

DS1905 PSP Metric Description

For Philips Biosensing Platform

Version 1.0, 14 Mar 2022

Subject to change at Philips sole discretion

Metrics

This specification defines and characterizes the metrics provided by the Biosensing by PPG, Biosensing by EDA, Sleep Sensing and Fall Detection by AGB library delivered under Philips Biosensing Platform. More information about testing and pre-validation studies can be made available under confidential terms.

Input Parameters

The system accepts properties of a person as input metrics. From these input metrics and its sensor data, the system extracts other metrics of the person, provided as output metrics. Input metrics may be set at any time by the Host. Below is a list of all possible input metrics.

Input Metric	Notes
Age	The age of the person [year]
Profile	Date of birth, gender, handedness
Height	The height of the person [cm]
Weight	The weight of the person [kg]
RHR	The resting heart rate* of the person [bpm]
Sleep Preference	Information about the person in relation to his/her sleep.
Time	The current time (UTC and time zone). The system keeps track of time itself. It is advisable to set time initially before enabling any output metrics that require Time. Time may also be set incidentally to compensate for clock drift in the system.
Body position	uion are sensed.

* is used for the AEE metric. If not available, accuracy may be impacted

The Quality indicator

Most of the metrics described in this document also mention to be accompanied by a quality indicator. This is a unique feature provided by the library. The quality indicator denotes the reliability of the metric values. The valid quality range is defined as 0..4, where the higher means more reliable. It is recommended to use metrics output if quality indicator is higher than zero.

For example, when comparing the heart rate measured by a PPG based device and heart rate measured by an ECG chest belt over time, one can determine the accuracy by calculating the Mean Absolute Errors (MAE).

However in a real time situation, there will be only the PPG device and no chest belt reference. The quality indicator in this case may help to qualify the reliability of metric value which is output from the library.

With this additional information, the developer of the PPG device can make case by case judgements how to present or register the particular output values.

The below table shows an example, based on evaluating many hours of recorded data, how the quality indicator can be used to qualify the metric value in relation to its MAE and availability.

Activity	Availability (%)				MAE (BPM)			
	Q 1	Q 2	Q 3	Q 4	Q 1	Q 2	Q 3	Q 4
Walk	99.0	89.3	74.1	52.9	2.0	1.5	1.0	0.8
Run	99.0	91.1	79.7	61.6	2.0	1.2	0.7	0.5
cycle	99.5	92.4	81.7	67.1	1.7	1.1	0.7	0.6

gym	98.6	88.2	74.3	53.1	3.0	1.7	1.0	0.8
sit	99.8	98.0	94.4	86.6	1.2	0.9	0.7	0.6
free living	99.6	91.7	77.6	56.1	2.3	1.8	1.5	1.2
sleep	99.9	99.4	98.5	96.6	0.4	0.4	0.3	0.3
Overall	99.5	94.6	87.0	75.4	1.4	1.0	0.7	0.5

Since the quality index evaluates the input signals coming from the PPG sensor and the accelerometer, a potential misjudgment of the

therefore recommended to only use the values provided by the quality index as a guideline next to the presented metric value, and should not be used to alter or replace the metric value.

The quality indicator denotes the reliability of the metric value(s). The valid quality range is defined as 0..4, where the higher means more reliable, and:

- 0 denotes that the value is unreliable, i.e. the accompanying metric value(s) shall be ignored;
- 4 denotes the most reliable value that the metric source can provide.

Note that this definition implies that quality only has a meaning in the context of the source and of the metric itself. Quality values cannot be quantitatively compared among metrics, nor among metrics generated by the current version and previous or future versions of their source.

Biosensing by PPG

Heart Rate

This metric measures the heart rate of the user, averaged over a time window of typically 5-10 seconds.

Heart Rate	
Definition	Number of beats of the heart per minute
Unit	beats/minute (bpm)
Display update interval	1 sec
Range	30-220
Sensors used (automatically)	PPG & ACC
Suitable Activity	All
acquisition time	5-10 sec (with no/less motion)
Input parameters	n.a.
Output	Heart Rate, Quality indicator

Low Power Heart Rate

Low Power Heart Rate is a metric introduced to save power when a lower update rate suffices.

