The statistical principles to set and improve the Performance Indicators and Indexes in the Nuclear Industry

Volodymyr Turbayevsky
World Association of Nuclear Operators,
London Office

Abstract

This article is the first one in a series to improve the WANO Performance Indicators (PI) and Index system. This article describes the main principle of how to collect and calculate Performance Indicators, Indexes and their source data, also it proposes some upgrades in the Index approach. The aim of the PI improvement project is to create a strong statistical base to give all members understanding of how to assess the nuclear industry current status and perspectives.

The author understands that the realisation of the whole PI improvement project (including overall PI redefining) may take a lot of resources, but it seems very necessary to provide overall nuclear industry progress.

It is clear that any PI changes lead to Index updating (a few PIs have been updated since January 2016), but understanding of the main Indexes principle, which are described in this article, allows us to save time during the PI improvement project.

Also it is clear that few PIs should be retained in order to compare WANO results with the International Atomic Energy Agency (IAEA), Institute of Nuclear Power Operations (INPO), VNIIAES (All-Russian Research Institute for NPP Operation) and other organisations.

During realisation the PI improvement project may also be extended from new units to support the New Unit Assistant (NUA) project and to units out of commercial operation.

Also it seems useful to connect the Operational Experience (OE), Core DB and Peer Review (PR) databases into one structure so as to provide in-depth units and industry analysis. Another ambitious plan is to use the Artificial Intelligence (AI) for comprehensive performance analysis.

Introduction

A performance indicator or key performance indicator (KPI) is a type of performance measurement [1]. KPIs evaluate the success of an organization or of a particular activity in which it engages. Often success is simply the repeated, periodic achievement of some levels of operational goal (e.g. zero defects, 10/10 customer satisfaction, etc.), and sometimes success is defined in terms of making progress toward strategic goals. Accordingly, choosing the right KPIs relies upon a good understanding of what is important to the organization. 'What is important' often depends on the department measuring the performance - e.g. the KPIs useful to finance will really differ from the KPIs assigned to sales. Since there is a need to understand well what is important, various techniques to assess the present state of the business, and its key activities, are associated with the selection of performance indicators. These assessments often lead to the identification of potential improvements, so performance indicators are routinely associated with 'performance improvement' initiatives. A very common way to choose KPIs is to apply a management framework such as the balanced scorecard.

Key performance indicators (KPIs) are ways to periodically assess the performances of organizations, business units, and their division, departments and employees. Accordingly, KPIs are most commonly

defined in a way that is understandable, meaningful, and measurable. They are rarely defined in such a way such that their fulfillment would be hampered by factors seen as non-controllable by the organizations or individuals responsible. Such KPIs are usually ignored by organizations.
KPIs should follow the SMART criteria. This means the measure has a Specific purpose for the business, it is Measurable to really get a value of the KPI, the defined norms have to be Achievable, the improvement of a KPI has to be Relevant to the success of the organization, and finally it must be Time phased, which means the value or outcomes are shown for a predefined and relevant period.
In practice, overseeing key performance indicators can prove expensive or difficult for organizations. Some indicators may be impossible to quantify. As such dubious KPIs can be adopted that can be used as a rough guide rather than a precise benchmark.
Key performance indicators can also lead to perverse incentives and unintended consequences as a result of employees working to the specific measurements at the expense of the actual quality or value of their work. For example, measuring the productivity of a software development team in terms of source lines of code encourages copy and paste code and over-engineered design, leading to bloated code bases that are particularly difficult to maintain, understand and modify.

WANO Performance Indicators

The WANO performance indicators have been adopted to provide a quantitative indication of plant performance in the areas of nuclear plant safety and reliability and personnel safety [2]. These indicators are intended principally for use by nuclear operating organisations *to monitor performance and progress, to set challenging goals for improvement, to gain additional perspective on performance relative to that of other plants, and to provide an indication of the possible need to adjust priorities and resources to achieve improved overall performance*. WANO performance indicators are intended to support the exchange of operating experience information and to allow consistent comparisons of nuclear plant performance. It is expected that WANO performance indicators will encourage emulation of the best industry performance and motivate the identification and exchange of good practices in nuclear plant operation.
WANO performance indicators are established on one or more of the following criteria:

a) The indicator provides a quantitative indication of nuclear safety, plant reliability and personnel safety.

b) The programme is limited to a few indicators that monitor fundamental results rather than the performance of intermediate processes or individual programme elements.

c) The indicator has wide applicability.

d) The indicator provides a meaningful perspective without a detailed knowledge of plant programmes and practices.

e) The indicator is objective and fair.

f) The indicator is amenable to goal setting.

g) Data is available and reliable.

h) Emphasis on improving the indicator value is unlikely to cause undesirable plant actions.

i) Indicators that primarily monitor plant reliability should reflect performance only in areas that can be controlled or influenced by plant management.

j) Indicators of nuclear plant or personnel safety should reflect overall plant performance including, in some cases, elements beyond plant management control.

Basic statistical reporting principle

Based on [3], performance measurement and targets demonstrates that:

- the practice of using WANO statistics to report performance measures and achievement against targets is carried out with mixed success;
- statistical producers have a crucial role to play in putting measures (of current performance) and targets (for intended performance) into context; and
- publishing information about measures and targets as WANO statistics provides assurance that performance levels are being measured and decisions made using statistics that are produced to high professional standards.

