stamps

4 KPI calculation examples

4.1 Example setup

KPIs are calculated for different scopes including work unit and production orders. The KPIs are determined from the work unit log.

The example given in Tables 1 and 2 consists of two work units (W1 and W2) within a time period of one calendar day. Two production orders (PO1 and PO2) are executed in this production area within this calendar day. A work unit log for each work unit is produced. Based on the data in the work unit logs, KPIs can be calculated. The scope of the KPI can be the work unit, the production order, the worker etc.

Each Production Order (PO) is composed of two Production Order Sequences (POS):

— PO1: POS 1/1 followed by POS 1/2;

— PO2: POS 2/1 followed by POS 2/2.

In the example POS x/1 is always executed on work unit W1.

In the example POS x/2 is always executed on work unit W2.

The calculation of the KPIs takes place in two steps.

a) Determine KPI elements.

The KPI elements can be determined based on the work unit logs

b) Calculate KPIs.

The KPIs can be calculated based on the KPI elements.

The details are defined in “comments on the work unit logs”. The examples use “pieces” (Pcs) as item unit, however, any kind of item unit can be used.

4.2 KPIs for work unit

From work unit scope the following KPIs can be determined based on the work unit logs:

— Utilization efficiency;

— Setup ratio;

— Technical efficiency;

— Allocation efficiency;

— Availability;

— Effectiveness;

— Quality ratio;

— Overall equipment effectiveness index (OEE);

— Net equipment effectiveness index (NEE);

— Scrap ratio;

— Rework ratio;

— Actual to planned scrap ratio;

— MTBF;

— MTTF;

— MTTR;

— Direct energy consumption effectiveness;

— Direct net energy consumption effectiveness;

— Direct energy efficiency;

— Direct net energy efficiency.

Table 1 — Log of work unit 1

	Determination of basics	
APT	= [06:30 – 07:00] + [07:30 – 08:00] + [08:30 – 09:00] + [09:30 – 10:30] + [15:00 – 17:30] + [18:00 – 19:00] + [20:00 – 20:30]	= 390 min
AUST	= [06:00 – 06:30] + [10:30 – 11:00] + [14:30 – 15:00] + [20:30 – 21:00]	= 120 min
ADET	= [08:00 – 08:30] + [19:00 – 19:30] + [07:00 – 07:30] + [09:00 – 09:30] + [19:30 – 20:00]	= 150 min
TTR	= [07:00 – 07:30] + [09:00 – 09:30] + [19:30 – 20:00]	= 90 min
PSDT	= [00:00 – 06:00] + [22:00 – 24:00]	= 480 min
PDOT	= [12:00 – 12:30] + [17:30 – 18:00]	= 60 min
PBT	= 1 440 min – PSDT – PDOT 1 440 min – 480 min – 60 min	= 900 min
AUPT	= APT + AUST = 390 min + 120 min	= 510 min
AUBT	= APT + AUST + ADET = = 390 min + 120 min + 150 min	= 660 min
GQ	$GQ_{POS\ 1/1}$ + $GQ_{POS\ 2/1}$ = 450 Pcs + 6 Pcs	= 456 Pcs
SQ	$SQ_{POS\ 1/1}$ + $SQ_{POS\ 2/1}$ = 40 Pcs + 2 Pcs	= 42 Pcs
RQ	$RQ_{POS\ 1/1}$ + $RQ_{POS\ 2/1}$ = 10 Pcs + 0 Pcs	= 10 Pcs
PQ	$PQ_{POS\ 1/1}$ + $PQ_{POS\ 2/1}$ = 500 Pcs + 8 Pcs	= 508 Pcs
PSQ	Planned scrap quantity in % × $PQ_{POS\ 1/1}$ + Planned scrap quantity in % × $PQ_{POS\ 2/1}$ = 5 % × 500 Pcs + 25 % × 8 Pcs	= 27 Pcs
$PEDI_{POS\ 1/1}$	= 0,42 kWh	= 0,42 kWh
$PEDI_{POS\ 2/1}$	= 1,05 kWh	= 1,05 kWh
ADEC	$ADEC_{POS\ 1/1}$ + $ADEC_{POS\ 2/1}$ = 115 m^3 × 0,102 8 kWh/m^3 + 10,5 m^3 × 10 kWh/m^3 + 120 kWh + 4,5 m^3 × 0,102 8 kWh/m^3 + 0,45 m^3 × 10 kWh/m^3 + 4,5 kWh	= 246,28 kWh

Table 1 *(continued)*

Calculation of KPIs			
Utilization efficiency	=	APT/AUBT	
	=	390 min/660 min	= 59,09 %
Setup ratio	=	AUST/AUPT	
	=	120 min/510 min	= 23,53 %
Technical efficiency	=	APT/(APT + ADET)	
	=	390/(390 + 150)	= 72,22 %
Allocation efficiency	=	AUBT/PBT	
	=	660 min/900 min	= 73,33 %
Availability	=	APT/PBT	
	=	390 min/900 min	= 43,33 %
Effectiveness	=	$Effectiveness_{POS\ 1/1}$ + $Effectiveness_{POS\ 2/1}$	
	=	($PRI_{POS\ 1/1}$ × $PQ_{POS\ 1/1}$ + $PRI_{POS\ 2/1}$ $PQ_{POS\ 2/1}$) /APT	
		(0,3 min/Pcs × 500 Pcs + 30 min/Pcs × 8 Pcs)/390 min	= 100,00 %
Quality ratio	=	($GQ_{POS\ 1/1}$ + $GQ_{POS\ 2/1}$)/($PQ_{POS\ 1/1}$ + $PQ_{POS\ 2/1}$)	
	=	(450 Pcs + 6 Pcs)/(500 Pcs + 8 Pcs)	= 89,76 %
OEE	=	Availability × Effectiveness × Quality ratio	
	=	43,33 % × 100 % × 89,76 %	= 38,89 %
NEE	=	AUPT/PBT × Effectiveness × Quality ratio	
	=	510 min/900 min × 100 % × 89,76 %	= 50,86 %
Scrap ratio	=	SQ/PQ	
	=	42 Pcs/508 Pcs	= 8,27 %
Rework ratio	=	RQ/PQ	
	=	10 Pcs/508 Pcs	= 1,97 %
Actual to planned scrap ratio	=	SQ/PSQ	
	=	42 Pcs/27 Pcs	= 155,56 %
MTBF	=	(AUST + APT + TTR)/(Number(FE) +1)	
	=	(120 min + 390 min + 90 min)/(3 +1)	= 150 min
MTTF	=	(AUST + APT)/(Number(FE) +1)	
	=	(120 min + 390 min)/(3 +1)	= 127,5 min
MTTR	=	TTR/(Number(FE) +1)	
	=	90 min/(3 +1)	= 22,5 min
Direct energy consumption effectiveness	=	($PDEI_{POS\ 1/1}$ × $PQ_{POS\ 1/1}$ + $PDEI_{POS\ 2/1}$ × $PQ_{POS\ 2/1}$)/ADEC	
	=	(0,42 kWh/Pcs × 500 Pcs + 1,05 kWh/Pcs × 8 Pcs)/246,28 kWh	= 88,68 %
Direct net energy consumption effectiveness	=	($PDEI_{POS\ 1/1}$ × $GQ_{POS\ 1/1}$ + $PDEI_{POS\ 2/1}$ × $GQ_{POS\ 2/1}$)/ADEC	
	=	(0,42 kWh/Pcs × 450 Pcs + 1,05 kWh/Pcs × 6 Pcs)/246,28 kWh	= 79,30 %

