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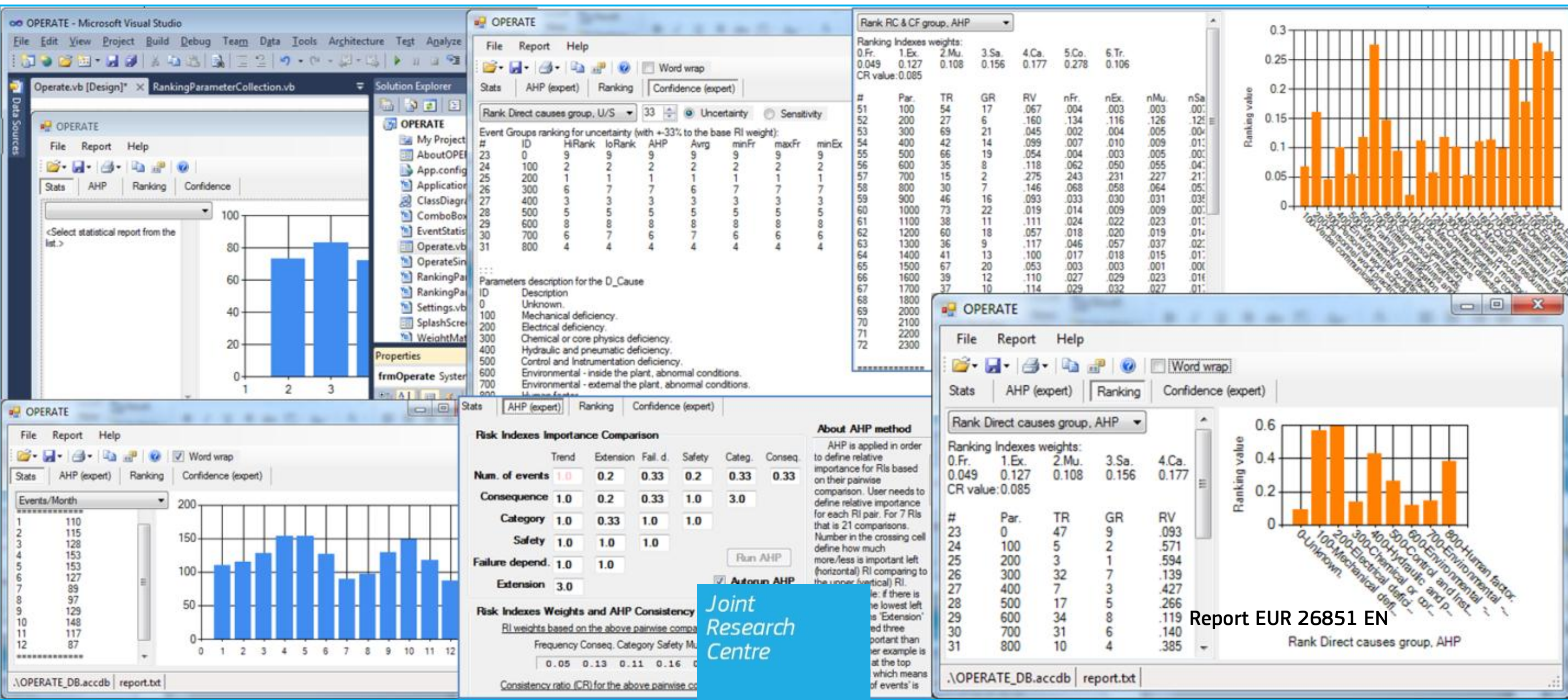
Development of the Statistical Tool for Operating Events Database Analysis

Operating Events Ranking Tool OPERATE

Institute for Energy and Transport

Zdenko Šimić

2014



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Abstract

This report contains a specification and implementation description for the statistical tool (desktop software program) which will allow detailed reporting and flexible ranking of operational events. The program is named Operational Events Ranking Tool (OPERATE).
Detail statistical reporting with a robust and consistent way of selecting most important events for more detailed investigation is very important. This provides better insight and saves the need for complete detail investigation which is neither feasible nor useful. It allows also to identify events trends and patterns across large databases.
The foundation for the statistical reporting and ranking is defined by the events parameters which are the base for reporting, grouping and ranking. This requires that each event should have characterisation which allows use of selected parameters for grouping and ranking.
Five parameters are used for events grouping: Activity, Direct cause, Systems, Components, and Root cause & Causal factor. Seven parameters are used for ranking: Frequency, Trend, Extension, Multiple, Safety, Category and Consequences. Some other parameters are used for statistics reports and future criteria (e.g. Vendor, Reactor type, Time of event, Status and Group of staff).
An important part of the implemented method is the way how ranking indexes are calculated. This is done in a consistent way based on previous experience and new research. OPERATE allows for each ranking index to be valued on the basis of relative importance determined by the experts' judgement evaluated with analytical hierarchy process (AHP). In this way weighting is easily determined and the importance of different parameters could be consistent. The tool is capable of analysing ranking for all groupings based on the expert and AHP determined relative importance.
In order to investigate the ranking confidence (uncertainty and sensitivity), the tool can analyse ranking for user-selected variations of parameters importance (e.g. ±30% weighting for all ranking indexes etc.). This is useful to determine the sensitivity of the results, which could expose the criticality of certain ranking parameters and respected weights.

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Operating Events Ranking Tool - OPERATE

Zdenko Šimić

EC JRC – IET, 2014

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1 Introduction

Operation experience feedback is based on the events investigation and on the conclusion about their relevance and implications for the operational and safety improvements. One specific issue is related to the selection of events which should have priority for the investigation.