Low Power Heart Rate	
Definition	Number of beats of the heart per minute with a lower update rate
Unit	beats/minute (bpm)
Display update interval	1 minute (sensor on-time = 6-15 sec/min)
Range	30-220
Sensors used (automatically)	PPG & ACC
Suitable Activity	All
Acquisition time	10 sec
Input parameters	n.a.
Output	Short term Heart Rate, Quality indicator

The metric is similar to the Heart Rate metric except that the PPG sensor is active for only 6-15 seconds per minute (depending on

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circumstances), enabling a reduced power consumption. From this, the system calculates one single Heart Rate value per minute.

The Low Power Heart Rate is the current heart rate, but extracted periodically at each update interval. No heart rate information is available for the periods between these extractions.

Respiration Rate

This metric measures the breathing rate of the user, averaged over a time window of typically 20-30 seconds, by analysis of various modulations induced in the PPG signal. When enabled it will automatically switch on the PPG & ACC. It needs at least the acquisition time to produce a reliable reading. When the quality is reliable, output values can be used with an update frequency of 1 second. To reduce power, the metric can be switched off.

	Respiration Rate
Definition	Number of breaths (inhalation - exhalation cycles) per minute
Unit	0.25 breaths/minute (brpm)
Display update interval	1 sec
Range	5 - 45 brpm
Sensors used (automatically)	PPG & ACC
Suitable Activity	Rest, sleep, absence of motion
acquisition time	20-30 Sec (check cold or warm start)
Input parameters	n.a.
Output	Average respiratory rate, Quality indicator

Respiration rate information can be used in the management of stress and chronic diseases, such as sleep apnea and COPD. Existing techniques to extract respiration rate are based on capnography (e.g. wearing a mask) or pneumography (a rubber band attached to the chest). They can be uncomfortable, in particular when observing breathing during sleep. This metric works in the absence of motion.

Heart beat Time stamps

The Heart beat Times tamps metric indicates the timestamp in milliseconds from system start of each detected heartbeat pulse, updated once per second.

	Heart beat Time stamps
Definition	The timestamp in milliseconds from system start of each detected heartbeat pulse
Unit	ms
Display update interval	1 sec
Range (practical values)	300-2000 ms
Sensors used	PPG & ACC
Suitable Activity	Rest, sleep, absence of motion
acquisition time	5-10 sec
Input parameters	n.a.
Output	Number of beats, Body position, Quality indicator, max 5 time stamps, type of beat (normal or last beat in sequence)

The series of heartbeat timestamps facilitate the analysis of heart rate variability (HRV), the variability of time intervals between consecutive heartbeats. The system associates a time stamp to each of the pulse onsets in the PPG signal with millisecond accuracy, making use of sophisticated and robust interpolation techniques. As the PPG waveform is susceptible to motion artifacts, the Heart beat Time stamps metric will yield values only when the user is at rest or asleep. So in case of motion, the Metric will then

Activity Count

The Activity Count metric indicates the amount of physical (motion) activity per second. Activity Count can be used to build applications activity over longer periods (hours or days) by combining (e.g. averaging) the activity count values over windows of time.

	Activity Count
Definition	Level of activity (movement)
Unit	Arbitrary units
Update interval	1 sec
Range	0-65535
Sensors used (automatically)	ACC
Suitable Activity	Any
acquisition time	1 sec
Input parameters	Body position of sensor
Output	Activity Count

Active Energy Expenditure

The Active Energy Expenditure (AEE) metric estimates the part of a expenditure related to physical activity. Total Energy expenditure (TEE) is the amount of metabolic calories needed to sustain basal metabolic rate, thermoregulation, digestion as well as physical activity. The Basal Metabolic Rate (BMR) is determined from

	Active Energy Expenditure
Definition	Energy spent by the body, due to Physical activity
Unit	kcal/h
Display update interval	1 sec
Range	0-1200
Sensors used (automatically)	PPG & ACC
Suitable Activity	All
acquisition time	5-10 sec
Input parameters	Time, Age, Gender, Height, Weight, Body position
Output	Energy expenditure, Quality indicator

The system combines measured activity levels, activity type and heart rate information into an accurate estimation of activity related energy expenditure. An application may combine the metric with BMR estimated from subject characteristics to determine total energy expenditure and physical activity level (PAL) or Metabolic Equivalent of Task (MET), which are other popular metrics of energy expenditure.