Table 1 *(continued)*

Direct energy efficiency	=	ADEC/PQ	
	=	246,28 kWh/508 Pcs	= 0,485 kWh/ Pcs
Direct net energy efficiency	=	ADEC/GQ	
	=	246,28 kWh/456 Pcs	= 0,540 kWh/ Pcs

Table 2 — Log of Work unit 2

Determination of basics			
APT	=	[12:00 – 12:30] + [13:00 – 14:00] + [14:30 – 15:00] + [16:00 – 16:30] + [18:00 – 19:30] + [20:00 – 21:30]	= 330 min
AUST	=	[11:30 – 12:00] + [16:30 – 17:00] + [17:30 – 18:00] + [21:30 – 22:00]	= 120 min
ADET	=	[12:30 – 13:00] + [15:30 – 16:00] + [15:00 – 15:30]	= 90 min
TTR	=	[15:00 – 15:30]	= 30 min
PSDT	=	[00:00 – 06:00] + [22:00 – 24:00]	= 480 min
PDOT	=	[14:00 – 14:30] + [19:30 – 20:00]	= 60 min
PBT	=	1 440 min – PDBT – PDOT	= 900 min
		1 440 min – 480 min – 60 min	
AUPT	=	APT + AUST	
	=	330 min + 120 min	= 450 min
AUBT	=	APT + AUST + ADET	
	=	330 min + 120 min + 90 min	= 540 min
GQ		$GQ_{POS\ 1/2}$ + $GQ_{POS\ 2/2}$	
	=	410 Pcs + 4 Pcs	= 414 Pcs
SQ		$SQ_{POS\ 1/2}$ + $SQ_{POS\ 2/2}$	
	=	30 Pcs + 2 Pcs	= 32 Pcs
RQ		$RQ_{POS\ 1/2}$ + $RQ_{POS\ 2/2}$	
	=	10 Pcs + 0 Pcs	= 10 Pcs
PQ		$PQ_{POS\ 1/2}$ + $PQ_{POS\ 2/2}$	
	=	450 Pcs + 6 Pcs	= 456 Pcs
PSQ		Planned scrap quantity in % × $PQ_{POS\ 1/2}$ + Planned scrap quantity in % × $PQ_{POS\ 2/2}$	
	=	5 % × 450 + 25 % × 6 Pcs	= 24 Pcs
$PEDI_{POS\ 1/2}$	=	0,94 kWh	= 0,94 kWh
$PEDI_{POS\ 2/2}$	=	2,10 kWh	= 2,10 kWh
ADEC		$ADEC_{POS\ 1/2}$ + $ADEC_{POS\ 2/2}$	
	=	210 m^3 × 0,102 8 kWh/m^3 + 18,7 m^3 × 10 kWh/m^3 + 222 kWh + 6,6 m^3 × 0,102 8 kWh/m^3 + 0,66 m^3 × 10 kWh/m^3 + 6,6 kWh	= 444,47 kWh
Calculation of KPIs			
Utilization efficiency	=	APT/AUBT	
	=	330 min/540 min	= 61,11 %
Setup ratio	=	AUST/AUPT	
	=	120 min/450 min	= 26,67 %

Table 2 *(continued)*

Technical efficiency	=	APT/(APT + ADET)	
	=	330 min/(330 min + 90 min)	= 78,57 %
Allocation efficiency	=	AUBT/PBT	
	=	540 min/900 min	= 60,00 %
Availability	=	APT/PBT	
	=	330 min/900 min	= 36,67 %
Effectiveness	=	$\text{Effectiveness}_{\text{POS 1/2}}$ + $\text{Effectiveness}_{\text{POS 2/2}}$	
		$\text{PRI}_{\text{POS 1/2}} \times \text{PQ}_{\text{POS 1/2}} + \text{PRI}_{\text{POS 2/2}} \times \text{PQ}_{\text{POS 2/2}})/\text{APT}$	
		(0,3 min/Pcs × 450 Pcs + 30 min/Pcs × 6 Pcs)/330 min	= 95,45 %
Quality ratio	=	$(\text{GQ}_{\text{POS 1/2}} + \text{GQ}_{\text{POS 2/2}})/(\text{PQ}_{\text{POS 1/2}} + \text{PQ}_{\text{POS 2/2}})$	
		(410 Pcs + 4 Pcs)/(450 Pcs + 6 Pcs)	= 90,79 %
OEE	=	Availability × Effectiveness × Quality ratio	
	=	36,67 % × 95,46 % × 90,79 %	= 31,78 %
NEE	=	AUPT/PBT × Effectiveness × Quality ratio	
	=	450 min/900 min × 95,46 % × 90,79 %	= 43,33 %
Scrap ratio	=	SQ/PQ	
	=	32 Pcs/456 Pcs	= 7,02 %
Rework ratio	=	RQ/PQ	
	=	10 Pcs/456 Pcs	= 2,19 %
Actual to planned scrap ratio	=	SQ/PSQ	
	=	32 Pcs/24 Pcs	= 133,33 %
MTBF	=	(AUST + APT + TTR)/(Number (FE) +1)	
	=	(120 min + 330 min + 30 min)/(1 +1)	= 240 min
MTTF	=	(AUST + APT)/(Number (FE) +1)	
	=	(120 min + 330 min)/(1 +1)	= 225 min
MTTR	=	TTR/(Number (FE) +1)	
	=	30 min/(1 +1)	= 15 min
Direct energy consumption effectiveness	=	$(\text{PDEI}_{\text{POS 1/2}} \times \text{PQ}_{\text{POS 1/2}} + \text{PDEI}_{\text{POS 2/2}} \times \text{PQ}_{\text{POS 2/2}})/\text{ADEC}$	
	=	(0,94 kWh/Pcs × 450 Pcs + 2,10 kWh/Pcs × 6 Pcs)/444,47 kWh	= 98,00 %
Direct net energy consumption effectiveness	=	$(\text{PDEI}_{\text{POS 1/2}} \times \text{GQ}_{\text{POS ½}} + \text{PDEI}_{\text{POS 2/2}} \times \text{GQ}_{\text{POS 2/2}})/\text{ADEC}$	
	=	(0,94 kWh/Pcs × 410 Pcs + 2,10 kWh/Pcs × 4 Pcs)/444,47 kWh	= 88,60 %
Direct energy efficiency	=	ADEC/PQ	
	=	444,47 kWh/456 Pcs	= 0,975 kWh/Pcs
Direct net energy efficiency	=	ADEC/GQ	
	=	444,47 kWh/414 Pcs	= 1,074 kWh/Pcs