Beyond the analysis of individual events, it is important to have a tool which allows to identify events trends and patterns across large database and, in a second stage, to focus the analysis efforts on these trends and patterns. A tool which will allow for different ways of ranking and prioritization is considered to be necessary. The basic idea for the prioritization which will be implemented in this tool comes from the Technical report [1] and the papers [2 and 3] with important expansion to additional events parameters which will allow their different groupings. In addition to the event groups ranking, this tool provides different ways of statistical reporting, viewing and analysing.

This report presents the complete description of statistical and ranking tool development. The tool is named OPERATE (Operating Events Ranking Tool). The description includes the design of key elements, the project specification, the development description and the presentation of the demonstration results with conclusions regarding usage, limitations and future potential.

2 Tool specification

The project specification presents a high level description of the tool. This helps as an introduction to the description of the tool development in the following section. This includes a general overview, the selection of an application platform for the tool, a database related description and examples of use (i.e. descriptions of how the tool is planned to be used).

2.1 General Overview

The general overview defines the tool's purpose, development and use platform, necessary inputs, results and development requirements. This also defines boundary conditions which are important when considering further tool application and development beyond the present scope.

2.1.1 Tool's Purpose

The statistical tool for operating events ranking and analysis (OPERATE) is a computer program for the operational events importance and statistical analysis which allows the following:

1. Report about numbers and time trends of events characterized according to predefined attributes.
2. Group events according to five selected criteria and respected parameters. All groups are processed further with ranking and confidence analysis.
3. Calculate events groups ranking indexes (RIs) values and weightings for all groupings based on the predefined formulas for events groups parameters and relations. The current implementation has seven different RIs. Weightings are determined on the basis of their relative importance using Analytical Hierarchy Process (AHP). The tool has initial relative RIs comparison, and allows for change.
4. Calculate total events groups ranking for all groupings, and quantified RIs weightings. The total ranking value is directly determining ranking for all event groups.
5. Calculate and compare events groups ranking for varied RIs weightings with separate uncertainty and sensitivity assessment for all grouping. This is providing insight for confidence in ranking results and allowing iterative ranking.

2.1.2 Necessary Input

The tool requires a database with properly characterised events. Events data characterisation and import, if done in a different format, is done as pre-processing outside the tool.
Characterised events in the database have to have the following: events with attributes for all selected predefined parameters which are used for reporting, grouping and ranking.

Full functionality of the tool is available even for just one year of events except that ranking index for trend requires at least two years of data. Because of the statistical and credibility confidence it is important that events are complete and cover as many years as available. Five complete years of data with hundreds of events should be considered as sufficient for meaningful and valuable assessment.

2.1.3 Results (Output)

Based on the input and users interaction, the tool is able to produce a complete report which documents all information used as input, with all calculations performed and all results.

The results are consisting of a statistical description for all parameters from the event characterisation and description, with all groupings ranking for selected weighting (default or user-determined) and confidence assessment (uncertainty and sensitivity with selected levels).

2.1.4 Development and Usage Requirements

In order to develop and use the tool it is necessary to:

1. Select an application platform (i.e. the spread sheet, stand-alone personal computer or web).
2. Define criteria for events grouping.
3. Develop equations for events groups ranking indexes (RIs) calculation and total ranking value calculation (i.e. AHP determined RIs weights).
4. Develop a sensitivity and uncertainty (i.e. confidence) quantification approach.
5. Implement (code) steps 2 to 4, and to develop a user interface
6. Select a representative event database, characterise it and analyse it with the tool.

2.2 Application platform selection

Before the tool is implemented an application platform is selected from these possible options:

1. A Microsoft Excel spreadsheet. This is a semi-manual application with some manual steps related not only to input data preparation and import but also to the usage. Coding is required for application and for special calculations. This is a flexible approach for development but hard for usage. Development requires fewer resources.
2. A personal computer desktop application is an option where a stand-alone application is developed. Microsoft Visual Studio is the reference programming environment for coding. This means that more resources are required for the development but application is much easier others to use.
3. A web application is an option where online usage is possible. This is more challenging to develop and requires outsourcing. The benefit would be that it

becomes easier to share some assessments and to cooperate between users, including connectivity with existing Clearinghouse effort.

The initial development started with MS Excel implementation. After the concept was proved, the use of a PC desktop application seemed to be the best solution. In the future, depending on the usage development, web online application might be the following step. Also there is enough room for further development with stand-alone implementation.

Microsoft Visual Studio 2010 was selected as the development environment platform with coding in Visual Basic. This is an environment for which a licence is available at the JRC.

2.3 Database and other related information

A database is going to be used for this tool as the source for all event data. The results are not stored in the database but they could be copied, printed and saved as textual files for further usage. Tables in database and reported results are later fully described as they are implemented. Even more information about database tables, computing approach and coding is available in the Appendix. The events coding was based on existing experience at the OE Clearinghouse (CH), US Nuclear Regulatory Commission (NRC), International Reporting System (IRS) and World Association of Nuclear Operators (WANO), ([5], [6], [7], [8], and [9]).

Table 1 presents complete list of parameters used for statistical reports and ranking with respected number of attributes and where is used (Statistical reports, Grouping or Ranking).