Low Power Active Energy Expenditure

The low-power energy Expenditure metric (LPAEE) provides estimates of activity-related energy expenditure (AEE) without using continuous measurements of heart rate. Instead, it uses heart rate data sampled on a minute-by-minute basis, thus offering increased battery lifetime at the cost of a slightly lower accuracy.

	Low-power Active Energy Expenditure
Definition	Energy spent by the body, due to Physical activity
Unit	kcal/h
Display update interval	60 sec
Range	0-1200
Sensors used (automatically)	PPG & ACC
Suitable Activity	All
acquisition time	5-10 sec
Input parameters	Time, Age, Gender, Height, Weight, Body position
Output	Energy expenditure, Quality indicator

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Cadence

Cadence measures the number of strides per minute (walking, running) or the number of crank revolutions per minute while cycling. It can be used in sports applications as well as to implement step counting.

	Cadence
Definition	# of periodic events per min in cyclical activities. Events interpretation depending on activity type Walking/running -> Event = Stride (=2 steps)
Unit	Strides/minute
Display update interval	1 sec
Range	20-120
Sensors used	ACC
Suitable Activity	Walk, run, cycling
acquisition time	10 sec
Input parameters	Body position
Output	Cadence, Quality indicator

Activity Type

The Activity Type metric estimates whether a user is performing a specific activity by analyzing acceleration patterns in overlapping time windows of 5-10 seconds. It can distinguish Walking, Running, Cycling and other.

	Activity Type
Definition	Detection of specific activities
Unit	Category
Display update interval	1 sec
Range	Walking, running, cycling, other
Sensors used (automatically)	ACC
Suitable Activity	Walking, running, cycling, resting, other, unspecified
acquisition time	5-10 sec
Input parameters	Body position
Output	Activity Type, Quality indicator

Speed

This metric estimates the speed of the user during walking and running by combining Cadence with subject information such as gender, height and body position. It can be used as a surrogate for more accurate speed values based on GPS or a foot pod in case these are not available.

	Speed
Definition	Rate of change of position
Unit	0.1m/sec
Display update interval	1 sec
Range	0-54km/h
Sensors used (automatically)	ACC
Suitable Activity	Walk, run
acquisition time	10 sec
Input parameters	Gender, Height, Body position
Output	Speed, Quality indicator

VO₂max

VO₂max represents the maximal amount of oxygen that can be taken in by the lungs and distributed to the working muscles. It measures the ability of the body to sustain metabolic needs during physical exertion. The number indicates how many milliliters of oxygen your body can consume, per minute and per kilogram body weight.

	VO2Max
Definition	Maximum rate of oxygen consumption during incremental exercise.
Unit	ml/kg/min
Display update interval	1 min
Range	10-100

Sensors used (automatically)	PPG & ACC
Suitable Activity	Walking >3km/h or running >6km/h
acquisition time	>20 mins at suitable activity
Input parameters	Age, Gender, Weight, Height, Body position
Output	VO ₂ max, Quality indicator

Accuracy is highest for running. Proper use is to enable the metric at the start of an exercise and disable it again at the end. The metric starts giving an output before the acquisition time, however accuracy increases when the acquisition time is achieved. All data measured after the start of an exercise will contribute to obtain a more accurate measure toward the end. The metric is suitable to provide estimates of fitness for users unaware of their physical condition. The metric offers the capability to monitor changes in fitness over time which could be useful to personalize services and track health progression.

Fitness Index

The Fitness Index (CFI) represents the relative cardio fitness of the person, compared to population mean with respect to age and gender.