It underlines the importance of:

- senior WANOs responsible for policy making working with senior statisticians to embed statistical thinking in the development of performance measures and targets;
- bringing statistical thinking to bear when performance management systems are developed, and performance measures and targets are evaluated;
- performance measures and targets being recognised explicitly in WANO statistics that report the underlying data;
- those engaged in policy making and statistical production recognising the twin, mutually beneficial roles of the statistician as expert advisors in the policy making process and as independent producers of statistics that are compliant with the Code of Practice for Official Statistics; and
- senior departmental WANOs providing active support to enable statisticians to fulfil these dual roles effectively.

Statistical producers should publish a range of contextual information including details of:

- the performance measure or target design; policy or operational rationale; definitions and changes;
- statistical methods; and
- quality including data quality assurance; the possible distortive effects of the performance measure or target on the data that underpin WANO statistics; any underlying seasonality; and other limitations arising from the use of the particular data source.

Statistical producers should provide narrative commentary supplemented by appropriate analysis that clearly explains what the statistics show in terms of progress in relation to the performance measure or target and the effects of that measure or target on behaviour, and also what the statistics show more generally.

The accountability for policy and service delivery necessitates the measurement of performance, often in the context of (implicit or explicit) statements about intended performance levels or policy goals which we are referring to as performance measures and targets. The statistics, produced using data from PI systems and other sources, are frequently used to report levels of performance and achievement against targets. While performance measures and targets are intended to stimulate changes in behaviours or activities or at least to indicate performance levels their existence can also lead to distortive effects which could influence the recording and reporting of data.

In reports we uses the terms performance measurement, measures and target. We have adopted the convention that performance measurement refers to ascertaining current or past levels of performance achieved,

and that a target relates to a particular level of performance that should be aimed for, met or exceeded over a period of time. Importantly, the recommendations apply equally to performance measures or targets regardless of the terminology used - that are drawn from the same underlying data as WANO statistics.
The complexity of measures and targets

- some measures and targets have a relatively simple, unambiguous definition;
- others involve a large number of separately defined concepts;
- in some cases, important details what is recorded and how it is recorded, or the actual definition are open to interpretation;
- a group of measures or targets are sometimes combined into a single overarching measure - index, the overall meaning of which may be difficult to interpret;

Professional statistical advice is equally valuable when those engaged in policy making wish to develop a new measure or target, or to change an existing one. Statisticians are best placed to advise about:

- data sources such as:
  - which data source is of suitable quality for use in measuring performance
  - the best way to collect data where no suitable source is identified
- design of measures and targets, including:
  - definitions and wording (in order to identify and ideally avoid misinterpretation and distortive effects)
  - the use of composite measures or collections of targets
- the appropriateness of a target to stimulate the required outcome

In order to realise the value of statistical thinking, those engaged in policy making need to create an environment in which statistical thinking is not regarded as optional, but as a vital component.
Statisticians always need to understand the quality of the source data used to measure performance, and this understanding needs to be particularly strong when targets have been set. Where data are collected through statistical surveys, statisticians typically understand the risks to data quality and explain them routinely. The risks to quality arising from the statistical use of administrative data tend to be less well understood and explained.
The simple existence of a performance measurement regime or target presents risks to data quality, regardless of whether the associated performance measurement system draws on administrative data or statistical surveys. One risk that statistical producers need to address relates to the definition of the measure or target.
/emphIf a measure or target is poorly designed ambiguous, or involving multiple concepts or definitions data recording is unlikely to be consistent or accurate, and the resulting statistics will be devalued. This does not necessarily involve deliberate misreporting, as was previously described.
The incentive to achieve a target or the consequences of not doing so may lead to deliberate misreporting or misrecording, or to other distortive effects. Even without a target being set, the very fact of performance measurement may also distort behaviour.
Where a performance measure or target draws on administrative data, statisticians should:

- implement the standard for quality assuring administrative data as set out in the Policy; and
- communicate the standards expected to the service providers who typically supply the data, and how providers are meeting those standards to users of the statistics.

Regardless of the type of data source, statisticians should consider the possible distortive effects of any measures or targets including taking advice from practitioners and where possible take action to address these effects in their design or redesign.
Statistical producers should publish a range of contextual information including details of:

- the performance measure or target design; policy or operational rationale; definitions and changes;
- statistical methods; and
- quality including data quality assurance; the possible distortive effects of the performance measure or target on the data that underpin WANO statistics; any underlying limitations arising from the use of the particular data source.

Statistical producers should provide narrative commentary supplemented by appropriate analysis that:

- clearly explains what the statistics show in terms of progress in relation to the performance measure or target and the effects of that measure or target on behaviour, and also what the statistics show more generally;
- conveys the uncertainty in the statistics, regardless of whether the data are drawn; and
- explains the implications of the contextual information about the performance measure or target, and about methods and quality for the use of the statistics.

