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Information technology — Data centres — Guidelines on holistic investigation methodology for data centre key performance indicators

Technologies de l'information — Centres de données — Lignes directrices relatives à la méthodologie de recherche holistique pour les indicateurs de performance clé du centre de données

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Foreword

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The committee responsible for this document is ISO/IEC JTC 1, *Information technology*, SC 39, *Sustainability for and by Information Technology*.

Introduction

The ISO/IEC 30134 series defines key performance indicators (KPIs) for data centre resource effectiveness. There are many aspects to be considered in order to improve data centre resource effectiveness. As for resources, it may include not only energy, but also water and other natural resources. As for data centre components, they include air conditioning, power supply, servers, storages, and network equipment. However, it is difficult to include all aspects into one KPI, so multiple KPIs are under development, which measure each aspects of resource effectiveness improvement. Resource effectiveness improvement in each aspect will be performed by measuring each KPI. On the other hand, there is a need to observe the state and trend of data centre as a whole, or holistically, by monitoring multiple KPIs in a single view. Analysis of the KPIs from the overall perspective is also referred to as a holistic investigation method. This document describes a spider web chart-based method and control chart method extending the functionality of the conventional spider web chart for viewing and analysing KPIs for data centre resource effectiveness. It also investigates considerations for applying holistic investigation methods to resource effectiveness evaluation of multiple data centre KPIs. The usefulness and applicability of holistic methods are discussed using a SWOT analysis. The methods described in this document are intended for analysis and continuous improvement of a specific data centre and not for comparing different data centres.

Information technology — Data centres — Guidelines on holistic investigation methodology for data centre key performance indicators

1 Scope

This document describes backgrounds, motivation, and general concept of holistic methodology for data centre key performance indicators (KPIs) to investigate the status of KPIs. It discusses the usefulness of holistic investigation methodology in terms of aggregating a KPI across different contexts, aggregation of two or more KPIs within a single context, aggregation of two or more KPIs across multiple contexts, and aggregation of the multiple KPIs into a single indicator. This document presents a conventional spider web chart-based data centre KPIs status observation method and a control chart method including upper bound and lower bound of the operational status of KPIs. This document presents SWOT analysis results for both methodologies. The methods described in this document are aimed at the self-monitoring of a data centre, not comparison among data centres.

Specifically, this document

a) describes backgrounds, motivation, and general concept of holistic investigation methodology for data centre KPIs,

b) analyses the usefulness of holistic investigation methodology for aggregating KPIs,

c) describes a spider web chart-based KPIs status observation method and a control chart extending spider web chart to observe the operational status of KPIs,

d) describes alternative and/or additional methods of representing dissimilar KPIs to track holistic resource effectiveness of the data centre, and

e) presents SWOT analysis results for holistic investigation methods described in this document.

2 Normative references

There are no normative references in this document.

3 Terms, definitions and abbreviated terms

3.1 Terms and definitions

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

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

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

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

3.1.1
holistic investigation method
data centre resource effectiveness investigation method considering multiple key performance indicators

3.1.2
spider web chart
chart that consists of multiple performance indicators which are set in a circle like a spider web

3.2 Abbreviated terms

IT	Information Technology
ITEEsv	IT Equipment Energy Efficiency for Servers
ITEUsv	IT Equipment Utilization for Servers
KPI	Key Performance Indicator
PUE	Power Usage Effectiveness
REF	Renewable Energy Factor
SWOT	Strength Weakness Opportunity Threat

4 Background and motivation

4.1 General concept of holistic investigation method

Improving the resource effectiveness and carbon footprint of a data centre requires the monitoring and analysis of multiple KPIs. ISO/IEC JTC 1/SC 39 has determined that it is impractical to aggregate multiple KPIs to determine the overall energy effectiveness of a data centre. There is a need to observe the state and trend of multiple KPIs in a single view.

With any performance indicator, it is necessary to understand the expected upper and lower limits and general behaviour of the performance indicator. There are typically two approaches that are applicable to holistic investigation of data centre KPIs:

— Engineering/modeling method: This method has been used to establish baseline performance. This methodology requires the development of an optimized economic and engineering model based on creating an idealized benchmark specific to each utility — incorporating the topology, demand patterns, and population density of the service territory. Typical limitations of this approach are as follows: the engineering models that support it can be very complicated, and the structure of the underlying components relationships can be obscured through a set of assumed coefficients used in the optimization process.

— Performance benchmarking method: This method includes a set of specific performance measurement indicators, such as volume billed per worker, consumed energy per product, quality of service (continuity, water quality, complaints), coverage, and key financial data. Usually, these indicators are presented in ratio form to control the scale of operations. These partial measures are generally available and provide the simplest way to perform comparisons: trends direct attention to potential problem areas.

Among the methods mentioned above, the performance benchmarking method is useful for evaluating the resource efficiency of data centres because ISO/IEC JTC 1/SC 39 is offering a selection of energy effectiveness KPIs. The performance benchmarking method may be further categorized into two types: performance indicator-based methods and chart-based methods.

— Performance indicator-based methods: In this category, the performance of the target is evaluated by developing performance indicators for the target. For example, Hz for CPU and bytes for storage are typical performance indicators. This category allows accurate performance evaluation and comparison among targets, if the performance indicators are defined. Typical limitation of this approach is that it is difficult to compare the evaluation results if performance indicators belong to different dimensions with different units.

— Chart-based methods: This category depicts the target's performance by using chart methods, such as pie, bar, line, and spider web, etc. This category is useful for evaluating performance by displaying multiple performance indicators, making analysis easier.