Table 1 List of events and groups parameters used for database and ranking tool

Parameter	**Description** (format or number of different values)	Use[!]
Plant	unique plant designation	S
Vendor	Supplier of the nuclear and steam side	S
Reactor	Reactor type	S
Status	of the reactors when event occurred (11)	S
Time	time when event happened (dd.mm.yy hh:mm)	S
Group	staff involved, or likely to learn from event (4)	S
Activity	performed when event occurred or detected (23)	G
Direct cause	of the event (9)	G
Systems	malfunctioning, failed, affected and degraded (10)	G3
Components	malfunctioning, failed, affected and degraded (7)	G3
Root cause/ Casual factor	multiple characterization (20)	G3
Consequences	caused by event (10)	R3
Category	broad event categorization (8)	R
Multiple	number of affected elements or common cause/mode (4)	R
Safety	estimated conditional safety relevance (3)	R[@]
SD/O ext.	duration of shutdown or outage caused by event (h)	R
Frequency[#]	ratio of events in group to total (-)	R
Trend	change of the events number over several years (-)	R[*]

! All parameters are used for **S**tatistical reports and some of them are used for **G**rouping or **R**anking. Number ***3*** means that event could have up to three parameter values, one value is always assigned.

@ Safety relevance is important: it is judged if explicit information in the report is not available.

Frequency is characterizing number of events in the group.

* Trend is not event parameter but calculated value for the group of events over time.

A Microsoft Access database is used for storing data of all events and respected characterisation. Characterisation was performed using MS Excel for the initial events. Figure 1 presents all tables in the tool's database. The central table is [OPERATE] and all other tables are used as reference sources for respective characterisation and other parameters description. This approach makes central table more compact for large number of events and easier to convert data created outside (important for characterisation).

The complete list of parameters and attributes is provided in the Appendix 8.2. together with the description of all the tables in the database . Relevant elements of the database and characterisation are further referenced in the report as needed.

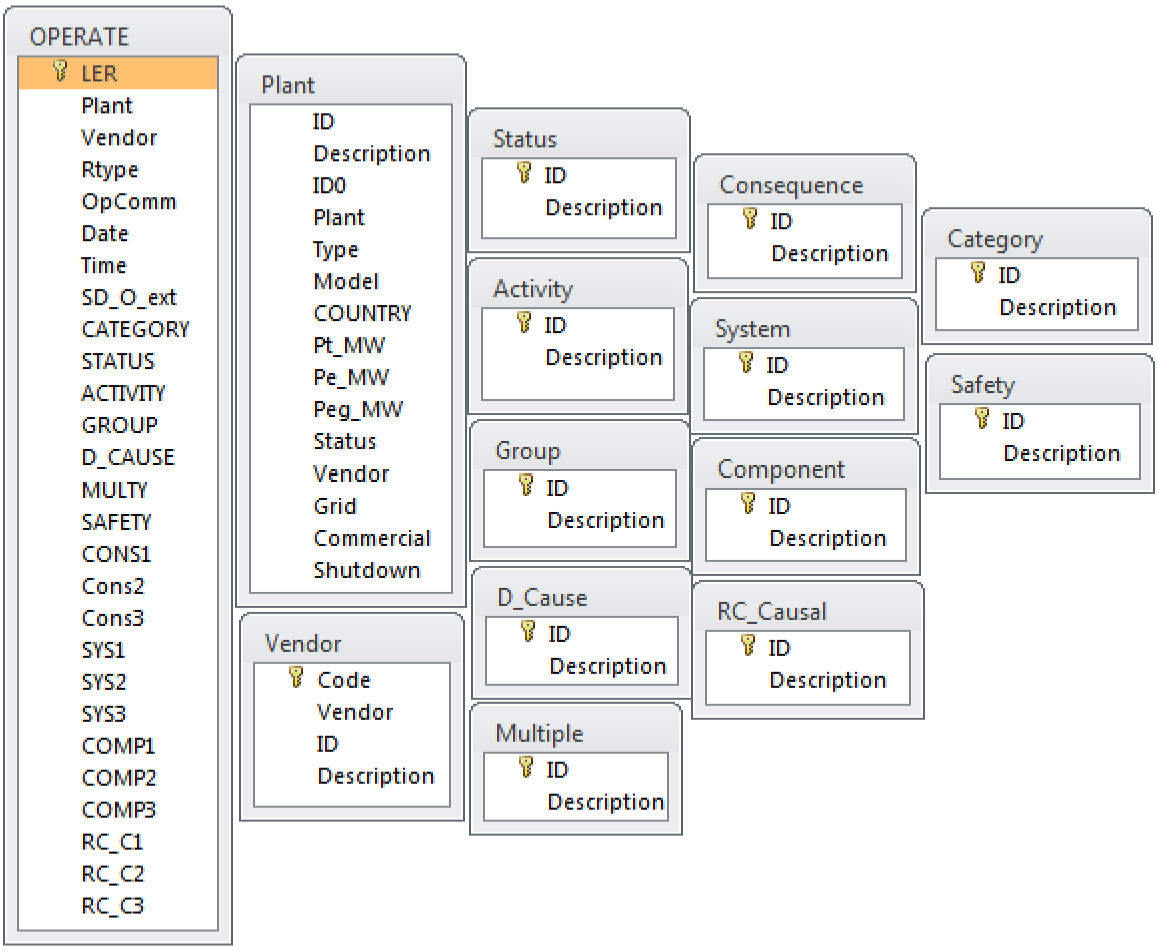


Figure 1 Tables present in the MS Access database with events and coding description

2.4 Use cases

Before further development it is important to define so-called use cases (i.e. the way how the user will interact with the application) at high level. The tool usage is not always linear and that will be taken care of later during the implementation. A description is made for the database application.