Statistical producers should seek out opportunities to engage with external experts to understand better some of the more complex statistical aspects of developing and presenting measures and targets and with other producers to share good practice.
Reporting levels of performance and progress against targets using WANO statistics presents strategic opportunities for statisticians to enhance the value of the statistics by increasing the role of the statistics to support expert scrutiny and accountability; by stimulating informed debate about a policy; and by encouraging better informed choices by the service providers.

WANO Performance Indicator Targets

In 2007, the WANO Governing Board approved the 2008-2010 WANO Long-term Plan, which included an action to develop worldwide reference values for key performance indicators. By promoting continued comparison and emulation of performance, these targets will support the WANO Mission and, at the same time, encourage continuous improvement in industry performance. The proposed values were subsequently approved by the WANO Governing Board in July 2010.
The meaning of a target is not a hard target which must be pursued with high priority and to which hard commitment is required, but more a target which allows for the individual plants to determine a gap and to define actions to close the gap. The reference will be helpful to identify plants in need of assistance and trend analyses per centre and worldwide to give direction to coordinated programs to support the pursuit of excellence.
In developing the targets, the WANO regional directors considered all 11 of the WANO performance indicators and selected four indicators for monitoring: operating period forced loss rate (FLR), collective radiation exposure (CRE), industrial safety accident rate (ISA), and safety system performance (SSPI).
The WANO staff reviewed the three-year industry results through 2006 and 2007 and used this data to propose targets. The WANO regional centre directors reviewed the proposed values and agreed they represent challenging but achievable performance targets. For each performance indicator selected, two values were proposed and eventually adopted. These are industry-level targets and individual unit or station targets.

For most performance indicators, the industry values were developed based on 2007 industry results. The industry-level targets are based on 75% of the industry achieving the 2007 industry median values. This would mean that overall industry performance has improved, with an additional one-fourth of the industry units or stations achieving performance indicators results better than the 2007 industry median. The individual unit or station performance targets are based on all units and stations achieving results that are better than the 2007 lowest quartile values.
The safety system performance targets are based on a continuing reduction of the industry average safety system unavailability to below 2007 industry average values. The unit/station safety system targets are based on first keeping the unavailability below a threshold value (0.020 or 0.025 depending on the system) and also either maintaining or decreasing the individual unit/station safety system unavailability.
The targets are provided in the table below. Graphical depictions of the relationship between the values and 2007 industry results are included to help explain the basis for the targets.
Web-based reports display performance relative to the targets. These reports will allow users (members and staff) to monitor performance relative to targets. Ongoing assessment of performance in comparison with the targets will continue.

WANO Performance Indicator Targets 2020

The 2020 long-term targets for the WANO Performance Indicators will now begin to be implemented, following the comparisons of the 2015 year-end performance against the 2015 targets.
The targets have been updated to reflect the fact that WANO members and the industry as a whole have met the challenging goals previously set by the organisation. Therefore, new goals for some indicators have had to be established. These were discussed within the PI programme teams across WANO, and then presented to and approved by the Executive Leadership Team (ELT) in its meeting in December 2014.
The most of the targets LTT-2020 are the same as those set out in LTT-2015, except for the following changes:

- Collective Radiation Exposure targets for AGRs have been changed due to the change in plant conditions since 2000;
- Personnel safety performance will be monitored against targets for a new Total Industry Safety Accident (TISA) indicator, which replaces the ISA indicator used for the 2015 targets;
- The safety system performance indicator industry target is now based on the percentage of units achieving all the individual SSPI targets (100 percent);
- Individual and industry targets have been added for the total unplanned scram rate per 7,000 hours critical indicator (US7). The US7 2020 industry target is based on the third quartile of the world-wide industry by reactor type.

The LTT-2020 below should be met by the end of 2020, i.e., the unit and industry indicator values should be less than or equal to the values defined below for each indicator.

Indicator	Unit	Individual target	Industry target
Operating Period Forced Loss Rate (FLR)	percent	5.0	2.0
Collective Radiation Exposure (CRE)	man-rem/man-Sievert	AGR: 10/0.10 BWR: 180/1.80 LWCGR: 320/3.20 PHWR: 200/2.00 PWR: 90/0.90	AGR: 5.0/0.05 BWR: 125/1.25 LWCGR: 240/2.40 PHWR: 115/1.15 PWR: 70/0.70
Total Industry Safety Accident rate (TISA)	number per 200,000 hours worked	0.50	0.20
Safety System Performance Indicator (SSPI)	unavailability	SP1 and SP2: 0.020 SP5 (EAC): 0.025	100 percent of worldwide units achieve the individual targets
Unplanned total Scrams per 7,000 hours critical (US7)	rate	BWR, PWR, LWCGR: 1.0 PHWR: 1.5 AGR: 2.0	BWR, PWR, LWCGR: 0.5 PHWR: 1.0 AGR: 1.0

Unfortunately, system modifications need to be carried out before we can produce reports on the new long term targets in the usual manner. Therefore, WANO London Office provides all LTT-related reports and calculations until these modifications have been completed.

Key Indicators Description

Forced Loss Rate (FLR)

The forced loss rate (FLR) is defined as the ratio of all unplanned forced energy losses during a given period of time to the reference energy generation minus energy generation losses corresponding to planned outages and any unplanned outage extensions of planned outages, during the same period, expressed as a percentage. Unplanned energy losses are either unplanned forced energy losses (unplanned energy generation losses not resulting from an outage extension) or unplanned outage extension of planned outage energy losses. Planned energy losses are those corresponding to outages or power reductions which were planned and scheduled at least 4 weeks in advance (see clarifying notes for exceptions).