Since the chart-based approach supports multiple performance indicators simultaneously, it is appropriate for a holistic method. The spider web chart in particular is well suited for the display and analysis of multiple KPIs. A spider web chart is useful for displaying multiple KPIs in a single chart. It is also useful for displaying multiple measurement values of several KPIs in a single chart, for example, temporal measurement values of several KPIs. Thus, this document focuses on the spider web chart-based holistic KPI investigation methods. It is noted that the chart-based approach, especially spider web chart, has typical issues for applying a KPI investigation, such as scaling and normalization of KPI values, KPIs with different dimensions, ordering of KPIs in the chart, graphical interpretation of the chart, and so on. These typical issues are discussed in Clause 6 in detail.

4.2 Usefulness of spider web chart methods for visualizing data centre KPIs

The spider web chart consists of a bundle of performance indicators which are set in a circle. The indicators are usually normalized from zero to one, one indicating the highest possible performance, but unnormalized indicators may be utilized. Individual axes may need to be inverted in order for the different indicators to correlate. It is clear that the quality of the spider web charts depends on the validity, reliability, and comprehensiveness of the performance indicators. It is known that the spider web chart has strength on visualizing the status of performance indicators.

Regarding visualization capability, spider web charts provide a synoptic description of multiple performance measures and make trade-offs between performance measures visible. Figure 1 shows a spider web chart consisting of three sets of performance measurements and five performance indices. In the figure, the values of each index are originally measured and unnormalized ones, and the farther from centre of the chart implies the better. Each green, blue, and red polygon connecting measurement values of five index shows a single observation of the five indices, respectively. Using the chart, it is possible to visually compare the performance achievement among multiple performance measurements and indicators.

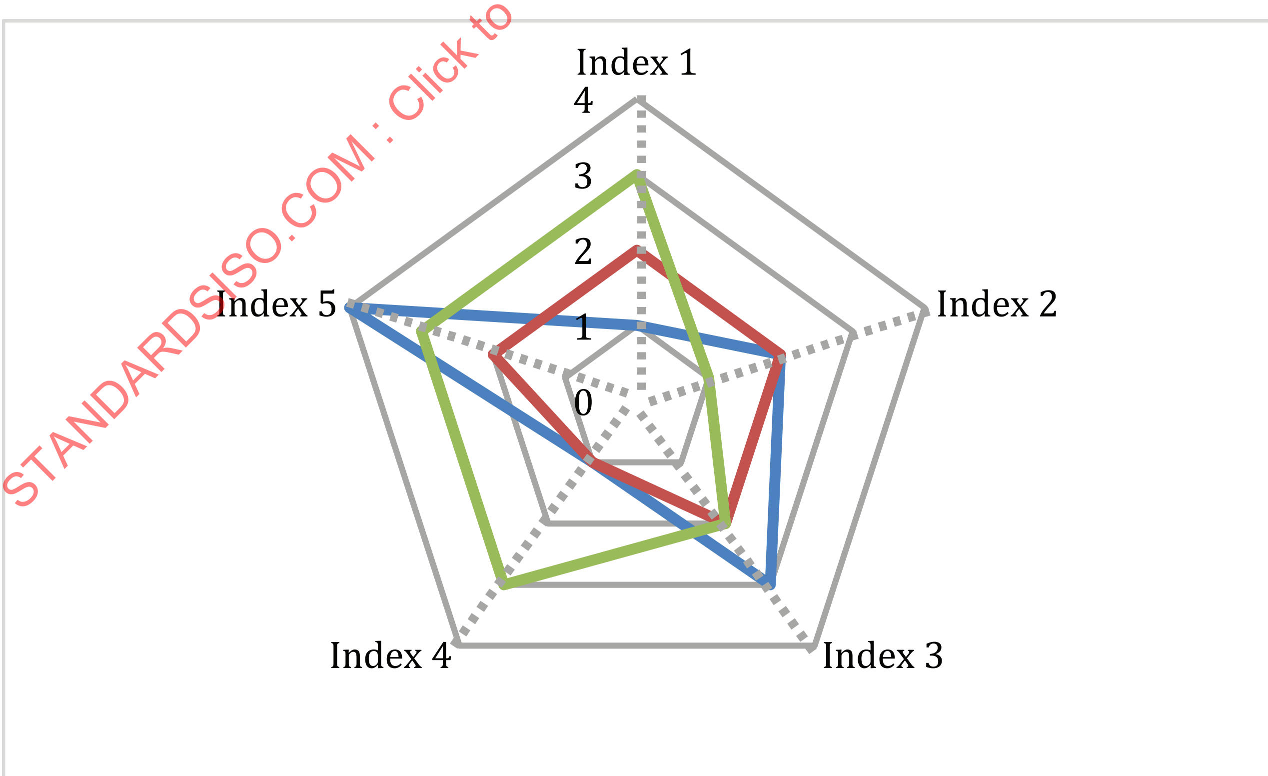


Figure 1 — Example of a spider web chart consisting three performance measurements (green, blue, and red)

Due to the advantages, spider web charts are popularly used to assess the performance of various evaluation objectives and to present a visual comparison of performance in various fields, especially business management. As discussed in this clause, the visualization capability of a spider web chart can help data centre administrators to monitor the specified performance KPIs of the data centre and their changes so that they can improve the efficiency of the data centre. For example, by regularly constructing the spider web chart showing the state of each KPI, the data centre administrator can effectively monitor the temporal behaviour of the KPIs. Further, the spider web chart has general advantages for assessing data centre KPIs rather than conventional charts such as bar chart when assessing the multiple measurement values of multiple KPIs. The advantages of a spider web chart are discussed in Clause 6 in detail.

4.3 Usefulness of aggregating data centre KPIs

The key objective of aggregating multiple performance indicators into a single indicator is to represent the overall achievement of each indicator as a single and integrated output. However, there are well-known problems with aggregating heterogeneous performance indicators. Each indicator can have a different dimension and scale, so aggregating multiple indicators by normalizing their original values can lose the characteristics of each indicator. Additionally, the aggregation process can cause a serious problem to be masked or a minor issue can be overstated depending on how the individual indicators are scaled. Further, depending on the dimension of indicators, it may be inappropriate to aggregate multiple indicators into a single indicator.