4.3 KPIs for production orders and production order sequences

From the production order scope the following KPIs can be determined based on the work unit logs:

— Utilization efficiency;

— Setup ratio;

— Technical efficiency;

— Allocation ratio (Production order related);

— Throughput rate (Production order related);

— Effectiveness;

— Production process ratio (Production order related);

— Quality ratio;

— Scrap ratio (Production order related);

— Rework ratio (Production order related);

— Actual to planned scrap ratio (Production order related);

— Fall off ratio (Production order related);

— First pass yield (Production order related);

— Direct energy consumption effectiveness;

— Direct net energy consumption effectiveness;

— Direct energy efficiency;

— Direct net energy efficiency.

Corresponding to “work unit scope” the required basics for the production order or production order sequence (planned time, actual time and logistical sizes) are determined by using the following table. Based on these determinations the KPIs will be calculated by considering the event notifications and messages from the work unit log.

The First Pass Yield (FPY) is described by the relation of Good Quantity [GQ first evaluation] (Good Part [GP]) to the Produced Quantity [PQ] within the evaluation period – related to the first test run for each test piece. A completed reworking the FPY cannot be influenced in the second test run, as opposed to Quality ratio that increases with every successful "verification".

To relate the KPI for each piece it requires a process-related "Serialized/unique-based" flow of products in which only the first test run of the product is used for the evaluation. Reapplication of testing of a product is no longer part of the calculation of a FPY, but improves the quality ratio. For the calculation of the FPY no differentiation takes place for "failed parts" in rework or scrap made by the FPY. If the piece identification is not possible, then the production order-related Good Quantity [GQ last operation] the Good Quantity [GQ first test] be equated as Good Parts [GP].

The calculation example given in Tables 3 to 6 is based on the work unit log of work unit W1 and W2. The quality indicators of the work unit W1 and W2 are determined for the evaluation period of the calendar day.

Table 3 — POS 1/1 on work unit 1 time period [06:00 - 11:00]

Determination of basics			
APT	=	[06:30 – 07:00] + [07:30 – 08:00] + [08:30 – 09:00] + [09:30 – 10:30]	= 150 min
AUST	=	[06:00 – 06:30] + [10:30 – 11:00]	= 60 min
ADET	=	[08:00 – 08:30] + [07:00 – 07:30] + [09:00 – 09:30]	= 90 min
TTR	=	[07:00 – 07:30] + [09:00 – 09:30]	= 60 min
PDOT	=		= 0 min
AUPT	=	APT + AUST	
	=	150 min + 60 min	= 210 min
AUBT	=	APT + AUST + ADET	
	=	150 min + 60 min + 90 min	= 300 min
PQ	=	$PQ_{POS\ 1/1}$	
	=	500 Pcs	= 500 Pcs
GQ	=	$GQ_{POS\ 1/1}$	
	=	450 Pcs	= 450 Pcs
RQ	=	$RQ_{POS\ 1/1}$	
	=	10 Pcs	= 10 Pcs
SQ	=	$SQ_{POS\ 1/1}$	
	=	40 Pcs	= 40 Pcs
PEDI	=	0,42 kWh	= 0,42 kWh
ADEC	=	115 m^3 × 0,102 8 kWh/m^3 + 10,5 m^3 × 10 kWh/m^3 + 120 kWh	= 236,82 kWh
Calculation of KPIs			
Utilization efficiency	=	APT/AUBT	
	=	150 min/300 min	= 50,00 %
Setup ratio	=	AUST/AUPT	
	=	60 min/210 min	= 28,57 %
Technical efficiency	=	APT/(APT + ADET)	
	=	150 min/(150 min + 90 min)	= 62,50 %
Effectiveness	=	PRI × PQ/APT	
		0,3 Pcs/min × 500 Pcs/150 min	= 100,00 %
Quality ratio	=	GQ/PQ	
		450 Pcs/500 Pcs	= 90,00 %
Direct energy consumption effectiveness	=	PDEI × PQ/ADEC	
	=	0,42 kWh/Pcs × 500 Pcs/236,82 kWh	= 88,67 %
Direct net energy consumption effectiveness	=	PDEI × GQ/ADEC	
	=	0,42 kWh/Pcs × 450 Pcs/236,82 kWh	= 79,81 %
Direct energy efficiency	=	ADEC/PQ	

Table 3 *(continued)*

	= 236,82 kWh/500 Pcs	= 0,474 kWh/ Pcs
Direct net energy efficiency	= ADEC/GQ	
	= 236,82 kWh/450 Pcs	= 0,526 kWh/ Pcs

Table 4 — POS 2/1 on work unit 1 time period [14:30 - 21:00]