1. Characterised events should be imported into the database. This is easiest done with MS Access by opening the database and using available functionality. It is possible to develop a special functionality inside the program but this could be implemented in the future if really necessary. Two data sources could be used: XLS or simple text (generated from XLS source). It is important that data columns and field formats match what is defined in the database (i.e. table [OPERATE]).
2. After the events are imported and the database is ready the OPERATE application could be used without any additional action from the user. The user is now able to generate statistical or ranking reports on the screen and print, copy or save them to the file. Reports stored to the file are textual and could be used for documentation and further processing (in XLS etc.). Graphics from the screen could be printed to the printer or to the file (choice of format is depending on the available drivers).
3. There are options for the user to make changes regarding the ranking. First, the user could change the relative importance of the RIs from the predefined values. Second, the user can change the level of sensitivity and uncertainty. Both these changes are influencing the ranking results and it is up to the user to navigate through all the different choices and make his conclusion about the results. All reported results contain these reference data.
4. All four modules could be used without a strict order. However, ranking depends on the RIs comparison and this is possible because of the default values.

In order to better explain the approach and the most appropriate or simple way to use the tool, a so called use tree is also provided. The best way to get familiar with the tool is just to use it because it is developed as a window-based application with graphical user interface. The suggested application use tree is as follows below.

1. OPERATE started - database automatically loaded from default directory with the name shown at the bottom. If not, it should be opened by the user.
2. From the **Reports** menu produce **Statistics**, **Ranking** and **Confidence** reports. Ranking and Uncertainty is based on the default values for AHP and range, and they could be generated after the user makes changes to the AHP and range values.
3. Four application tabs (i.e. **Stats**, **AHP**, **Ranking** and **Confidence**) allow the user to view results and to see how certain changes (AHP and confidence range) influence the ranking. From each tab it is possible to make a copy or print the results.

It is clear that many details could be implemented with different levels of flexibility, and that after final implementation it will be clear what is left for future improvement and development. This is related both to the use cases (i.e. flexibility and number of choices) and method (i.e. quantification approach for weightings and uncertainty) implementation questions and treated later in a separate section.

3 Tool development

The tool development describes all aspects of the application related to the method applied. There are four different parts and each is described in separate section. This introduction explains how individual parts are connected. After the database is accessed (automatically or manually) statistical reports are available without any action from the user. Ranking is also available immediately if the user accepts the default weighting estimates for RIs. Alternatively the user could go to the AHP part and change that.

The user is also able to allocate different weights to each of these ranking parameters thanks to the Analytical Hierarchy Process part where these weights are calculated from the pairwise comparison of all ranking indexes. The level of confidence in the results obtained is then evaluated with confidence (uncertainty and sensitivity) analysis. Here the user can accept the default range or set some other value separately for uncertainty and sensitivity.

The tool is designed with an intuitive user interface for on-screen, text, graphical and file reporting options. The program consists of four different parts: ***Statistics, AHP (expert), Ranking*** and ***Confidence (expert)***.

The ***Statistics*** part presents reports for all parameters which are used for grouping and ranking plus for the following parameters: *Vendor, Reactor type, Status, Group of staff and Time of event (yearly, monthly, daily and hourly).*

In the ***AHP (expert)*** part of the application, the user can perform pairwise ranking comparison for the program to calculate the allocated RIs weights. The program also provides consistency ratio (CR) for resulted weighting (pairwise comparison is considered inconsistent if CR value is >0.01). Ranking is then performed on the basis of the AHP results.

The ***Ranking*** part determines the total and groups ranking on the basis of the AHP and ranking weights values for five event groups, both separately and together.

Finally, the ***Confidence (expert)*** part calculates the uncertainty and sensitivity for the event groups ranking, both separately and together. This is done by repeating the ranking for changed RI weighting. For each RI two additional cases were calculated with increased and decreased weighing by selected factor. Based on confidence results the user can go back on the AHP module and change the RI relative importance comparison in order to better reflect their importance and impact on the final ranking order.

All results can be copied, printed and saved to the file. This allows results to be incorporated into a report or used as a basis for some additional assessment.

Results from real demonstration set of five years of US NRC LERs are presented to prove that the method is working and that the tool is providing interesting and valuable results.

3.1 Statistical reports

The tool has 19 statistical reports available:

1. Number of events per year: a) Total number of events, years (Figure 2); and b) Number of events per plant, per vendor and per reactor type.

2. Distribution of events based on the time of occurrence:
   a) Monthly: the total number of events having occurred in each month during the year (for all years);
   b) Daily (i.e. Mon/Tue/…/Sun): the total number of events having occurred on each day in the week; and
   c) Hourly: the total number of events having occurred in each hour of the day (1-24). Notice: some events do not have a value for the time of the event occurrence.

3. Distribution of the shutdown/refuelling extension time duration as a number of events for certain hours duration interval: 0, >0-1, >1-4, >4-24, >24-72, >72-240, >240). Notice: some events do not have a value for this parameter and others have a value (negative value in the database) estimated during the characterisation.

4. Distribution of the total number of events for all other fields (parameters from OPERATE table): *Category*, *Status*, *Group*, *D. cause*, *Dep. failure*, *Safety*, *Conseq.* *System*, *Component*, *RC&CF*. Counting for the last four parameters is also done separately for each field since they can have one, two or three values.

All 19 statistical reports are illustrated in the Appendix subsection 8.3 with screenshot from the tool.