However, if all indicators are measured with the same dimension, aggregating multiple indicators into a single indicator may be useful. For example, if an indicator measures the operational achievement ratio of a KPI and its operational target value, the achievement ratio explains whether the data centre is operated effectively according to the operational target value. The operational target value of a KPI indicates the intended threshold for the KPI. Assume that a KPI measures the utilization ratio of IT server equipment and the administrator of the IT server sets upper bound and lower bound of the KPI as the operational target values. If the measured KPI value exceeds the upper bound of the KPI, the administrator may consider to install more IT servers in order to reduce the utilization ratio of IT servers. Whereas the administrator may consider to consolidate underutilized IT servers if the measured KPI value is below the lower bound of the KPI. Thus, by integrating the achievement ratios of each KPI into a single value, the data centre administrator can easily determine whether the data centre is operated as planned. It should be noted that observing the aggregated number of the measured KPI values may overlook the detailed characteristics. For example, by looking at the aggregate number of measured KPI values for server utilization, the overuse of one server may be masked by the underuse of another. Careful review of the individual server data for such events should be conducted to avoid data masking issues that may occur during KPI aggregation. However, even in this case, the relative importance (e.g. weighting) of each indicator is obscured. Thus, the aggregated overall operational achievement helps with management of the temporal changes in data centre operational efficiency. For example, let us assume that a data centre regularly examines the values of the overall operational achievement. At some time, if the overall operational achievement of the data centre is below the threshold for the data centre, the statuses of each KPI will be investigated and KPIs of which achievement is less than threshold could be managed by an administrator. Once the overall operational achievement value of the data centre exceeds the threshold, only the overall operational achievement value may be used to regularly manage the data centre.

5 Spider web chart-based KPIs status observation method

A holistic approach enables awareness of the effect of changes made to the data centre specific from an overall viewpoint by use of various efficiency metrics. A holistic approach helps the operator keep in mind the effects on all metrics simultaneously.

5.1 Principles for constructing a spider web chart using KPIs

5.1.1 Selection of axis on a spider web chart

To start a holistic approach, a data centre should define its whole scope or whole boundary to measure. This scope might vary by each data centre, since each data centre's functionality or service is different. This scope defines the holistic view, within which KPIs are chosen. Then, it is most important to select an appropriate combination of axes or KPIs used in the spider web chart. "Holistic approach" implies that data centre should consider all ways within the scope to achieve data centre energy reduction, CO_2 reduction, or improvement of sustainability. It is desirable for the combination of these axes to reflect all available ways within the scope to improve data centre energy efficiency. Also, it is desirable that the axes do not have much inter-relationship or much inter-dependency. In order to select the appropriate combination of axes, there is a good principle called the "MECE" principle.

The "**MECE" principle**, pronounced "me see," mutually exclusive and collectively exhaustive, is a grouping principle for separating a set of items into subsets. In the holistic approach, when choosing a combination of KPIs, KPIs should be mutually exclusive and collectively exhaustive as much as possible.

Two KPIs are **mutually exclusive** if they do not share the same ways of improvement. **Mutually exclusive** principle eliminates overlapping of the aims of two KPIs and reducing inter-relationship or inter-dependency of KPIs.

A combination of KPIs is **jointly** or **collectively exhaustive** if all methods of improvement are taken into account by at least one of KPIs because they encompass the entire range of possible ways within the scope. **Collectively exhaustive** principle guarantees that the data centre considers all ways of improvement within the scope when selecting multiple KPIs, or these KPIs can provide holistic view.

5.1.2 Presentation of KPIs on axes

A spider web chart is constructed using a set of equally angular axes on a two-dimensional chart. Each axis represents one KPI. The data length of an axis is generally proportional to the magnitude of the KPI for the data point relative to the maximum magnitude of the KPI across all data points. A line is drawn connecting the data values for each axis. This gives a spider web chart. Since the spider web chart consists of multiple axes representing KPIs for data centre and originally measured values of each KPI are mapped into the designated axis, there exist guidelines for presenting KPIs on axes of the spider web chart.

The basic principle is that the larger value in an axis implies the higher efficiency. The following are a set of guidelines for presenting KPIs on axes.

— The values in each axis are originally measured values of the designated KPI for the axis.

— The values in each axis are presented as the farther value from the centre of the chart is considered as the more efficient.

— When the lower value of a KPI indicates the higher efficiency, the value in an axis of the KPI can be inverted.

— Depending on a KPI, the values of an axis can be normalized. The normalization can be performed by various ways depending on the characteristics of the KPI, for example, uniform values between 0 and 1, uniform values between *a* and *b*, nonlinear values, and so on.

— The range of the normalized values of the KPI can be determined by a data centre considering the characteristics of the data centre, such as region, type, and so on.

5.2 Example of a holistic approach

To better understand the way in which a holistic approach is meant to improve energy efficiency in data centres, it is useful to consider the metaphor of automobile fuel efficiency. We can consider a "scope" of automobile fuel efficiency as a whole society. Then, the improved fuel efficiency has not come about solely through the efforts of car manufacturers. Rather, progress has been made by involving automobile manufacturers, component manufacturers, materials manufacturers, fleet operators and the drivers themselves; thus the combined efforts of these stakeholders. The holistic approach of automobile fuel efficiency will consist of KPIs or axes for each stakeholder's effort toward automobile fuel efficiency.