Determination of basics		
APT	= [15:00 – 17:30] + [18:00 – 19:00] + [20:00 – 20:30]	= 240 min
AUST	= [14:30 – 15:00] + [20:30 – 21:00]	= 60 min
ADET	= [19:00 – 19:30] + [19:30 – 20:00]	= 60 min
TTR	= [19:30 – 20:00]	= 30 min
PDOT	= [17:30 – 18:00]	= 30 min
AUPT	= APT + AUST	
	= 240 min + 60 min	= 300 min
AUBT	= APT + AUST + ADET	
	= 240 min + 60 min + 60 min	= 360 min
PQ	= $PQ_{POS\ 2/1}$	
	= 8 Pcs	= 8 Pcs
GQ	= $GQ_{POS\ 2/1}$	
	= 6 Pcs	= 6 Pcs
RQ	= $RQ_{POS\ 2/1}$	
	= 0 Pcs	= 0 Pcs
SQ	= $SQ_{POS\ 2/1}$	
	= 2 Pcs	= 2 Pcs
PEDI	= 1,05 kWh	= 1,05 kWh
ADEC	= 4,5 m^3 × 0,102 8 kWh/m^3 + 0,45 m^3 × 10 kWh/m^3 + 4,5 kWh	= 9,46 kWh
Calculation of KPIs		
Utilization efficiency	= APT/AUBT	
	= 240 min/360 min	= 66,67 %
Setup ratio	= AUST/AUPT	
	= 60 min/300 min	= 20,00 %
Technical efficiency	= APT/(APT + ADET)	
	= 240 min/(240 min + 60 min)	= 80,00 %
Effectiveness	= PRI × PQ/APT	
	30 Pcs/min × 8 Pcs/240 min	= 100,00 %
Quality ratio	= GQ/PQ	
	6 Pcs/8 Pcs	= 75,00 %
Direct energy consumption effectiveness	= PDEI × PQ/ADEC	
	= 1,05 kWh/Pcs × 8 Pcs/9,46 kWh	= 88,79 %

Table 4 *(continued)*

Direct net energy consumption effectiveness	=	PDEI × GQ/ADEC	
	=	1,05 kWh/Pcs × 6 Pcs/9,46 kWh	= 66,60 %
Direct energy efficiency	=	ADEC/PQ	
	=	9,46 kWh/8 Pcs	= 1,183 kWh/Pcs
Direct net energy efficiency	=	ADEC/GQ	
	=	9,46 kWh/6 Pcs	= 1,577 kWh/Pcs

Table 5 — POS 1/2 on work unit 2 time period [06:00 - 17:00]

Determination of basics			
APT	=	[12:00 – 12:30] + [13:00 – 14:00] + [14:30 – 15:00] + [16:00 – 16:30]	= 150 min
AUST	=	[11:30 – 12:00] + [16:30 – 17:00]	= 60 min
ADET	=	[12:30 – 13:00] + [15:30 – 16:00] + [15:00 – 15:30]	= 90 min
TTR	=	[15:00 – 15:30]	= 30 min
PDOT	=	[14:00 – 14:30]	= 30 min
AUPT	=	APT + AUST	
	=	150 min + 60 min	= 210 min
AUBT	=	APT + AUST + ADET	
	=	150 min + 60 min + 90 min	= 300 min
PQ	=	$PQ_{POS\ 1/2}$	
	=	450 Pcs	= 450 Pcs
GQ	=	$GQ_{POS\ 1/2}$	
	=	410 Pcs	= 410 Pcs
RQ	=	$RQ_{POS\ 1/2}$	
	=	10 Pcs	= 10 Pcs
SQ	=	$SQ_{POS\ 1/2}$	
	=	30 Pcs	= 30 Pcs
PEDI	=	0,94 kWh	= 0,94 kWh
ADEC	=	210 m^3 × 0,102 8 kWh/m^3 + 18,7 m^3 × 10 kWh/m^3 + 222 kWh	= 430,59 kWh
Calculation of KPIs			
Utilization efficiency	=	APT/AUBT	
	=	150 min/300 min	= 50,00 %
Setup ratio	=	AUST/AUPT	
	=	60 min/210 min	= 28,57 %
Technical efficiency	=	APT/(APT + ADET)	
	=	150 min/(150 min + 90 min)	= 62,50 %
Effectiveness	=	PRI × PQ/APT	
		0,3 Pcs/min × 450 Pcs/150 min	90,00 %

Table 5 *(continued)*

Quality ratio	= GQ/PQ	
	410 Pcs/450 Pcs	= 91,11 %
Direct energy consumption effectiveness	= PDEI × PQ/ADEC	
	= 0,94 kWh/Pcs × 450 Pcs/430,59 kWh	= 98,24 %
Direct net energy consumption effectiveness	= PDEI × GQ/ADEC	
	= 0,94 kWh/Pcs × 410 Pcs/430,59 kWh	= 89,50 %
Direct energy efficiency	= ADEC/PQ	
	= 430,59 kWh/450 Pcs	= 0,957 kWh/Pcs
Direct net energy efficiency	= ADEC/GQ	
	= 430,59 kWh/410 Pcs	= 1,050 kWh/Pcs

Table 6 — POS 2/2 on Work unit 2 time period [17:30 - 22:00]

Determination of basics		
APT	= [18:00 – 19:30] + [20:00 – 21:30]	= 180 min
AUST	= [17:30 – 18:00] + [21:30 – 22:00]	= 60 min
ADET	=	= 0 min
TTR	=	= 0 min
PDOT	= [19:30 - 20:00]	= 30 min
AUPT	= APT + AUST	
	= 180 min + 60 min	= 240 min
AUBT	= APT + AUST + ADET	
	= 180 min + 60 min + 0 min	= 240 min
PQ	= $PQ_{POS\ 2/2}$	
	= 6 Pcs	= 6 Pcs
GQ	= $GQ_{POS\ 2/2}$	
	= 4 Pcs	= 4 Pcs
RQ	= $RQ_{POS\ 2/2}$	
	= 0 Pcs	= 0 Pcs
SQ	= $SQ_{POS\ 2/2}$	
	= 2 Pcs	= 2 Pcs
PEDI	= 2,10 kWh	= 2,10 kWh
ADEC	= 6,6 m^3 × 0,102 8 kWh/m^3 + 0,66 m^3 × 10 kWh/m^3 + 6,6 kWh	= 13,88 kWh
Calculation of KPIs		
Utilization efficiency	= APT/AUBT	
	= 180 min/240 min	= 75,00 %
Setup ratio	= AUST/AUPT	
	= 60 min/240 min	= 25,00 %