	Fitness Index
Definition	VO ₂ max normalized for age and gender
Unit	Number (integer)
Display update interval	1 min
Range	0-100
Sensors used (automatically)	PPG & ACC
Suitable Activity	Walking (>3km/h) & running, min. 30 min
acquisition time	1 hour
Input parameters	Age, Gender, Weight, Height, Left/Right wrist
Output	Cardio-Fitness Index ¹ , Quality indicator

Objective measures of cardio-respiratory fitness such as VO₂max vary considerably between individuals. Values can range from about 10 ml O₂/kg/min in ill people such as cardiac patients to 80-90 ml O₂/kg/min in highly trained athletes. Based on data from thousands of individuals of different ages, normative VO₂max values and fitness categories have been established. These normative values can be used to generate intuitive, individualized feedback in the cardio fitness index (CFI). The Fitness Index metric can be used to track individual fitness over time. Additionally, the metric can be used to create categories of propositions for lifestyle coaching and training guidance to match the individual physical condition. The Fitness Index uses VO₂max information and characteristics as input. Gender and age specific thresholds are designed to map the VO₂max metric onto a universal fitness scale ranging from 0 to 100, with increments of 20. The CFI is derived from the five step segmentation of the VO₂max distribution as defined by *American College of Sport Medicine, 2010a*. For CFI legend, it is defined as:

CFI Range	Score
95 - 100	Superior
80 - 94	Excellent
60 - 79	Good
40 - 59	Fair
20 - 39	Poor
1 - 19	Very Poor

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Resting Heart Rate is the heart rate when you are sitting or lying calm and relaxed.

	Resting Heart Rate
Definition	Heart rate of person at rest, in neutrally temperature environment, not undergone any recent exertion or stimulation.
Unit	beats/minute (bpm)
Display update interval	1 hour
Range	30-120
Sensors used (automatically)	PPG & ACC
Suitable Activity	Sitting, relaxing, calm position (NOT sleeping), min. 1 minute with good quality.
acquisition time	1 hour
Input parameters	n.a.
Output	Resting heart rate, Quality indicator

The resting heart rate metric, while enabled, tracks the RHR of a person continuously over the most recent seven days. The heart rate information is collected regularly during inactive periods of the entire day. Long periods of rest are excluded, since these could indicate the person is asleep. The objective of the RHR algorithm is to estimate *without* any protocol the RHR value one would get if the person *would follow* the standard RHR measurement protocol used e.g. in sports, the HR measured in the morning immediately after main sleep, before any physical activity, and before eating or drinking. To get to this value *without* following a protocol, the RHR metric here uses a validated, statistical algorithm to estimate the RHR from information collected during periods of inactivity over the most recent 7 days. When the watch is not worn or temporarily off skin for e.g. charging, the RHR value will be kept as long as the period is not too long (several hours to max 1 day). When the RHR metric is disabled, no new information is built up, and after seven days or more the information is lost.

During periods of inactivity longer than 1 minute, the RHR measurement will request PPG only for maximally 1 minute. It then will wait for 15 minutes to request PPG again.

The time between subsequent heart beats (so-called Inter Beat
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the heart rate, but also more subtly, such as a small random
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variability) is a sign of good health.

- < Atrial Fibrillation: the heart rhythm is an AF rhythm
- < Other: the heart rhythm is a non-AF rhythm (i.e. normal rhythm or another type of arrhythmia)

Atrial Fibrillation (AF) is the most common type of cardiac arrhythmia, more detailed description can be found in [3]

	Heart Rhythm Type
Definition	Describes heart rhythm type of a person for a time interval of 60 seconds, update every 30 seconds
Unit	Type indication
Display update interval	30 sec
Range	AF, Other, Unspecified
Sensors used	PPG & ACC
Suitable Activity	Rest and or sleep situations
1st reading acquisition time	immediate
Input parameters	n.a.
Output	Heart Rhythm Type, delay time of the event, Quality indicator

contribution by monitoring the lower envelope of the heartrate signal. After subtraction of this envelope signal from the heartrate signal, we are left with only physical and mental heartrate contributions. An adaptive filter cancels the physical heartrate contribution in this signal by minimizing the correlation between its output (mental heartrate) and the activity signal. Therefore, this metric measures the mental stress based on the heart rate. It takes approximately 52 – 60s to produce the first Stress Level value after first valid PPG sample captured. Another concept is the ^h-up (with valid inputs) to first functionally valid stress level output. Now it is roughly less than 5 minutes.