Car manufacturers develop fuel-efficient engines and bodies, while component and materials manufacturers set out to design and develop new materials with the goal of reducing weight. In addition, engine control technologies and systems are developed in order to realize high levels of fuel efficiency. A KPI for a car manufacturer might be a fuel efficiency of an automobile through its design or through its benchmark performance. Fleet operators strive to load their vehicles in the most efficient ways, and formulate and implement energy-saving operating plans that take routes and travel time frames into consideration, while drivers are conscious of the need for energy conservation and adopt a style of eco-driving. A KPI for a fleet operator might be a distance of a route or a travel time of all fleet aggregated. These combined efforts — from the development and manufacture of automobiles through to how they are actually used — bring about considerable reductions in energy consumption and CO_2 emissions as a whole.

Moreover, within the scope of an automobile manufacturer, there are two main approaches to improving the fuel efficiency of the automobile itself. One involves improving the design of the body, while the other focuses on improving the engine. So, the automobile manufacturer may divide its KPI into two KPIs, a KPI for body efficiency and a KPI for engine fuel efficiency. By improving the design of the body, we can realize lighter components and parts and improved body aerodynamics. In a data centre, body improvement might be equivalent to improving the energy efficiency of air conditioning and power supply facilities that are associated with a building. There are limits to the degree of improvement in fuel efficiency that can be gained just by improving a vehicle's body. In the case of automobiles, more improvements in fuel efficiency can be achieved by improving the engine, which is central to enabling cars to perform their primary function of traveling on the road. In a data centre, a car's engine is equivalent to the servers that perform data processing. In other words, it is vital to deploy a high percentage of energy-efficient servers.

Then, we can expand the scope to include drivers and fleet management. After deploying energy-efficient automobile, drivers try to adopt a style of eco-driving by not taking off rapidly, accelerating suddenly, or braking sharply. A fleet operator may have a KPI for eco-driving performance for each driver or for all drivers. In the same way, it is important for users of IT equipment to adopt the optimum way of using the equipment so that even higher levels of energy efficiency can be attained.

As such, a holistic approach for automobile fuel efficiency of a society may have four axes; for an automobile manufacture, one axis for engine and one axis for body, for a fleet operator, one axis for a delivery planning and one axis for drivers' eco-driving performance. For a data centre, if we consider IT equipment manufacturers, IT users, building facility manufacturers, and power suppliers as a holistic scope, then all play their respective roles in improving energy-efficient, low-carbon performance for data centre operations, significant CO_2 reductions can be attained holistically. For example, if users increase their utilization efficiency by 20 %, equipment manufacturers improve their energy efficiency by 20 %, building facility manufacturers improve their energy efficiency by 20 %, and power utilities increase the ratio of low-carbon power by 20 %, we could theoretically achieve an improvement of $0{,}8 \times 0{,}8 \times 0{,}8 \times 0{,}8 \fallingdotseq 0{,}4$, or about 60 % reduction of CO_2.

5.3 Example of holistic approach of data centre by use of a spider web chart

When we consider the consumption of energy in a data centre and look at the flow of energy holistically, we find that there are three main stages, as shown in Figure 2. For example, we can think these three stages as a scope of data centre energy efficiency.

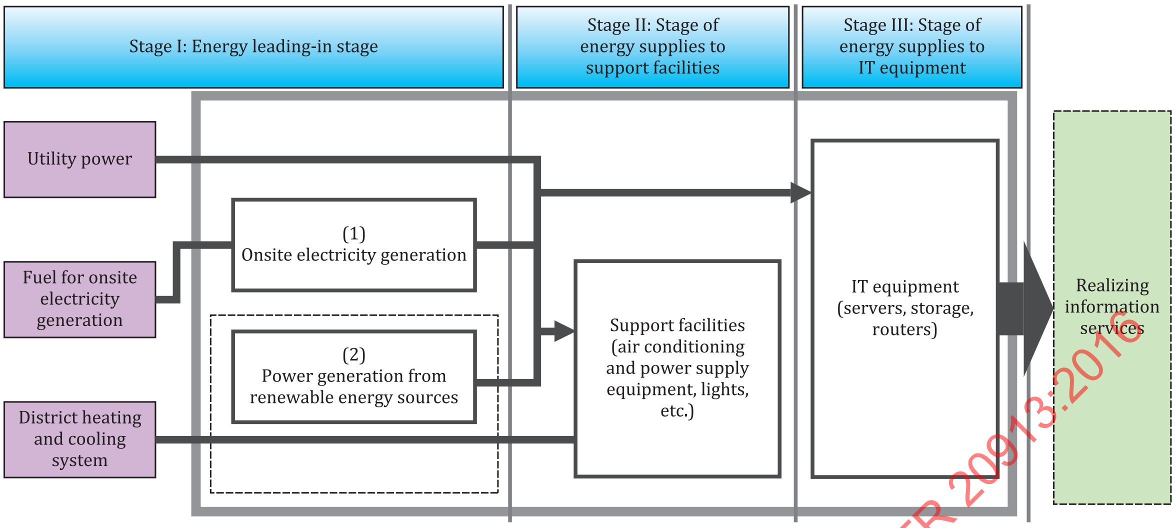


Figure 2 — Flow of energy in a data centre

First, at the "energy leading-in" stage (Stage 1), electricity is usually taken from a commercial supply that is provided by an electric utility at a high voltage. In addition, diesel or gas might be consumed to generate electricity on-site. When a district heating and cooling facility is available nearby, chilled water for cooling is supplied to the building. A district heating and cooling company often has cogeneration equipment that simultaneously generates heat and electricity, offering high energy conversion efficiency. For a data centre, having such a facility as a source of energy that is separate and distinct from the electric power utility offers the advantage of reducing energy risks and improve its sustainability. To reduce CO_2 emissions to mitigate climate change, data centres can also introduce sources of renewable energy such as solar and wind power.

The energy that the data centre draws then moves to the stage of "energy supplies to support facilities" (Stage 2). These support facilities consist mostly of the air conditioning equipment that is used to expel the heat generated by servers, and they are responsible for around half of all the energy that is consumed by a data centre.