Table 6 *(continued)*

Technical efficiency	=	APT/(APT + ADET)	
	=	180 min/(180 min + 0 min)	= 100,00 %
Effectiveness	=	PRI × PQ/APT	
		30 Pcs/min × 6 Pcs/180 min	= 100,00 %
Quality ratio	=	GQ/PQ	
		4 Pcs/6 Pcs	= 66,67 %
Direct energy consumption effectiveness	=	PDEI × PQ/ADEC	
	=	2,10 kWh/Pcs × 6 Pcs/13,88 kWh	= 90,78 %
Direct net energy consumption effectiveness	=	PDEI × GQ/ADEC	
	=	2,10 kWh/Pcs × 4 Pcs/13,88 kWh	= 60,52 %
Direct energy efficiency	=	ADEC/PQ	
	=	13,88 kWh/6 Pcs	= 2,313 kWh/Pcs
Direct net energy efficiency	=	ADEC/GQ	
	=	13,88 kWh/4 Pcs	= 3,470 kWh/Pcs

Based on the data of the single production order sequence or the work unit log the order-related actual times and KPIs can determined. This is shown in Tables 7 and 8.

Table 7 — Production order-related actual times and KPIs PO1 in conjunction with POS1/1 and POS1/2

		Determination of basics	
AOET	=	Endtime $_{POSPO1/2}$ – Starttime $_{POSPO1/1}$	
	=	[17:00] – [06:00]	= 660 min
GQ		$GQ_{POS\ 1/2}$	
	=	410 Pcs	= 410 Pcs
SQ		$SQ_{POS\ 1/1}$+ $SQ_{POS\ 1/2}$	
	=	40 Pcs+ 30 Pcs	= 70 Pcs
RQ		$RQ_{POS\ 1/1}$+ $RQ_{POS\ 1/2}$	
	=	10 Pcs + 10 Pcs	= 20 Pcs
PQ		$PQ_{POS\ 1/1}$	
	=	500 Pcs	= 500 Pcs
PSQ		Planned scrap quantity in % × $PQ_{POS\ 1/1}$ + Planned scrap quantity in % × $PQ_{POS\ 1/2}$	
	=	5 % × 500 Pcs + 5 % × 450 Pcs	= 48 Pcs
GP		Complies with GQ because there is no serialization to identify a first pass	
		410 Pcs	= 410 Pcs
IP		Complies with PQ because there is no serialization to identify a first pass	
		500 Pcs	= 500 Pcs

Table 7 *(continued)*

ADEC	$ADEC_{POS\ 1/1} + ADEC_{POS\ 1/2}$ = 115 m^3 × 0,102 8 kWh/m^3 + 10,5 m^3 × 10 kWh/m^3 + 120 kWh + 210 m^3 × 0,102 8 kWh/m^3 + 18,7 m^3 × 10 kWh/m^3 + 222 kWh	= 667,41 kWh
$PEDI_{POS\ 1/1}$	= 0,42 kWh	= 0,42 kWh
$PEDI_{POS\ 1/2}$	= 0,94 kWh	= 0,94 kWh
Calculation of KPIs		
Allocation ratio	= $(AUBT_{POSPO1/1} + AUBT_{POSPO1/2})/AOET$ = 600 min/660 min	= 90,91 %
Throughput rate	= PQ/AOET = 450 Pcs/660 min	= 0,71 Pcs/min
Production process ratio	= $(APT_{POSPO1/1} + APT_{POSPO1/2})/AOET$ = (150 min + 150 min)/660 min	= 47,62 %
Quality ratio	= GQ/PQ = 410 Pcs/500 Pcs	= 82,00 %
Scrap ratio	= SQ/PQ = 70 Pcs/500 Pcs	= 14,00 %
Rework ratio	= RQ/PQ = 20 Pcs/500 Pcs	= 4,00 %
Actual to planned scrap ratio	= SQ/PSQ = 70 Pcs/48 Pcs	= 145,83 %
Fall off ratio	= (PQ – GQ)/PQ = (500 – 410 Pcs)/500 Pcs	= 18,00 %
First pass yield	= GP/IP = 410 Pcs/500 Pcs	= 82,00 %
Direct energy consumption effectiveness	= $(PDEI_{POS\ 1/1} \times PQ_{POS\ 1/1} + PDEI_{POS\ 1/2} \times PQ_{POS\ 1/2})/ADEC$ = (0,42 kWh/Pcs × 500 Pcs + 0,94 kWh/Pcs × 450 Pcs)/667,41 kWh	= 94,84 %
Direct net energy consumption effectiveness	= $PDEI_{POS\ 1/1} \times GQ_{POS\ 1/1} + PDEI_{POS\ 1/2} \times GQ_{POS\ 1/2}) /ADEC$ = (0,42 kWh/Pcs × 450 Pcs + 0,94 kWh/Pcs × 410 Pcs)/667,41 kWh	= 86,06 %
Direct energy efficiency	= ADEC/PQ = 667,41 kWh/450 Pcs	= 1,483 kWh/ Pcs
Direct net energy efficiency	= ADEC/GQ = 667,41 kWh/410 Pcs	= 1,628 kWh/ Pcs

Table 8 — Production order-related actual times and KPIs PO2 in conjunction with POS2/1 and POS2/2