	Stress Level Heart Rate
Definition	Describes the level of mental stress of a person based on heart rate
Unit	Arbitrary units
Display update interval	1 sec
Range	0 - 1000
Sensors used	PPG & ACC
Suitable Activity	Daily activities
1st reading acquisition time	Typical 1 min.
Input parameters	n.a.
Output	Stress Level Heart Rate, Quality indicator

The SPO2 metric in the PSP library measures the blood oxygen level in a similar way as the pulse oximeters. To measure, it makes use of the reflection of light signals on the photodiode (PD) coming from a set of Green, k-) @ k Q. It also takes in account of accelerometer signals to improve the robustness. Typically, SPO2 value for healthy adults is above 90%.

	SPO2
Definition	Estimated Blood Oxygen level
Unit	Percentage
Display update interval	1 sec
Range	70% 100%
Sensors used	PPG & ACC
Suitable Activity	Sitting still and wrist resting on table without any (wrist or finger) movement
1st reading acquisition time	20 30 sec
Input parameters	Calibration coefficients (given during library initialization)
Output	SPO2, Quality indicator

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Skin Proximity

Skin Proximity uses skin conductance and/or PPG & ACC if present to determine (wearable) on skin or off skin status depending on which output metrics are enabled.

	Skin Proximity
Definition	Skin Proximity status
Unit	Category
Update interval	1 sec
Range	0-255
Sensors used (automatically selected)	Skin Conductance or PPG & ACC
Suitable Activity	Any
Acquisition time	2 sec for On skin, 10 sec for Off skin
Input parameters	n.a.
Output	On skin/Off skin

Biosensing by EDA

Stress Level Skin Conductance

The Stress Level Skin Conductance metric indicates the amount of physical and emotional stress of the user at current time based on skin conductance. It is the immediate response to a stressor. It requires a skin conductance signal as input in continuous measurement mode. The output is a number between 0-1000 accompanied by the quality indicator. It is to be noted that the algorithm captures both the physical and emotional stress.

	Stress Level Skin Conductance
Definition	Level of Stress (Mental & Physical)
Unit	Unitless
Update interval	1 sec
Range	0-1000
Sensors used	Skin Conductance
Suitable Activity	Any
Acquisition time	5-10 sec
Input parameters	User Profile, Time
Output	Stress level, Quality indicator

A unique feature of the Biosensing by EDA technology is the ability of the algorithms to adapt to the physiology of the user. For that, the algorithm builds up user profile data daily and makes use of the user profile history in order to accurately determine the output metrics. For Stress Level Skin Conductance, the minimum duration of uninterrupted skin conductance measurement per day is at least 6 hours for personalized performance.

Cognitive Zone and Predictive Output Metrics

The Cognitive Zone metric is a collection of sub metrics including the current and predicted Cognitive Zone and the estimated amount of Cortisol Contribution by a stressor in the blood accompanied by the quality indicator. It requires a skin conductance signal as input in continuous measurement mode. The algorithm determines the amount of cortisol contribution by a stressor from the skin conductance input and based on the cortisol contribution value, determine the cognitive state of the user in 3 different states known as Cognitive Zones. The Cognitive Zones are classified as under stimulated, balanced and overstimulated. The algorithm also predicts the Cognitive Zones based on the skin conductance input history. The corresponding predictive output metrics are Predictive Cognitive Zone together with Predictive Cognitive Zone transition time (time to reach Predicted Cognitive Zone) and Cognitive Zone in One Hour if the user continues to perform the similar activities. The user application can use the current and predictive output metrics information to proactively guide the users with their mental balance states.

	Cognitive Zone
Definition	Cognitive Zone based on skin conductance
Unit	Category
Update interval	60 sec
Range	Undefined, Under Stimulated, Balanced, Over Stimulated
Sensors used (automatically)	Skin Conductance
Suitable Activity	Any
Acquisition time	30-45 minutes
Input parameters	User Profile (Gender), Time
Output	Cognitive Zone, Quality Indicator

	Predictive Cognitive Zone
Definition	Next predicted Cognitive Zone with the time defined in the Predictive Cognitive Zone Transition Time assuming user performing similar activities.
Unit	Category
Update interval	60 sec
Range	Undefined, Under Stimulated, Balanced, Over Stimulated
Sensors used (automatically)	Skin Conductance
Suitable Activity	Any
Acquisition time	30-45 minutes
Input parameters	User Profile (Gender), Time
Output	Predictive Cognitive Zone, Quality Indicator