Finally, at the stage of "energy supplies to IT equipment" (Stage 3), electricity is provided to IT equipment, whereby servers, storage, routers, and so on operate to provide information services to users.

Because energy flows as described above, the improvement of energy efficiency and reduction of CO_2 emissions of the entire data centre can be separated to the following three categories, which are aiming for improvement at each stage, respectively.

Category 1) Switching energy sources used in the data centre to energy sources that produce electricity with less or no CO_2 emissions.

Category 2) Improving the energy efficiency of support facilities needed by data centre operations such as air conditioning and power supply equipment.

Category 3) Improving the energy efficiency of the IT equipment used in the data centre.

To help understand and improve energy efficiency and CO_2 emissions of a data centre, it is useful to view all these categories in a single chart. A spider web chart such as Figure 3 is a way to view the various metrics in a holistic framework. In the spider web chart, KPIs for Category 1, Category 2, and Category 3 are distributed to its axes to evaluate energy efficiency of a data centre holistically.

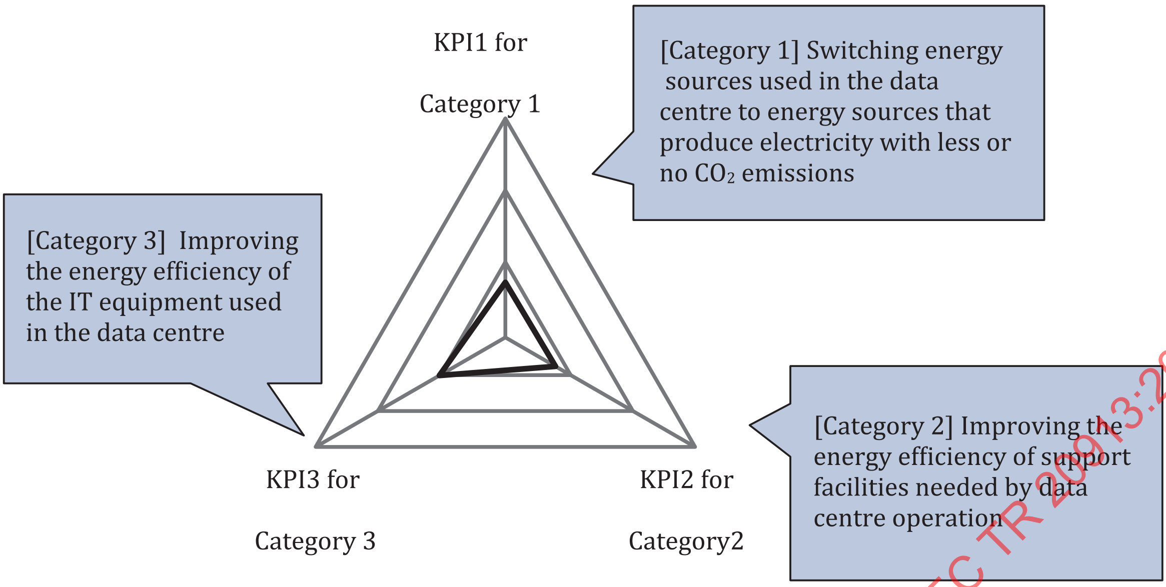


Figure 3 — Example of "Holistic approach with three KPIs"

As a holistic approach, each category should have at least one, or more where applicable, metric in the spider web chart. The number of axes may vary depending on the selection of metrics chosen by the data centre operator. Figures 3 and 4 show variations of the spider chart with three and four axes, respectively. In Figure 3, one KPI is adopted to each category.

For Category 3, we can divide the stage into two parts, keeping MECE principle in mind:

Category 3-1) Replacing servers with high processing capacity per unit energy.

Category 3-2) Improving server operation by reducing the number of server units by employing virtualization technology or cutting server power consumption in idle mode by using energy management software.

In Figure 4, two metrics are adopted to Category 3. Based on the abovementioned concept, there can be four KPIs chosen to improve data centre energy efficiency:

KPI for category 1: Measure how data centres produce their own carbon-neutral electric power such as solar- and wind-powered generation to reduce CO_2 emissions.

KPI for category 2: Measure how data centres provide highly energy-efficient facilities, thereby reducing the amount of power being drawn for cooling and power supplies.

KPI for category 3-1: Measure how data centres introduce highly energy-efficient equipment.

KPI for category 3-2: Measure how data centres operate such equipment in the most energy-efficient way.

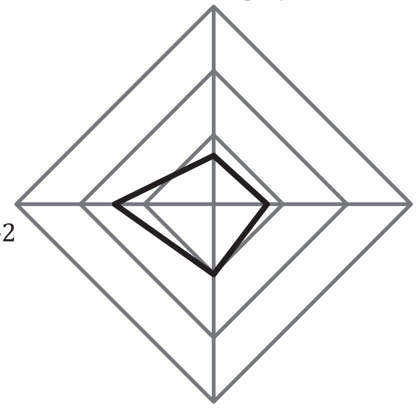


Figure 4 — Example of "Holistic approach with four KPIs"

Figure 5 shows an example of a spider web chart displaying the measured values of four KPIs from a data centre. The values on each axis imply the originally measured value of each KPI and the farther value from the centre of the chart is considered more efficient. The scale of each axis is determined by considering the characteristics of each KPI.

— ITEUsv: The possible minimum and maximum value are 0 and 1.

— PUE: 1 is the best value and the theoretical worst value is infinite. The range for PUE is chosen between 1,00 and 5,00 because most data centres have PUE value less than 3,00. Or an energy-efficient data centre may choose the range between 1,00 and 2,00. Also, since the smaller PUE value means the better, PUE value 1,00 is set on the farthest point from the centre of the chart.

— REF: Renewable energy usage in a data centre is much smaller than the total energy usage of the data centre in general. Therefore, the scale of REF is chosen by considering the REF measurement results of the example data centre.