Determination of basics			
AOET	=	$Endtime_{POS\ 2/2}$ – $Starttime_{POS\ 2/1}$	
	=	[22:00] – [14:30]	= 450 min
GQ		$GQ_{POS\ 2/2}$	
	=	4 Pcs	= 4 Pcs
SQ		$SQ_{POS\ 2/1}$ + $SQ_{POS\ 2/2}$	
	=	2 Pcs + 2 Pcs	= 4 Pcs
RQ		$RQ_{POS\ 2/1}$ + $RQ_{POS\ 2/2}$	
	=	0 Pcs	= 0 Pcs
PQ		$PQ_{POS\ 2/1}$	
	=	8 Pcs	= 8 Pcs
PSQ		Planned scrap quantity in % × $PQ_{POS\ 2/1}$ + Planned scrap quantity in % × $PQ_{POS\ 2/2}$	
	=	25 % × 8 Pcs + 25 % × 6 Pcs	= 4 Pcs
IP		Number of pieces being tested on both production sequences (serial number S01 bis S08)	
	=	8 Pcs	= 8 Pcs
GP		Number of pieces that are good on both production sequences in the first round without reworking (serial number S01)	
	=	1 Pcs	= 1 Pcs
$IP_{POS\ 2/1}$		Number of pieces that have been tested (serial number S01 to S08)	
	=	8 Pcs	= 8 Pcs
$GP_{POS\ 2/1}$		Number of pieces being good in the first round (serial number S01, S05, S07, S08)	
	=	4 Pcs	= 4 Pcs
$IP_{POS\ 2/2}$		Number of pieces that have been tested (serial number S01, S02, S05, S06, S07, S08)	
	=	6 Pcs	= 6 Pcs
$GP_{POS\ 2/2}$		Number of pieces being good in the first pass (serial number S01, S06)	
	=	2 Pcs	= 2 Pcs
ADEC		$ADEC_{POS\ 2/1}$ + $ADEC_{POS\ 2/2}$	
	=	4,5 m^3 × 0,102 8 kWh/m^3 + 0,45 m^3 × 10 kWh/m^3 + 4,5 kWh + 6,6 m^3 × 0,102 8 kWh/m^3 + 0,66 m^3 × 10 kWh/m^3 + 6,6 kWh	= 23,34 kWh
$PEDI_{POS\ 2/1}$	=	1,05 kWh	= 1,05 kWh
$PEDI_{POS\ 2/2}$	=	2,10 kWh	= 2,10 kWh
Calculation of KPIs			
Allocation ratio	=	($AUBT_{POS\ 2/1}$ + $AUBT_{POS\ 2/2}$)/AOET	
	=	600 min/450 min	= 133,33 %
Throughput rate	=	PQ/AOET	
	=	6 Pcs/450 min	= 0,01 Pcs/min
Production process ratio	=	($APT_{POS\ 2/1}$ + $APT_{POS\ 2/2}$)/AOET	
	=	(240 min + 180 min)/450 min	= 93,33 %

Table 8 *(continued)*

Quality ratio	= GQ/PQ	
	= 4 Pcs/8 Pcs	= 50,00 %
Scrap ratio	= SQ/PQ	
	= 4 Pcs/8 Pcs	= 50,00 %
Rework ratio	= RQ/PQ	
	= 0 Pcs/8 Pcs	= 0,00 %
Actual to planned scrap ratio	= SQ/PSQ	
	= 4 Pcs/4 Pcs	= 133,33 %
Fall off ratio	= (PQ – GQ)/PQ	
	= (8 - 4 Pcs)/8 Pcs	= 50,00 %
First pass yield PO2	= GP/IP	
	= 1 Pcs/8 Pcs	= 12,50 %
First pass yield POS2/1	= GP/IP	
	= 4 Pcs/8 Pcs	= 50,00 %
First pass yield POS2/2	= GP/IP	
	= 2 Pcs/6 Pcs	= 33,33 %
Direct energy consumption effectiveness	= $(PDEI_{POS\ 2/1} \times PQ_{POS\ 2/1} + PDEI_{POS\ 2/2} \times PQ_{POS\ 2/2})/ADEC$	
	= (1,05 kWh/Pcs × 8 Pcs + 2,10 kWh/Pcs × 6 Pcs)/23,34 kWh	= 89,97 %
Direct net energy consumption effectiveness	= $(PDEI_{POS\ 2/1} \times PQ_{POS\ 2/1} + PDEI_{POS\ 2/2} \times PQ_{POS\ 2/2})/ADEC$	
	= (1,05 kWh/Pcs × 6 Pcs + 2,10 kWh/Pcs × 4 Pcs)/23,34 kWh	= 62,98 %
Direct energy efficiency	= ADEC/PQ	
	= 23,34 kWh/8 Pcs	= 2,918 kWh/ Pcs
Direct net energy efficiency	= ADEC/GQ	
	= 23,34 kWh/4 Pcs	= 5,835 kWh/ Pcs

4.4 KPIs for worker

An important indicator is the worker efficiency. It provides information on the ratio of job-related work of the workers in relation to the total attendance of workers.

Following the description of the work unit log the following status are in place.

— Worker/Operator OP1 is working on work unit 1 from 06:00 to 14:00 hours.

— Worker/Operator OP2 is working on work unit 1 from 14:00 to 22:00 hours.

— Worker/Operator OP3 is working on work unit 2 from 06:00 to 14:00 hours.

— Worker/Operator OP2 is working in parallel on work unit 1 from 14:00 to 22:00 hours.

The attendance time of multiple work unit operator OP2 is allocated proportionally to both of the two work units, the multi-work unit operator operates two work units. The respective production order related time or the total attendance is cut into halves in those cases. See Tables 9 to 11.

Table 9 — Log of operator 1

Determination of basics			
	=	End time $_{OP1}$ – Start time $_{OP1}$ - PDOT $_{OP1}$	
	=	[14:00] – [06:00] – [00:30]	= 450 min
APWT	=	($AUBT_{POS\ 1/1}$) OP1	
	=	300 min	= 300 min
Calculation of KPIs			
Worker efficiency	=	APWT/APAT	
	=	300 min/450 min	= 66,67 %

Worker efficiency OP1:

APAT (OP1) =

[6:00 - 12:00] + [12:30 - 14:00] =

360 min + 90 min = 450 min

APWT (W1) =

[06:00 – 06:30 AUST] +

[06:30 – 07:00 APT] +

[07:00 – 07:30 TTR] +

[07:30 – 08:00 APT] +

[08:00 – 08:30 ADET] +

[08:30 – 09:00 APT] +

[09:00 – 09:30 TTR] +

[09:30 – 10:30 APT] +

[10:30 – 11:00 AUST] =

30 min + 30 min + 30 min + 30 min + 30 min + 30 min + 30 min + 60 min + 30 min = 300 min

Worker efficiency OP1 = APWT/APAT = 300 min/450 min = 66,67 %

Table 10 — Log of operator 2

Determination of basics			
APAT	=	End time $_{OP2}$ – Start time $_{OP2}$ – PDOT $_{OP2}$	
	=	[22:00] – [14:00] – [00:00]	= 480 min
APWT	=	($AUBT_{POS\ 1/2}$ + $AUBT_{POS\ 2/2}$) $_{OP2}$	
	=	450 min	= 450 min
Calculation of KPIs			
Worker efficiency	=	APWT/APAT	
	=	450 min/480 min	= 93,75 %

Worker efficiency OP2:

APAT(OP2) =

[14:00 – 14:30 W1] + [14:30 – 17:30 W1+W2] +

[17:30 – 18:00 W2] + [18.00 – 22:00 W1+W2] =

30 min + 180 min + 30 min + 240 min = 480 min

APWT(W1 + W2) =

[14:30 – 15:00 W1 AUST + W2 APT] +

[15:00 – 16:00 W1 APT] +

[16:00 – 16:30 W1 APT + W2 APT] +

[16:30 – 17:00 W1 APT + W2 AUST] +

[17:00 – 17:30 W1 APT] +

[17:30 – 18:00 W2 AUST] +

[18:00 – 19:00 W1 APT + W2 APT] +

[19:00 – 19:30 W1 ADET + W2 APT] +

[19:30 – 20:00 W1 TTR] +

[20:00 – 20:30 W1 APT + W2 APT] +

[20:30 – 21:00 W1 AUST + W2 APT] +

[21:00 – 21:30 W2 APT] +

[21:30 – 22:00 W2 AUST]

= 30 min + 60 min + 30 min + 30 min + 30 min + 30 min + 60 min + 30 min + 30min + 30 min + 30 min + 30 min + 30 min = 450 min

Worker efficiency OP1 = APWT/APAT = 450 min/480 min = 93,75 %

Table 11 — Log of operator 3

Determination of basics		
APAT	= End time $_{OP3}$ – Start time $_{OP3}$ - PDOT $_{OP3}$	
	= [14:00] – [06:00] – [00:00]	= 480 min
APWT	= (AUBT$_{POS\ 1/2}$) $_{OP3}$	
	= 150 min	= 150 min
Calculation of KPIs		
Worker efficiency	= APWT/APAT	
	= 150 min/480 min	= 31,25 %

Worker efficiency OP3:

APAT(OP3) =

[06:00 - 14:00] = 480 min

APWT(W2) =

[11:30 – 12:00 AUST] +

[12:00 – 12:30 APT] +

[12:30 – 13:00 ADET] +

[13:00 – 14:00 APT] =

30 min + 30 min + 30 min + 60 min = 150 min

Worker efficiency OP3 = APWT/APAT = 150 min/480 min = 31,25 %

Annex A
(informative)

Example: Work unit data recording for KPI calculation

A.1 Abbreviations for examples

A.1.1 General

POS x/y	Production order sequence (POS) y within production order x
Wz	Work unit z
OPa	Operator a
Snn	Serial number nn
Serial number	Unambiguous identifier for serialization of pieces
Test cycle	Number of testing passes. „1“ means that the piece has passed testing as „acceptable“, in one pass.
Air	Consumed compressed air; Number of dm^3, which have been consumed within the time period directly on the work unit.
Gas	Consumed Gas; Number of m^3, which have been consumed within the time period directly on the work unit.
Electricity	Consumed Electricity; Number of kWh, which have been consumed within the time period directly on the work unit.

A.1.2 Time type

APT	Actual production time
AUST	Actual unit setup time
ADET	Actual unit delay time
TTR	Time to repair
ADOT	Actual unit down time
PSDT	Planned shut down time
PDOT	Planned down time
PBT	Planned busy time

A.2 Comments on the work unit log

The work unit log serves as a basis for the presentation of sample calculations for the particular KPI elements and KPIs. It refers to the period of a calendar day for two work units with limited capacity.

These two work units run by two production orders on the same day. In doing so, each of the two production orders is using both work units during two production order sequences. A production order sequence is intended as a manufacturing step to be performed on a work unit. Thus, the production order sequence specifies the successive manufacturing steps within a production order.

The two work units are independent one from the other. This means that eventual stops or speed losses of one work unit do not influence the other work unit.

In this example the production order sequence 1 is assigned to work unit 1 and the production order sequence 2 is assigned to work unit 2. Thus, in this example each production order sequence is assigned to a different work unit.

In these examples, production order 1 is processed with two production order sequences, one after the other: POS1/1 is executed on work unit 1 and POS2/1 starts on work unit 2 only when POS1/1 is completed. Differently, production order 2 is processed with two production order sequences partially overlapped in time: POS2/1 is executed on work unit 1 and POS2/2 starts on work unit 2 while POS2/1 is still being processed. Many other combinations can also be possible but will not be considered in these examples.

The overlap of the first and second production order sequences of the second production order (PO2) is shown for demonstrating the effect on the allocation ratio or production process ratio. The first production order refers to a big lot production, while the second production order represents a small lot. Only the second production order has serialized items.

In order to allow an easy traceability for the calculations an idealized grid of 30 minutes has been introduced as basis for the particular time periods during the operating time, i.e. time bucket for this specific example has been set to 30 minutes. In reality, the time periods of the logs are corresponding with the actual recorded time stamps.

The quantities given always refer to the corresponding entry of that particular time period. When referring to processed quantities, fractional number has been rounded up.

Actual unit down times for both work units are visible between the first and second production order

The basis for calculation is a 3-shift model with the early, late and night shift with shift change times 06:00, 14:00 and 22:00. The night shift is defined as no production time (planned shut down time) period for both work units.

The first production order is of a nominal amount of 500 pieces. The second production order has a nominal amount of 8 pieces, but with serial numbers.

The first production order has a planned runtime per item (PRI) of 200 pieces per hour, or time per item of 0,3 minutes. The second production order has planned time per item (PRI) of 2 pieces per hour or a time per item of 30 minutes.

The setup time is 30 minutes.

Time to restoration (TTR) is included in the actual unit delay time (ADET)

In this example, the planned scrap quantity (PSQ) is computed for each production order sequence, i.e. for each manufacturing step, and the computation is performed after the completion of the processes, i.e. PSQ is computed on the actual number of units entering each manufacturing step, not on the planned number of units entering the manufacturing step or on the number of units entering the entire process. This difference is significant for production orders composed of multiple production order sequences, as it is shown in this example. For all production order sequences in the first production order (POS1/1 and POS1/2), PSQ is set at 5 % while or all production order sequences in the second production order (POS2/1 and POS2/2), PSQ is set at 25 % The rework quantity exits from the process, which means that subsequent work is not performed on the work units involved in this example.

The planned energy consumption per item and work unit production order is given in Table A.1 as a virtual example.