Collective Radiation Exposure (CRE)

Collective radiation exposure, for purposes of this indicator, is the total external and internal whole body exposure determined by primary dosimeter (thermoluminescent dosimeter (TLD) or film badge), and internal exposure calculations. All measured exposure should be reported for station personnel, contractors, and those personnel visiting the site or station on official utility business. Visitors, for purposes of this indicator, include only those monitored visitors who are visiting the site or station on official utility business.

Total Industrial Safety Accident Rate (TISA)

This indicator is defined as the number of accidents for all plant personnel, including all staff, contractors, supplemental personnel, and all other non-utility personnel working onsite that result in one or more days away from work (excluding the day of the accident) or fatalities per 200,000 (TISA2) or per 1,000,000

(TISA1) man-hours worked. The selection of 200,000 man-hours worked or 1,000,000 man-hours worked for the indicator will be made by the country collecting the data, and international data will be displayed using both scales.

Safety System Performance (SSPI)

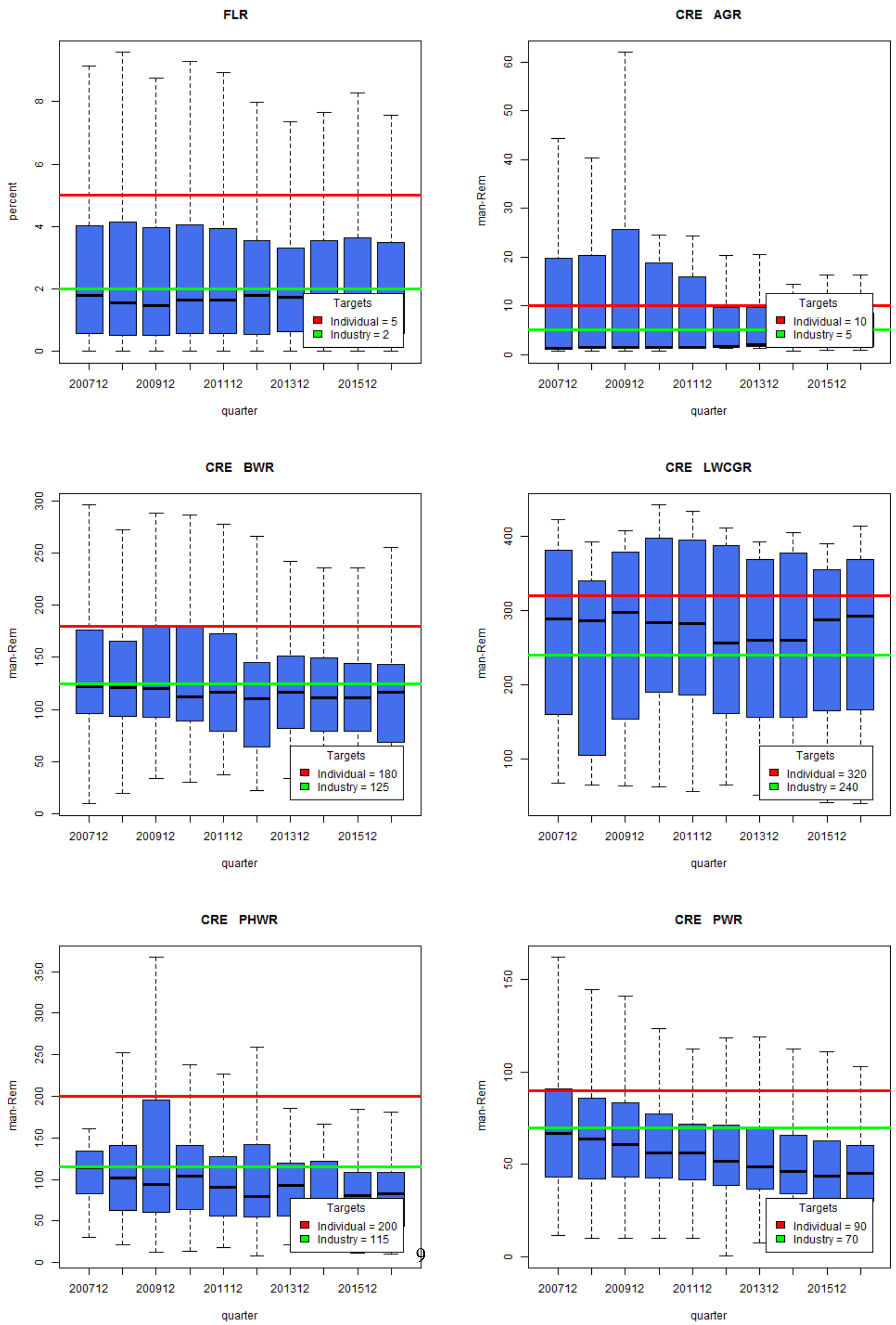
The purpose of the safety system performance indicator is to monitor the readiness of important safety systems to perform certain functions in response to off-normal events or accidents. This indicator also indirectly monitors the effectiveness of operation and maintenance practices in managing the unavailability of safety system components. The safety system performance indicator provides a simple indication of safety system unavailability that shows good correlation with results of system unavailability calculations using more precise system modelling techniques (e.g. fault trees). A low value of the safety system performance indicator indicates a greater margin of safety for preventing reactor core damage and less chance of extended plant shutdown due to failure of a safety system to function during an operational event. However, the objective should not be to attain a safety system performance indicator (unavailability) value that is near zero over a long term. Rather, the objective should be to attain a value that, while low, allows for maintenance activities to help maintain system reliability and availability consistent with safety analyses. The safety system performance indicator is defined for the many different types of nuclear reactors within the WANO membership. To facilitate better understanding of the indicator and applicable system scope for these different type reactors a separate section has been developed for each reactor type.