— ITEEsv: ITEEsv is the ratio of server performance and power consumption, so its values can theoretically range from 0 to infinite. In this example, the range is determined by considering the ITEEsv measurement results of the example data centre.

The measurement values of the KPIs marked as blue points are connected to build a solid line polygon, which indicates a single measurement result for the four KPIs. The second measurement results of the KPIs are marked as yellow points and connected to construct a yellow dashed line polygon. It is noted that the central area of the chart does not have any meaning in this document. Also, the relationships among KPIs are not considered in this example. Investigating the inter-relationships among KPIs is not within the scope of this document.

Figure 5 can be interpreted as the data centre has some potential to improve the resource efficiency by replacing old IT equipment. In the figure, the dotted line implies design values for each KPI.

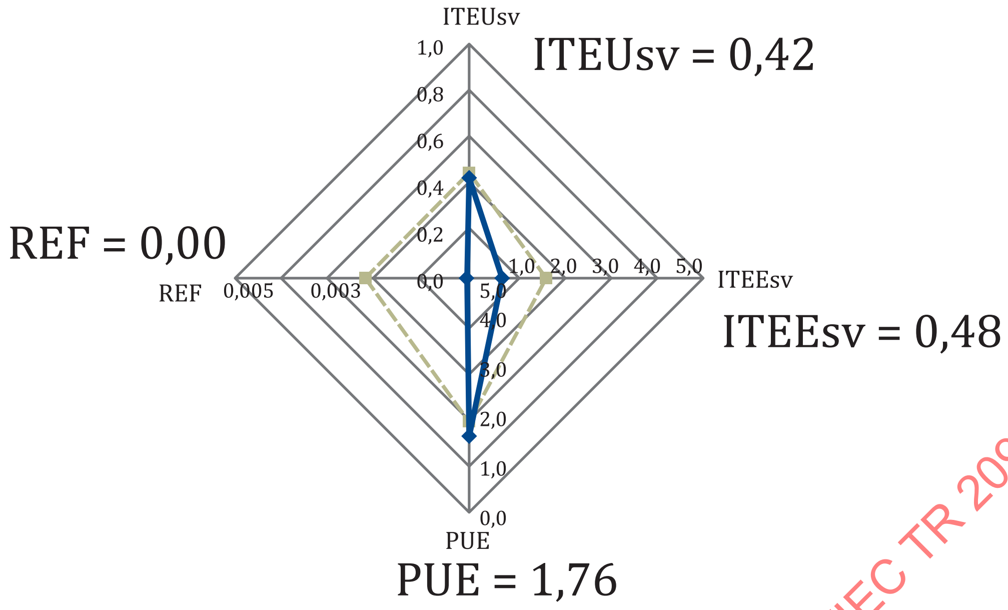
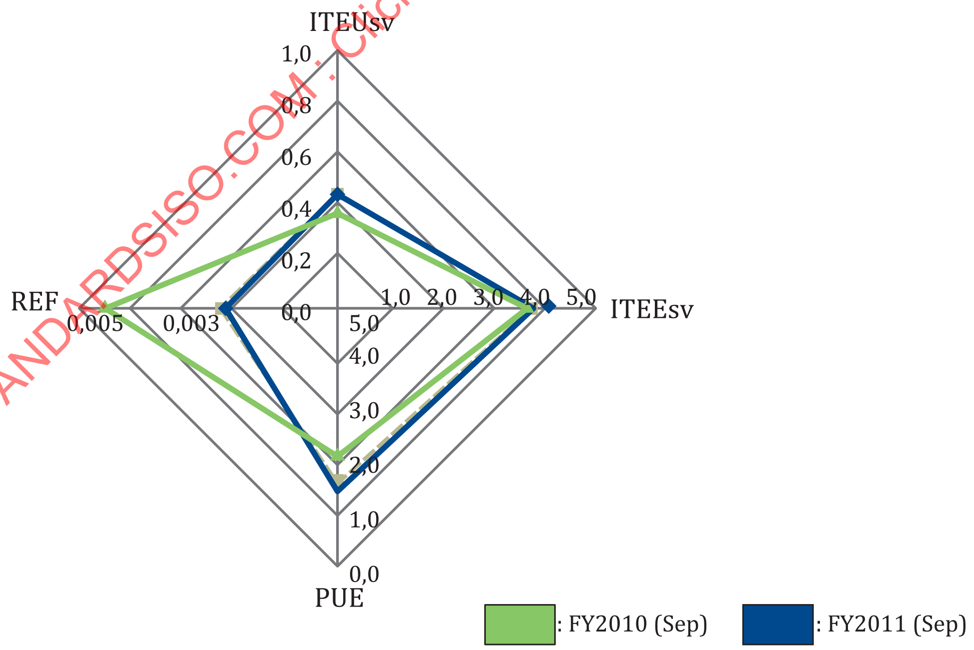


Figure 5 — Example of a spider web chart display using four KPIs

Figure 6 shows the applicability of a spider web chart to temporal change observation of four KPIs in a data centre. By observing this figure, a data centre manager can confirm how his actions between year 2010 and year 2011 to improve data centre energy efficiency worked to and influenced each KPI. His action to introduce consolidation of servers resulted in an improvement of server utilization and increased ITEUsv from 0,36 to 0,43. He did not change almost any server equipment, so ITEEsv was unchanged at 3,72. He can confirm that his action for cooling structure improvement resulted in the PUE improvement from 2,12 to 1,60. However, due to the weather condition, solar panel did not generate more energy, REF decreased from 0,004 9 to 0,002 2. Thus, he could confirm the effects of his action on each KPI. Then, he can make a plan for his next action to improve data centre energy efficiency and estimate changes in each KPI value.



NOTE PUE cannot be less than 1,0.