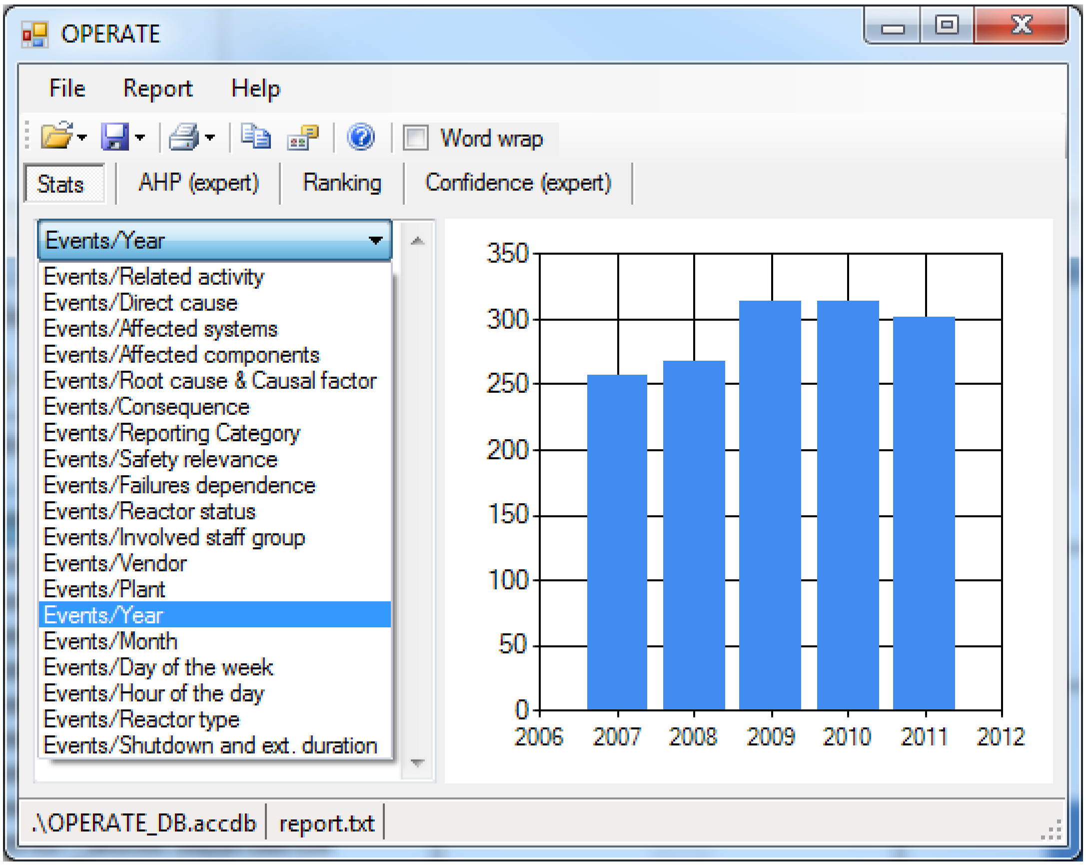


Figure 2 List of available statistical reports and graph showing the number of events per year.

3.2 Grouping and ranking indexes determination

The ranking method implemented in the tool requires a defined fixed scheme for events characterization and a consistent ranking algorithm. For this approach the events characteristics format in the database was defined on the basis of the accepted coding format from well-known and respected sources (IAEA IRS in Zhang et al., 2011; and WANO in Revuelta, 2004) with small changes in respect to the total number of possible values and several specific parameters. This means that the total number of possible values for all parameters is limited compared to, for example, the IRS coding format. The main reason for this was that a too big number of values for parameters is not optimal for grouping and ranking. In addition to that, it is also practically over-demanding for an events characterization. The ranking algorithm consists of ranking indexes values quantification and their relative importance determination. The relative importance is determined by the use of an analytical hierarchy process (AHP). The final ranking value is determined by the sum of ranking indexes values modified with respect to their relative importance.

The details about events characterization and ranking algorithm are presented below.

3.2.1 Events characterization

Based on the reference sources and the goal to optimize a number of parameters used for events characterization, a final list of parameters is determined and applied to a selected set of US NRC LERs. Table 1 (in previous section) presents all parameters used for events characterization in the ranking database. This characterization format has in total almost 120 parameters values, and the majority of them are for grouping purposes.

A complete characterization of events from the database allows their groupings based on attributes for five selected grouping parameters, i.e.: *Activity*, *Direct cause*, *Systems*, *Components,* and *Root cause/Causal factors*. Table 2 presents a complete set of values for one group. All groups have a predefined set of categories. The characterization is also the basis for values of seven ranking parameters defined as follows: *Category*, *Multiple*, *Safety*, *Shutdown/outage extension*, *Frequency* and *Trend*. Table 3 presents all values for one ranking group. All ranking parameters have a predefined set of categories except the last three. For each grouping, the respective categories are ranked on the basis of the ranking parameters (further referred to as indexes) and applied algorithm. This is further explained in the following subsection.

The parameters and respective values (categories) determine the complete base for grouping and ranking.. For this analysis it was necessary to perform characterization on already collected data. Four European Commission experts of the Clearinghouse (i.e. A.L. Guerra Munoz, D. Kancev, S. El Kanbi, and R. Sanda) were engaged in the characterization process. This was important not just to prepare the demonstration and tool testing database but also to help gaining necessary experience points to the resources requirements and the need for verification (consistency etc.). For the characterizations of the close to 1500 events required, resource were not insignificant (approx. 8 man-months) but if characterization is an integrated part of the data collection process then the required resources should be reduced. Characterization quality is also an important issue and it could be improved by experience and by user friendly software implementation.