Unplanned Total Scrams Per 7,000 Hours Critical (US7)

The indicator is defined as the sum of the number of unplanned automatic scrams (reactor protection system logic actuations) and unplanned manual scrams that occur per 7,000 hours of critical operation. The value of 7,000 hours is representative of the critical hours of operation during a year for most plants. It provides an indicator value that typically approximates the actual number of scrams occurring during the year.

Long-Term Targets Updating

As it has been described in the 'Performance Indicator' section above and will be described in the 'Index Proposals' section below, the existing Long-Term Tergets have been set generally based on the median and worst quartile values for 2007. Some targets (CRE AGR) have been updated based on statistical analysis and WIO negotiations, some have been updated (TISA instead of ISA2 for LTT-2015), some have been added (US7).
There are some problems in using LTT-2020 *'to set challenging goals for improvement, to gain additional perspective on performance relative to that of other plants, and to provide an indication of the possible need to adjust priorities and resources to achieve improved overall performance'* as it is described in the PI Reference Manual [2].
The existing situation with LTT may be presented as the following charts.


FLR
percent
quarter
Targets
Individual = 5
Industry = 2
CRE AGR
man-Rem
Targets
Individual = 10
Industry = 5
CRE BWR
Targets
Individual = 180
Industry = 125
CRE LWCGR
Targets
Individual = 320
Industry = 240
CRE PHWR
Targets
Individual = 200
Industry = 115
CRE PWR
Targets
Individual = 90
Industry = 70
200712
200912
201112
201312
201512

There are clearly shown that some of the LTT should be singnificantly canged *'to set challenging goals for improvement...'*
Therefore the statistical analysis for the key performance indicator has been provided and the results of this analysis are described below.
The LTT updating process can be devided to the following stages:

- define the most appropriate data depth
- define the appropriate 'data rolling window'
- assess the existing LTT approach and upgrade it if needed
- define the updated LTT.

As for the most appropriate data depth, the previous LTT have been defined in the 2007 for 2015, the next one have been updated in the 2015 for 2020. It seems reasonable to use five years in depth analysis to upgrade the LTT.
As for data rolling window, all the LTT use three years data window. It means that all indicators are calculated using three year 'in the back' source data. It seems reasonable continue to use the same approach.
The existing approach for most of the LTT (excepting SSPI) means that units with values in the 'worst' quartile in the current year should move to the next better quartile in five years. Thus individual targets have been defined as the 'worst' quartile limit, and all units have to be better than individual targets. The industry targets have been defined as a median values in the current year; it means that in five years 3/4 unit values should be better than median ones in the current year. This approach looks appropriate enough to be used in the future.
So, using five years in-depth analysis for three-years rolling data, the following values may be suggested for implementation. The individual values have been defined as the 'worst' quartile value, and the industry target - as median values.

Indicator	**Unit**	**Individual target**	**Industry target**
Operating Period Forced Loss Rate (FLR)	percent	3.8	1.7
Collective Radiation Exposure (CRE)	man-rem/man-Sievert	AGR: 11/0.11 BWR: 160/1.60 LWCGR: 390/3.90 PHWR: 130/1.30 PWR: 75/0.75	AGR: 1.8/0.018 BWR: 120/1.20 LWCGR: 290/2.90 PHWR: 90/0.90 PWR: 55/0.55
Total Industry Safety Accident rate (TISA)	number per 200,000 hours worked	0.40	0.11
Safety System Performance Indicator (SSPI)	unavailability	SP1 and SP2: 0.004 SP5 (EAC): 0.012	100 percent of world-wide units achieve the individual targets
Unplanned total Scrams per 7,000 hours critical (US7)	rate	BWR, PWR, LWCGR: 1.0 PHWR: 1.8 AGR: 2.7	BWR, PWR, LWCGR: 0.45 PHWR: 0.6 AGR: 1.0

The comparison with the acting LTT the proposed one looks as follows

Indicator	Individual target changing	Industry target changing
Operating Period Forced Loss Rate (FLR)	slightly stronger	slightly stronger
Collective Radiation Exposure (CRE)	AGR: slightly easier BWR: almost the same LWCGR: significantly easier PHWR: stronger PWR: slightly stronger	AGR: stronger BWR: almost the same LWCGR: significantly easier PHWR: slightly stronger PWR: slightly stronger
Total Industry Safety Accident rate (TISA)	slightly stronger	stronger
Safety System Performance Indicator (SSPI)	SP1 and SP2: stronger SP5 (EAC): slightly stronger	the same
Unplanned total Scrams per 7,000 hours critical (US7)	BWR, PWR, LWCGR: the same PHWR: easier AGR: significantly easier	BWR, PWR, LWCGR: slightly stronger PHWR: slightly stronger AGR: the same