Figure 6 — Example of a spider web chart for temporal change of four KPIs

The spider chart approach offers several benefits by providing a combined visualization of all metrics. One benefit is that the spider chart lets an operator visualize the effects of an efficiency improvement on all metrics. The goal is to move all metrics in the same direction toward increased efficiencies. Therefore, it would be important after investing in changes at a data centre to review the spider chart and confirm that all metrics have improved. Finally, the spider chart can be used not only to plot current measured performance, but also to plot target performance, so that progress towards a target can be tracked for all metrics at once.

6 Control chart method extending a basic spider web chart to observe the operational status

This clause describes the control chart method, which extends the conventional basic spider web chart method in order to monitor and observe the operational status of a single or multiple KPIs.

6.1 Motivation for control chart method for energy efficiency monitoring

To monitor the energy management efficiency of a data centre, a method of monitoring energy management efficiency using a control chart, such as a spider web chart, is generally used. As we investigated in Clause 5, a spider web chart is designed to indicate multiple KPIs on a single chart. A spider web chart is used to monitor the state and/or efficiency of equipment in various sites, such as a data centre, a power plant, and a building. In particular, in a data centre, target values for the energy management efficiency measurement indicators of the data centre are indicated on a spider web chart in the form of upper and lower limits, and energy management efficiency is monitored based on locations at which values currently measured for the measurement indicators are indicated on the chart. A conventional system for monitoring the energy management efficiency of a data centre based on a spider web chart provides the function of visualizing the results of a current measurement using a graph. However, there is an increasing demand for extending the spider web chart-based energy efficiency monitoring method in order to provide the data centre operators with immediate awareness of current energy efficiency status. The extension can provide the energy efficiency operational status in the form of quantitative numeral values and help to monitor the temporal trend of the energy management efficiency of a data centre.

6.2 Control chart approach for energy efficiency monitoring

Figure 7 illustrates an example of a control chart-based energy efficiency monitoring system in a data centre using a spider web chart with five KPIs. The energy efficiency monitoring system in the figure shows the measurement results of the operational status of each KPI and the measurement results can be compared with lower bound and upper bound of target efficiency of each KPI. In the figure, KPI1 to KPI5 are measurement indicators that are used to measure and evaluate operational status of energy efficiency in a data centre. The methodology described in the figure is based on the spider web chart and extends the chart by introducing upper and lower bound of the status of KPIs so as to help data centre administrators to manage a data centre's operational status using a control chart. The values of each indicator show the operational achievement of each KPI from 0 to 1. Graph with blue line illustrates upper limit target values for the operational efficiency of each KPI, graph with green line indicates the current measured operational efficiency, and graph with red line illustrates the lower limit target values of the operational efficiency of each KPI.

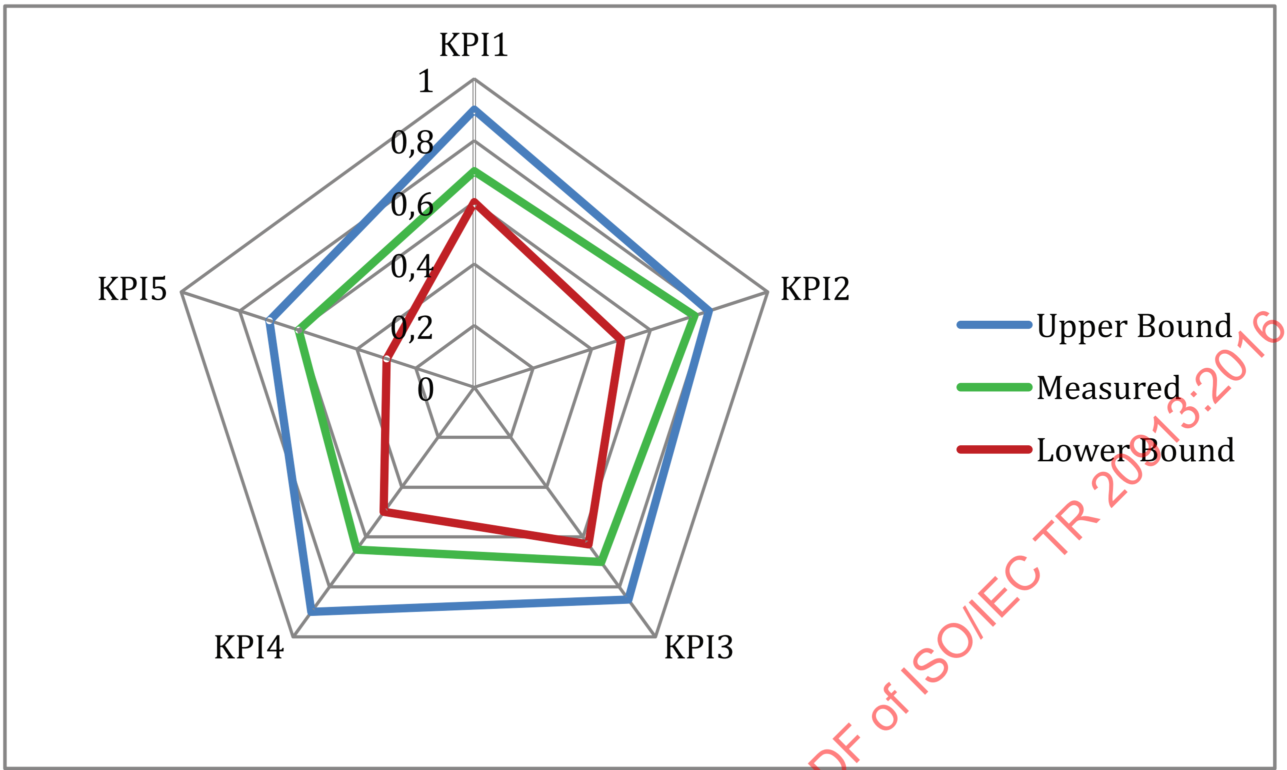


Figure 7 — Example of a control chart-based energy efficiency monitoring system with five KPIs

Figure 8 shows a problem of the conventional control chart-based operational efficiency monitoring method for a data centre. In the figure, the portions marked by purple lines indicate that currently measured operational achievement of energy efficiency values deviate from the upper and lower limit target values in terms of management targets. In other words, the outlier and inlier marked by purple line in the figure indicate that the current operational achievement of a corresponding KPI exceeds the upper of lower target values. In this case, the administrator of the data centre takes necessary measures to enable the values of the corresponding operational achievement to fall within the management target values. However, it is difficult to perform effective monitoring and control using the conventional control chart method because the corresponding portions do not provide quantitative numerical values. The integrated value of outliers and inliers may quantify the amount of uncontrolled operation. Therefore, minimizing the integrated value is desirable for effective operation of a data centre.