Table 2 List of all attributes used for of the Activity parameter event characterization

1. Not relevant
2. Normal operations
3. Shutdown operations
4. Equipment start-up
5. Planned / preventive maintenance
6. Isolating / de-isolating
7. Repair (i.e. unplanned / breakdown maintenance)
8. Routine testing (of existing equipment) with existing procedures/documents
9. Special testing one-off special procedure
10. Post-modification testing
11. Post-maintenance testing
12. Fault finding
13. Commissioning (of new equipment)
14. Recommissioning (of existing equipment)
15. Decommissioning
16. Fuel handling / refuelling operations
17. Inspection
18. Abnormal operation (external/ internal constraints)
19. Engineering review
20. Modification implementation
21. Training
22. Actions taken under emergency conditions
23. Other

Each event could have one two or three different attributes.
Human factors: 1 – 10; Management: 11-18; Equipment: 19-22

Table 3 List of all event characterization attributes used for of the 'Category' parameter

0	Cancelled, incomplete or otherwise irrelevant event
1	Severe or unusual plant transient
2	Safety system malfunctions or improper operations
3	Major equipment damage
4	Excessive radiation exposure or severe personnel injury
5	Unexpected or uncontrolled release of radioactivity that exceeds on-site or offsite regulatory limits
6	Fuel handling or storage events
7	Deficiencies of design, analysis, fabrication, construction, installation, operation, configuration management, man-machine interface, testing, maintenance, procedure, or training
8	Other events involving plant safety or reliability Equipment performance.

3.2.2 Ranking algorithm

The rank for each category of events for each grouping is determined on the basis of the value and relative importance of the categories ranking indexes. Therefore the ranking is performed after following three steps: (1) events grouping, (2) ranking parameters value determination (for all groups in each category), and (3) ranking indexes importance determination. Grouping is the first step which consists of allocating events based on the selected groupings and respected categories. This means for example that events will be allocated into 23 categories for the *Activity* group (Table 2). The result of this step is presented as an illustration for a few parameters in the group [Direct cause]. The first row shows the total number of events for each ranking index and the following rows show ranking indexes for each attribute in the group (i.e. 0, 100, …, 800). All ranking indexes but trend have to be calculated from the number of events. Trend, also has to be scaled to the range between 0 and 1.

Table 4 Example of the intermediate values for grouping based on the parameter Direct cause

P	RI_Freq	RI_Trend	RI_Ext	RI_F.dep	RI_Safety	RI_Cat	RI_Cons
Total	942	na	4321.1	982	396	188	231
0	55	0.0075	520.3	91	37	17	21
100	24	-0.005	230.5	42	19	7	12
…							
800	33	0.0009	350.2	63	28	11	16

After events grouping for each category, seven ranking indexes values are quantified. All ranking indexes values, except for Trend, are determined as ratios between the number of events in a category and the total number of events in the group. A Trend RI is representing the measure of how the number of events changes for each category during the analysed period. It is calculated on the basis of the LSQ (Least-squares) line fit derived from minimizing the sum of the squares of the residuals (i.e. difference between line and real data). Table 5 presents all ranking indexes description and the general quantification formula. All ranking indexes have a quantified value between 0 and 1. For Trend RI this was accomplished with transformation, which makes the value 0.5 representing 'no change' of the number of events in a category during the analysed period and a higher or lower value represents an increasing or decreasing trend. This means that Trend RI values close to 1 have an increasing trend and values closer to 0 have a decreasing trend.

Table 5 List of ranking indexes with definition and calculation formula

Parameter	Definition	Formula
Conseque-nces	Ratio of the number of events in the group with selected attributes (i.e. 2, 4, 5 and 8) and total number of events with these attributes*.	$G_{2,4,5,8}/T_{2,4,5,8}$
Category	Ratio of the number of events in the group with selected attributes (i.e. 1, 2 and 5) and total number of events with these attributes.	$G_{1,2,5}/T_{1,2,5}$
Failure dependency	Sum of attribute values (0 - Unknown, 1 - Single, 2 – Mult. independent, 3 – Mult. dependent, common cause/mode) for events in the group divided with the total sum of these attributes for all events.	$\sum_{Group} M / \sum_{All} M$
Safety	Sum of attribute values (0 – No safety relevance, 1 – Low safety relevance, 2 – High safety relevance) for events in the group divided with the total sum of these attributes for all events.	$\sum_{Group} S / \sum_{All} S$
SD/O Extension	Sum of all extension time for events in the group divided with sum of extension time for all events.	$\sum_{Group} T / \sum_{All} T$
Frequency	Ratio of the number of events in the group divided with total number of events.	N_{Group}/N_{All}
Trend	Presented by the LSQ line fit of the change for the number of events across years in consideration. Approximation is made using least-squares regression. Final trend index is calculated using line coefficient ($\boldsymbol{k}$, where $\boldsymbol{y}$ is the number of events for year $\boldsymbol{x}$) with normalization between 0 ÷ 1 (0 ≡ -90° and 1 ≡ 90°). Values smaller than 0.5 are for declining and larger for increasing number of events.	$\boldsymbol{k} = \frac{n\sum x_i y_i - \sum x_i \sum y_i}{n\sum x_i^2 - (\sum x_i)^2}$ $\boldsymbol{Tr.} = \frac{\operatorname{atan}(k)}{\pi} + \frac{1}{2}$

Note: all ranking indexes have a range between 0 and 1.
* For categories where more than one attribute could be assigned to one event all are counted.

The third step is determining the relative importance (weight) for all seven ranking indexes. Depending on the ranking purpose or the expert view different ranking indexes might be more or less important. In order to make ranking more consistent and transparent the ranking indexes weights should ideally be determined with some appropriate method for such a high number of parameters. The analytical hierarchy process (AHP) from the decision-making field presents an adequate choice.