Indexes

Concept of a composite index

Some WANO members have found that using a single value reflecting unit and station performance, measured by WANO performance indicators, is of great value in trending and comparing performance[1] [2]. A single value calculated from multiple inputs is referred to as a composite index. In addition to providing a single value of overall performance, an index may also provide insight into specific areas of performance that can be improved from added attention or focus. To assist WANO and its members, a performance indicator composite index, often simply referred to as the index, has been calculated for units within WANO.

An index is calculated for an individual unit and can have a maximum value of 100 points (a higher value indicates better performance) and is a weighted average of specific WANO indicators.

One method that has been in use for several years and is viewed as being successful in helping the industry achieve performance improvement is identified as Method 4. In 2013, this method was been applied to all WANO members and is described herein. This method includes most WANO indicators; however, it does not include UCL or relatively new indicators.

Besides trending individual performance, the value can also be used to compare individual performance to statistical values of groups of units to give an indication of relative performance. For example the individual unit value is compared to the median value of all of a member's units. (Statistical values include the mean, median, and quartiles.)

The methodology provided below is the manner of implementation of an index currently applied worldwide. (This methodology is referred to as Method 4). The methodology is subject to management philosophy and judgment and may be changed as necessary.

[1] It seems useful to use OEE [4] approach for this purpose as well

Index calculation principle

The main principle to calculate the indicator index points are the following:

$$\text{local index} = (\text{Upper limit} \pm \text{Indicator value}) \times \text{indicator coefficient} \tag{1}$$

$$\text{indicator coefficient} = \frac{100}{\text{Upper limit} - \text{Lower limit}} \tag{2}$$

$$Index = \sum \text{local index} \times \text{indicator weighting factor} \tag{3}$$

The $\pm$ in formula 1 means the appropriate sign depends on the best value indicator directions.
Each performance indicator which is included in the table assigned points, ranging from 0 to 100, based on the value of the indicator relative to the zero and 100 point values listed in the associated table. The resulting points are then multiplied by an indicator weighting factor listed in the associated weight table to provide the contribution toward the overall unit index for that indicator (see equation 3). The unit index is the sum of the indicator point contributions for a unit.

The existing index issues

It is necessary to update the existing Method 4 because it does not reflect the updated WANO Long Term Target (LTT-2020) which has been implemented since 2016. The updated index should reflect all key Performance Indicators (KPI) described in the section on page 6. Also the index may include some additional indicators to reflect the units or plant status in a more appropriate way.
Figure 1 reflects the existing indexes distribution. It is quite far from normal distribution [5] therefore *it is a problem to define the problem areas for units based only on the unit index because there are many units with indexes more than 90%. Also it can lead to misinterpretation of results.*
It is obvious that units' indicators and indexes are covered by probability theory and have to reflect the normal parameter distribution.
To upgrade the index method we have to find *Upper* and *Lower* limits and *Weighting factors* for each indicator. If the indicator value is beyond the *Upper* and *Lower* limits the indicator index points is set to 100 or 0 respectively. The sum of the *Weighting factors* should be equal to one.
During initial discussions regarding WANO Long Term Targets and Indexes, WANO staff did not have enough statistical material to implement statistical methods to define and substantiate proposed limits and factors. The LTT programme was started in 2007 and currently we have enough base material to use statistical methods to improve and substantiate LTTs and indexes.

New index method definition

To define indexes limits it seems quite reasonable to set the Upper and Lower limits as the upper and lower limits of the first and third quartile of units' value distribution between the years 2007 and 2016 as it is shown in figure 2.
The same approach may be used in the future to define the Individual and Industrial Long Term Targets as described in the appropriate section on page 6.
The index process may include the following steps :