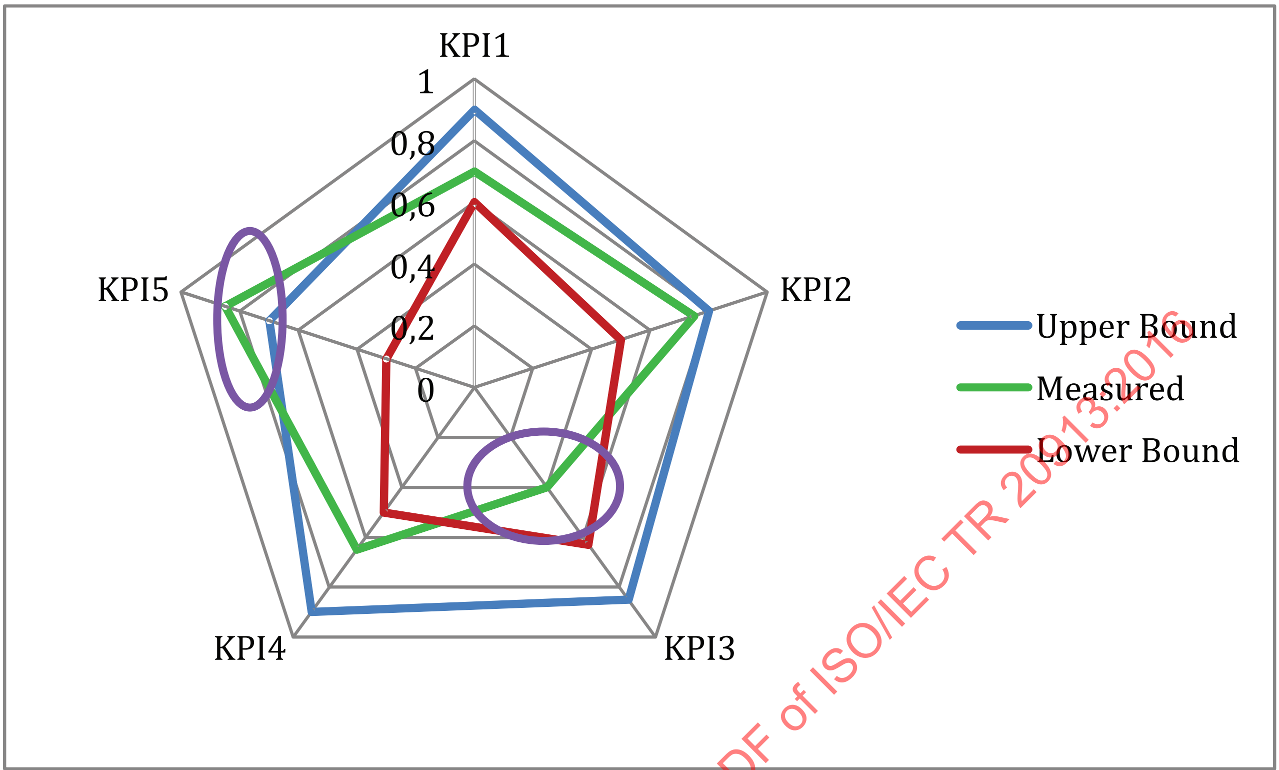


Figure 8 — Problem of the conventional control chart-based operational efficiency monitoring method

There exist two cases for the control chart-based operational achievement monitoring.

Case 1) Current measurement chart, i.e. green chart, is within the control range of KPIs

The ratio of the area of current measurement chart to the area of upper bound chart can be measured. The ratio indicates the overall operational achievement with respect to the target. The area of outlier and inlier are zero.

Case 2) Current measurement chart has outlier and inlier of control chart

The ratio of the area of current measurement chart to the area of upper bound chart can be measured. The area of outlier and inlier quantifies the amount of uncontrolled KPI operation. In this case, it is desirable to minimize outlier and inlier.

For example, if it is assumed that the operational achievement for energy efficiency of a data centre is monitored using five KPIs, the degree of non-achievement of management efficiency may be defined by Formula (1):

$$\mathrm{AV}_{\mathrm{ef}}^{5} = \frac{\sum_{i=1}^{5}\left(\mathrm{MAX}\left(\left|x_i - \mathrm{UB}_i\right|,\left|x_i - \mathrm{LB}_i\right|\right)\right)^2}{5} \qquad (1)$$

In Formula (1), $\mathrm{AV}_{\mathrm{ef}}$ is the average rate of non-achievement of the energy management efficiency of a data centre, x_i is the operational achievement for the i_{th} KPI measurement value ($0 \le x_i \le 1$), LB_i is a lower bound for the operational achievement of i_{th} KPI ($0 \le \mathrm{LB}_i \le 1$), and UB_i is an upper bound for the i_{th} KPI ($0 \le \mathrm{UB}_i \le 1$). When the measured values listed in Table 1 and Figure 6 are applied to Formula (1), the average rate of non-achievement of the operational achievement of the data centre may be calculated as 6,75 %.