The AHP method was introduced with the main purpose to simplify the process of determining the relative importance of a large number of parameters in a multi-criterion hierarchical decision problem by reducing it to the level of pairwise comparison. Many different fields (e.g. engineering, manufacturing, industry, government, social sector and education) use AHP for various types of problems (e.g. priority and ranking, benefit-cost analysis, allocations, planning and development), (Subramanian & Ramakrishnan, 2012). Here follows a short description of the AHP method (Saaty, 2008) and the implementation used in the tool.

The core of the AHP is that it determines the relative importance for an unlimited number of indexes requiring only their pairwise comparison. If we assume that we are comparing $\boldsymbol{n}$ elements (ranking indexes in our case), $\boldsymbol{E_1 \dots E_n}$ and we use value $\boldsymbol{a_{ij}}$ to denote a priority of significance of element $\boldsymbol{E_i}$ with respect to element $\boldsymbol{E_j}$ then the pairwise comparison table is formed with the following constraints:

$$\boldsymbol{a_{ij}} = 1/\boldsymbol{a_{ji}},\ \text{for } \boldsymbol{i \neq j} \qquad \textbf{\textit{and}} \qquad \boldsymbol{a_{ii}} = 1,\ \text{for all } \boldsymbol{i} \tag{1}$$

This forms the reciprocal square matrix $\boldsymbol{A} = (\boldsymbol{a_{ij}})$ of order $\boldsymbol{n}$ where pairwise comparisons are consistent only if they are transitive, i.e. $\boldsymbol{a_{ik}} = \boldsymbol{a_{ij}} \bullet \boldsymbol{a_{jk}}$ for all $\boldsymbol{i}, \boldsymbol{j}, \boldsymbol{k}$. The usual range for comparison values is between 1/9 and 9. For a consistent matrix there is a principal eigenvalue which is the same as the matrix order, i.e. $\boldsymbol{\lambda} = \boldsymbol{n}$ and we can find eigenvector $\boldsymbol{\omega}$ such that $\boldsymbol{A\omega} = \boldsymbol{n\omega}$. Since human judgment is expected to be inconsistent to a greater or lesser degree for a larger number of elements the transitivity relation does not hold on the pairwise comparison table. In this case the principal eigenvalue $\boldsymbol{\lambda}$ which belongs to eigenvector ω satisfies condition $\boldsymbol{\lambda} \geq \boldsymbol{n}$. The difference between $\boldsymbol{\lambda}$ and $\boldsymbol{n}$ is an indication of the inconsistency in judgments and can be measured by the so called 'Consistency index' (CI) with the following formula: CI = $(\boldsymbol{\lambda}-\boldsymbol{n})/(\boldsymbol{n}-1)$. The CI needs to be compared to completely random judgments and Saaty has calculated the CI of such random judgements for different values of $\boldsymbol{n}$. Then the ratio between the calculated CI and the CI from Saaty's table of order $\boldsymbol{n}$ makes the 'Consistency ratio' (CR):

$$CR = CI/CI_{Saaty} \tag{2}$$

Saaty suggested that we accept judgments about pairwise relative importance as acceptably consistent if that ratio does not exceed 0.1, otherwise the judgments may be too inconsistent to be reliable. The CR equals to zero means that the pairwise comparison table represents perfectly consistent judgments.

The major issue in AHP calculation is the principal eigenvector determination. There are many methods for determination of the principal eigenvector and the corresponding eigenvalue. The tool uses an approximate method based on repeated squaring of the pairwise matrix and normalizing the sum of each row from the resulting matrix. At the end of this iterative process the normalized row approximates the principal eigenvector $\boldsymbol{\omega}$ elements from which the principal eigenvalue may be calculated by the equation $\boldsymbol{\lambda} = |\boldsymbol{A\omega}|/|\boldsymbol{\omega}|$. Finally, the elements of the principal eigenvector give us the relative weights of our ranking indexes.

The final ranking value for each group $\boldsymbol{RV_{Gi}}$ is quantified by the sum of ranking indexes values $\boldsymbol{RI_j}$ derived from the data normalized and modified with weights $\boldsymbol{w_j}$ from the AHP:

$$RV_{Gi} = \sum_{j=1}^{7} \mathrm{RI}_j \times w_j \quad (3)$$

Figure 3 represents the AHP part of the tool as implemented with pairwise comparison, resulting weights and relative importance matrix. It is important to note that this should be used only by someone familiar with the method and for all others default values are built in the tool (as seen on the screenshot below).