1. define the list of indicators (out of KPI) to be included in the index

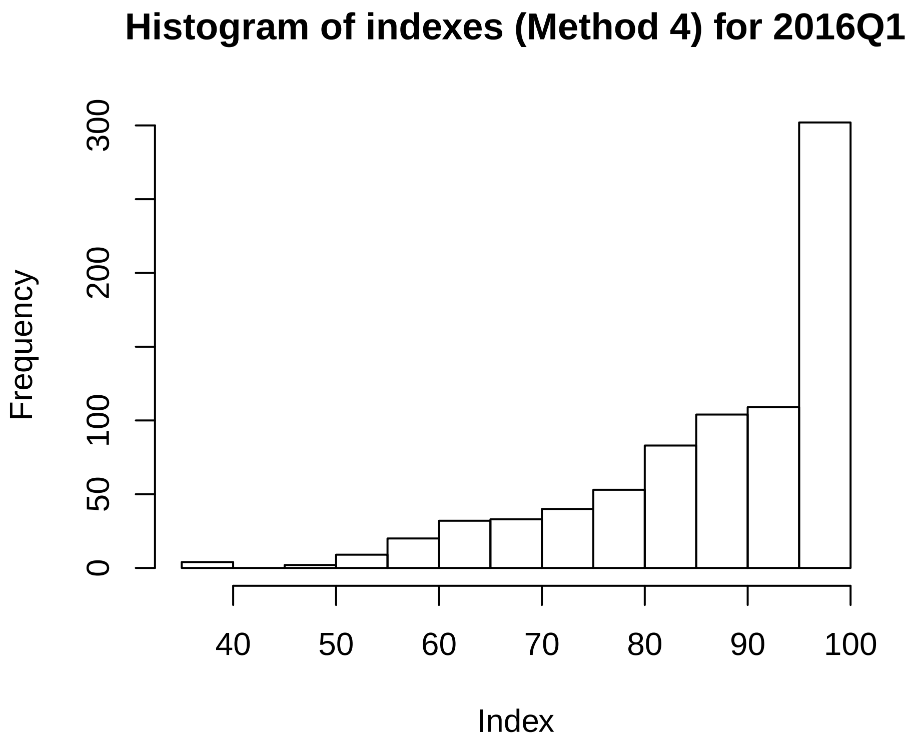


Figure 1: Histogram of indexes for 2016Q1

2. define the Upper and Lower limits based on IQR[2] as Q1 and Q3 limits for this list. To define these limits statistical analysis should be used. The indicator data 'window' (length of data collecting period) might be correlated with refueling cycle for most of the indicators (see Method-4 description on page **??**). However, taking into account that KPIs always use three year period in order to compare to the Long Term Targets, this time period should be used for calculation.

3. define the coefficient using equation 2

4. define the Weighting factor

The R calculation package [6] can be used for this purpose and to meet the PI programme aim as described on page 2.
The results of the steps described above on page 12 are the following:

1. *The list of the indicators.* Five KPI should be included in the index process. There are Forced Loss Rate (FLR), Collective Radiation Exposure (CRE), Total Industrial Safety Accident Rate (TISA), Unplanned Total Scrams Per 7,000 Hours Critical (US7) and Safety System Performance (SSPI, consists of three indicators). Please see page 7 for details. The Unit Capability Factor (UCF), as well as Unplanned Capability Loss Factor (UCLF), might be ignored due to the same number

[2]The interquartile range of an observation variable is the difference of its upper and lower quartiles. It is a measure of how far apart the middle portion of data spreads in value.

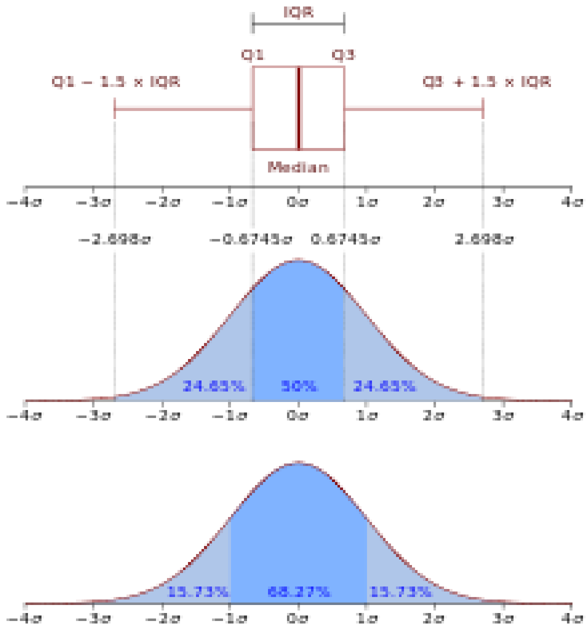


Figure 2: R-CRAN Quartile method

of source data used to calculate FLR. Grid-Related Loss Factor (GRLF) is defined as the ratio of energy losses due to grid instability or a loss of electrical grid due to causes *not under plant management control* during a given period of time. The reference energy generation during the same period will be ignored. Unplanned Automatic Scrams Per 7,000 Hours Critical (UA7) is a part of US7 indicator and will not be included in the list. Fuel Reliability (FRI) and Chemistry Performance (CPI) indicators are dependent on plant design and might be ignored. Also it looks necessary to have a good balance between the main KPI directions which are generation, nuclear and personnel safety, and reliability. Unit reliabilty may be reflected by Unit Capability Factor (UCF).*As a result only KPI and UCF will be included in the index list.*

2. The Upper and Lower limits are defined using *boxplot.stats* function of the R [6] package. The selection of this function is due to IQR coefficient = 1.5 as it is described in figure 2. This method allows us not only define the Q1 and Q3 limits but *define the outline values*. It is the *key point* - to define the statistically justified limits for each indicator. The values out of these limits - so called outliers - are the candidates for additional attention. It is important to note that CRE and US7 are dependent on reactor type, therefore the limits for these indicators should be defined for each reactor type or their group.