	Predictive Cognitive Zone Transition Time
Definition	Time to reach the next predicted Cognitive Zone
Unit	Minutes
Update interval	60 sec
Range	0-60 minutes or 255 (unknown)
Sensors used (automatically)	Skin Conductance
Suitable Activity	Any
Acquisition time	30-45 minutes
Input parameters	User Profile (Gender), Time
Output	Predictive Cognitive Zone Transition Time, Quality Indicator

	Predictive Cognitive Zone in One Hour
Definition	Predicted Cognitive Zone in an hour later assuming user performing similar activities
Unit	Category
Update interval	60 sec
Range	Undefined, Under Stimulated, Balanced, Over Stimulated
Sensors used (automatically)	Skin Conductance
Suitable Activity	Any
Acquisition time	30-45 minutes
Input parameters	User Profile (Gender), Time
Output	Predictive Cognitive Zone in One Hour, Quality Indicator

	Cortisol Contribution
Definition	Estimated Cortisol Contribution from skin conductance
Unit	Unitless
Update interval	60 sec
Range	0-65535
Sensors used (automatically)	Skin Conductance
Suitable Activity	Any
Acquisition time	30-45 minutes
Input parameters	User Profile (Gender), Time
Output	Cortisol Contribution, Quality Indicator

A unique feature of the Biosensing by EDA technology is the ability of the algorithms to adapt to the physiology of the user. For that, the algorithm builds up user profile data daily and makes use of the user profile history in order to accurately determine the output metrics. For Cognitive Zone, the minimum duration of

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uninterrupted Skin Conductance measurement per day is at least 4.5 hours for personalized performance.

Fall Detection by AGB

Fall Occurrence can be detected by analyzing combination of accelerometer, gyroscope and/or barometer sensor data. The acceleration input is necessary while the barometer and gyroscope are recommended. With all three sensors together, the Wrist-Based Fall Detection (WFD) library solution can have the best performance. The false alarm rate threshold is a customizable parameter to balance between the fall detection frequency and false alarm rate. It can be once a day/week/month. Setting it to once per day asks the library to be more sensitive to fall occurrence with a higher chance of false detection (false positives) while setting the false alarm rate to once per month will increase the chance of missing falls (false negatives).

	Fall Occurrence
Definition	Prediction of fall occurrence
Unit	Category
Update interval	1 sec
Range	Binary
Sensors used	Possible combination: Accelerometer: <ul style="list-style-type: none">- Gyroscope, and Barometer- Accelerometer and Gyroscope- Accelerometer and Barometer- Accelerometer only
Suitable Activity	Walking, Sitting, Standing, Sleeping
Acquisition time	6 to 10 second to report fall
Input parameters	Fall alarm rate (given during library initialization)
Output	Fall Occurrence, Quality Indicator

For more detailed information on the Sleep Stages metric running on the wearable, see chapter 2 of the Metrics Specification [1]. For more detailed information on the Sleep Stages metric running on the mobile device, see FXC Application Programming Interface Specification [2].

References:

[1] SY1902 Philips HR Metrics Specification

[2] SY1901 Philips FXC API Specification

Sleep Sensing

Sleep Stages

To generate the sleep information, the system has to consist of two parts, one in the wearable and another in a mobile device (e.g. phone or tablet). In the wearable, intermediate data packets (Private Data) are calculated based on the sensor inputs from the PPG and the accelerometer. These packets with update interval of 1-minute need to be sent, or stored first on the wearable, and then to the mobile device for the Sleep Stages calculation.

While the Sleep Stages metric is enabled, the system automatically

can also be manually overruled (sleep preference).

	Sleep Stages
Definition	Detection of specific sleep stages & sleep HR
Unit	sleep stage
Display update interval	Upon end of the entire sleep event
Range	Wake, light sleep, deep sleep, REM
Sensors used	PPG & ACC
Suitable Activity	Sleep
1st reading acquisition time	Upon end of the entire sleep event
Input parameters	Set Time, Sleep preference (start/end) is optional
Output	Sleep Stage, Quality indicator