Table A.1 — Log for work unit W1

Production order sequences	Compressed air dm^3	Gas m^3	Electrical energy (KWh)	PDEI (KWh)
POS 1/1	200	0,02	0,2	0,2 × 0,102 8 + 0,02 × 10 + 0,2 = 0,42
POS 1/2	400	0,04	0,4	0,4 × 0,102 8 + 0,04 × 10 + 0,4 = 0,94
POS 2/1	500	0,05	0,5	0,5 × 0,102 8 + 0,05 × 10 + 0,5 = 1,05
POS 2/2	1 000	0,10	1,0	1,0 × 0,102 8 + 0,10 × 10 + 1,0 = 2,10

In this example the first production order has planned energy consumption per item (PDEI) of 1,36 kWh. The second production order has planned energy consumption per item (PDEI) of 3,15 kWh excluding a calculated average for setup time, tear down time and any delay time.

To calculate the actual direct energy consumption (ADEC) it has to be considered that the energy consumption has been measured per time period thus it has to be converted to a unit related basis in kWh.

A.3 Log for work unit W1

Table A.2 — Log for work unit W1

Start time	End time	Duration	Work unit	Planned time	Planned order time	shift	Actual order time	Time Type	Time type description	Operator	GQ	SQ	RQ	Input Charge	Output Charge	Serial-No.	Test cycle
00:00	06:00	6:00	W1	PSDT		3		PSDT	Shut down time								
06:00	06:30	0:30		PBT	POS 1/1	1	POS 1/1	AUST	Setup	OP1							
06:30	07:00	0:30						APT	Production		100	0	0	C01	C11		
07:00	07:30	0:30						TTR	Time to repair								
07:30	08:00	0:30						APT	Production		80	20	0		C12		
08:00	08:30	0:30						ADET	Delay								
08:30	09:00	0:30						APT	Production		80	10	10	C02	C21		
09:00	09:30	0:30			POS 1/1			TTR	Time to repair								
09:30	10:00	0:30			POS 2/1			APT	Production		90	10	0				
10:00	10:30	0:30						APT	Production		100	0	0				
10:30	11:00	0:30					POS 1/1	AUST	Setup								
11:00	11:30	0:30						ADOT	Actual unit down								
11:30	12:00	0:30															
12:00	12:30	0:30		PDOT				PDOT	Break								
12:30	13:00	0:30		PBT				ADOT	Actual unit down								
13:00	13:30	0:30															
13:30	14:00	0:30								OP1							
14:00	14:30	0:30				2				OP2							
14:30	15:00	0:30			POS 2/1		POS 2/1	AUST	Setup								
15:00	15:30	0:30						APT	Production		1	0	0	C03		S01	1
15:30	16:00	0:30						APT	Production		1	0	0			S02	2
16:00	16:30	0:30						APT	Production		0	1	0			S03	1
16:30	17:00	0:30						APT	Production		0	1	0			S04	1
17:00	17:30	0:30						APT	Production		1	0	0			S05	1

Table A.2 *(continued)*

Start time	End time	Duration	Work unit	Planned time	Planned order time	shift	Actual order time	Time Type	Time type description	Operator	GQ	SQ	RQ	Input Charge	Output Charge	Serial-No.	Test cycle
17:30	18:00	0:30		PDOT				PDOT	break								
18:00	18:30	0:30		PBZ				APT	Production		1	0	0	C04		S06	2
18:30	19:00	0:30						APT	Production		1	0	0			S07	1
19:00	19:30	0:30						ADET	Delay								
19:30	20:00	0:30						TTR	Time to repair								
20:00	20:30	0:30						APT	Production		1	0	0			S08	1
20:30	21:00	0:30					POS 2/1	AUST	Setup								
21:00	21:30	0:30						ADOT	Actual unit down								
21:30	22:00	0:30								OP2							
22:00	00:00	2:00		PSDT		3		PSDT	Shut down time								

A.4 Log for work unit W2

Table A.3 — Log for work unit W2

Start time	End time	Duration	Work unit	Planned time	Planned order time	Shift	Actual order time	Time Type	Time type description	Operator	GQ	SQ	RQ	Input Charge	Output Charge	Serial-No.	Test cycle
00:00	06:00	6:00	W2	PSDT		3		PSDT	Shut down time								
06:00	06:30	0:30		PBT		1		ADOT	Actual unit down	OP3							
06:30	07:00	0:30															
07:00	07:30	0:30															
07:30	08:00	0:30															
08:00	08:30	0:30															
08:30	09:00	0:30															
09:00	09:30	0:30															
09:30	10:00	0:30															
10:00	10:30	0:30			POS 1/2												
10:30	11:00	0:30															
11:00	11:30	0:30															
11:30	12:00	0:30					POS 1/2	AUST	Setup								
12:00	12:30	0:30						APT	Production		90	10	0	C11	C31		
12:30	13:00	0:30						ADET	no material								
13:00	13:30	0:30			POS 1/2			APT	Production		70	10	0	C12	C32		
13:30	14:00	0:30			POS 2/2			APT	Production	OP3	80	0	0	C21	C33		
14:00	14:30	0:30		PDOT		2		PDOT	break	OP2							
14:30	15:00	0:30		PBT				APT	Production		80	0	10				
15:00	15:30	0:30						TTR	Time to repair								
15:30	16:00	0:30						ADET	No material								
16:00	16:30	0:30						APT	Production		90	10	0		C34		
16:30	17:00	0:30					POS 1/2	AUST	Setup								
17:00	17:30	0:30						ADOT	Actual unit down								
17:30	18:00	0:30					POS 2/2	AUST	Setup								

Table A.3 *(continued)*

Start time	End time	Duration	Work unit	Planned time	Planned order time	Shift	Actual order time	Time Type	Time type description	Operator	GQ	SQ	RQ	Input Charge	Output Charge	Serial-No.	Test cycle
18:00	18:30	0:30						APT	Production		1	0	0			S01	1
18:30	19:00	0:30			POS 2/2			APT	Production		1	0	0			S02	2
19:00	19:30	0:30						APT	Production		1	0	0			S05	2
19:30	20:00	0:30		PDOT				PDOT	break								
20:00	20:30	0:30		PBT				APT	Production		1	0	0			S06	1
20:30	21:00	0:30						APT	Production		0	1	0			S07	1
21:00	21:30	0:30						APT	Production		0	1	0			S08	1
21:30	22:00	0:30					POS 2/2	AUST	Setup	OP2							
22:00	00:00	2:00		PSDT		3		PSDT	Shut down time								

A.5 Log for work unit W1 for energy calculation