   Based on statistical approach described above, the results of the calculation (from 2007Q4 till 2015Q4) are as follows:

Indicator	Lower limit (Lower quartile)	Upper limit (Upper quartile)	Coefficient
CRE AGR	1.32	10.3	10.4
CRE BWR	84	162	1.28
CRE LWCGR	97	390	0.34
CRE PHWR	56	128	1.39
CRE PWR	37	75	2.6
FLR	0.57	3.75	31
UCF	91	86	8.11
SP1	0	0.0033	3.03E5[3]
SP2	0	0.004	2.6E5
SP5	1E-4	0.012	8550
US7 AGR	0.51	2.72	45
US7 BWR	0	0.98	100
US7 LWCGR	0	0.82	122
US7 PHWR	0.28	1.76	68
US7 PWR	0	0.75	133
TISA2	0.03	0.39	275

We set the lower limit for SP1 and SP2 equal to zero due to very low time of these system unavailability and taking into account that these systems usually (excepting SP2 BWR) are out of operation during outage. SP5 has the non-zero lower limit because this system should be in operation all time but setting the zero level as the lower one means system could not be maintained.

3. Define the Weighting factor. The existing weighting factors according to [2] are as follows:

Indicator	Weighting factor
Unit Capability Factor	0.15
Forced Loss Rate	0.15
Unplanned Automatic Scrams per 7,000 Hours Critical	0.10
Safety System Performance (3 used per unit)	
SP1 (per unit reactor type)	0.10
SP2 (per unit reactor type)	0.10
SP5 (station value)	0.10
Fuel Reliability (all reactor types)	0.10
Chemistry Performance (all reactor types)	0.05
Collective Radiation Exposure (all reactor types)	0.10
Industrial Safety Accident Rate (per 200,000 man-hours worked)	0.05
Total	1.00

Taking into account the changes proposed to the indicator list on page 6, the following weight factor might be considered:

Indicator	Weighting factor	Associated with
Forced Loss Rate	0.15	Generation and reliability
Unit Capability Factor	0.15	Generation and reliability
Unplanned Total Scrams per 7,000 Hours Critical	0.10	Nuclear safety and reliability
Safety System Performance (3 used per unit)		Reliability
SP1 (per unit reactor type)	0.10	
SP2 (per unit reactor type)	0.10	
SP5 (station value)	0.10	
Collective Radiation Exposure (all reactor types)	0.10	Personnel safety
Total Safety Accident Rate (per 200,000 man-hours worked)	0.20	Personnel safety
Total	1.00	

When re-defying the weight factors some points have been taken into account: a) the main purpose of the nuclear industry is *safe energy generation* and b) the IAEA indicator list includes FLR (as well as UCL/UCLF) and US7 (and UA7).

The result of this adjustment can be seen in figure 3.

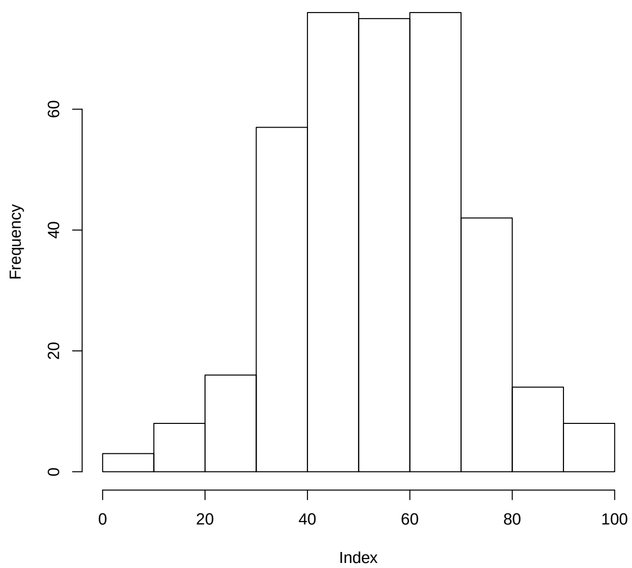


Figure 3: Histogram of new method indexes distribution

Conclusion

Normal distributions are important in statistics and are often used in the natural sciences to represent real-valued random variables whose distributions are not known [5].
As a result of index method adjusting we have the units' index distribution much closer to normal. This index method allows us a) represent a units' performance in more real way b) define the unit problems more clearly c) suggest low performance units increasing their potential
The problem of the proposed method is there are very few units have 100% performance index (a unit for 2016Q2 have 100% index and three units have index more than 95%). However, it will define good and weak sides of a unit and reinforce itself to solve the problems.

Implementation

There are two possible way to implement the proposed approach into the existing system:

- develop temporary calculation module and provide WANO members the results spreadsheet. Also it looks reasonable to redefine TISA in the calculation as only numbers of lost time/fatality accidents as a raw value (not a rate based on unreliable hours worked.) Fatalities and lost-time accidents are more readily verifiable we would expect. As for SSPI, we would suggest using only the number of defects of SP5 to monitor SSPI at all.

- change a bit the table 2 - use ISA2 instead of TISA2 and create the new Index method inside the existing PI Report system.

References

[1] Wikipedia. Performance indicator.

[2] World Association of Nuclear Operators (WANO). *MN 2014-2 Performance Indicator Programme Reference Manual*, 2014.

[3] UK Statistics Authority. Monitoring review. official statistics, performance measurement and targets.

[4] Wikipedia. Overall equipment effectiveness.

[5] Wikipedia. Normal distribution.

[6] Kurt Hornik. R FAQ, 2016.