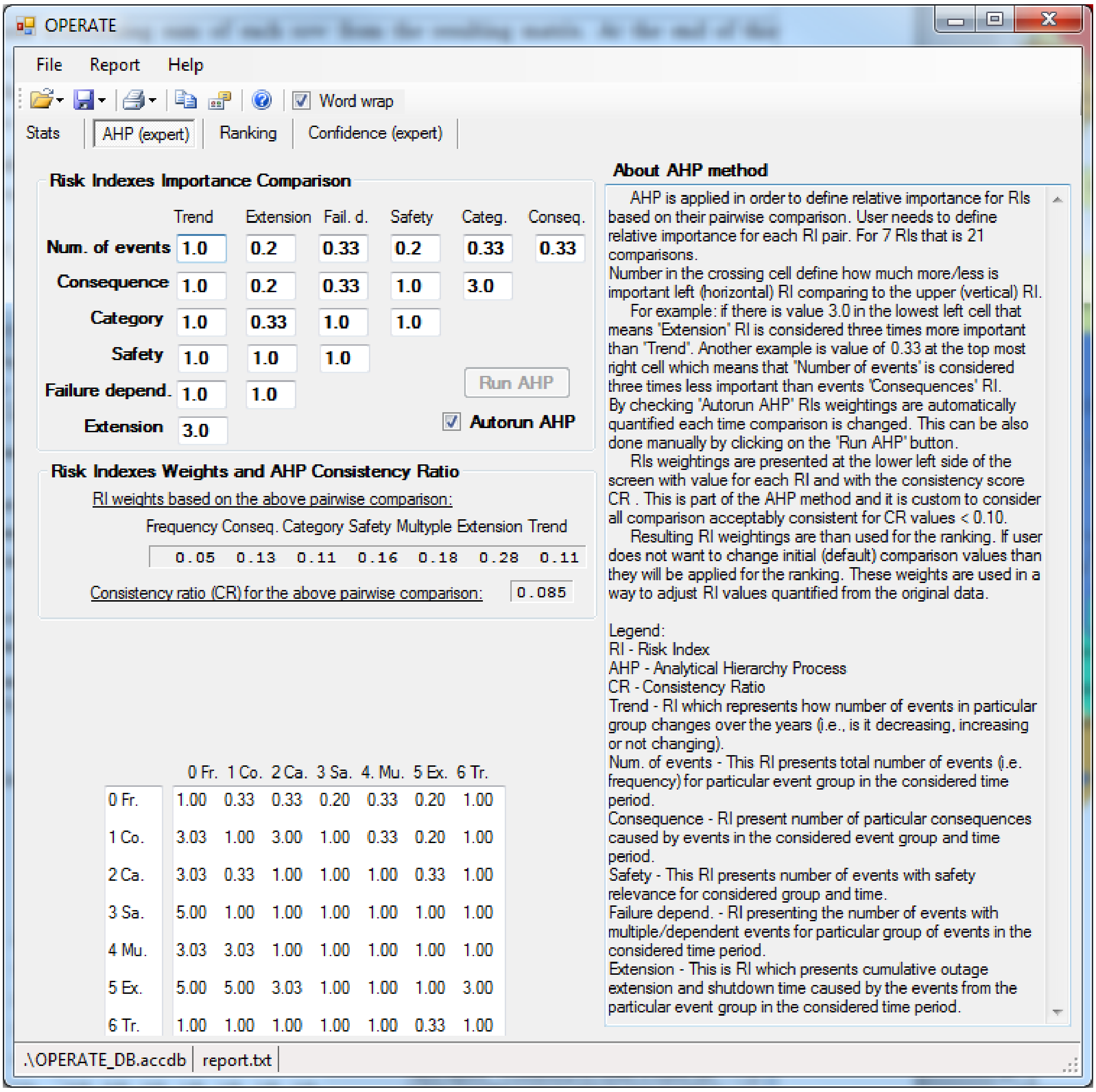


Figure 3 The analytical hierarchy process (AHP) part of the tool where pairwise comparison of all ranking indexes is used in the tool. The user can change this with his knowledge of the AHP method or just use default values and proceed to the ranking.

With defined RIs the weights ranking is determined on the basis of the total ranking value. Table 6 and Figure 4 present these results for the Components group. The textual report presents the complete information with the weight values for each RI, and the total ranking value for each member of the group. Before the final ranking value is quantified (eq. 3) all RI values are renormalized on the basis of the maximum value for each RI. This is done considering all the groupings in order to make comparable ranking values. There are certainly other ways to perform this but with this approach it is possible to make the total ranking across all groupings. The utility of this result might be debatable since these grouping are overlapping and therefore this should be viewed as with caution.

The details about individual RI values for each group member provided in the Table 6 are not necessary to use the results. They are provided for someone interested in precise contributions from each RI and also as a base for a potential different way of assessment.

The full textual report which could be saved from the tool provides also intermediate results from the event counting (like presented in the Table 4) and this could also serve as a base for some additional different way of analysis.

The results for all groups individually are presented in Appendix 8.4.2.

Table 6 List of ranking indexes with definition and calculation formula

@Rank **Components** group, AHP

Ranking Indexes weights:

0.Fr.	1.Ex.	2.Mu.	3.Sa.	4.Ca.	5.Co.	6.Tr.
0.049	0.127	0.108	0.156	0.177	0.278	0.106

CR value: 0.085

#	**Par**.	TR	**GR**	**RV**	nFr.	nEx.	nMu.	nSa.	nCa.	nCo.	nTr.	Group
43	**0**	29	**4**	**.149**	.105	.069	.054	.077	.105	.016	.886	3
44	**100**	13	**3**	**.317**	.408	.385	.406	.304	.401	.241	.181	3
45	**200**	2	**1**	**.873**	1.000	1.000	.982	1.000	1.000	.550	1.000	3
46	**400**	4	**2**	**.586**	.596	.635	.671	.575	.596	.424	.854	3
47	**500**	52	**6**	**.071**	.011	.013	.010	.011	.010	.002	.604	3
48	**600**	45	**5**	**.096**	.037	.049	.039	.030	.041	.040	.573	3
49	**700**	58	**7**	**.058**	.004	.006	.005	.003	.004	.004	.509	3
50	**800**	63	**8**	**.056**	.007	.002	.000	.000	.006	.000	.509	3

Parameters description for the Component

ID	Description	ID	Description
0	Unidentified, no specific component involved or where in-appropriate human action is the direct cause of the event.	**400**	Electrical.
		500	Lifting devices.
		600	Nuclear assemblies.
100	Instrumentation.	**700**	Computers (HW / SW).
200	Mechanical.	**800**	Civil structures.

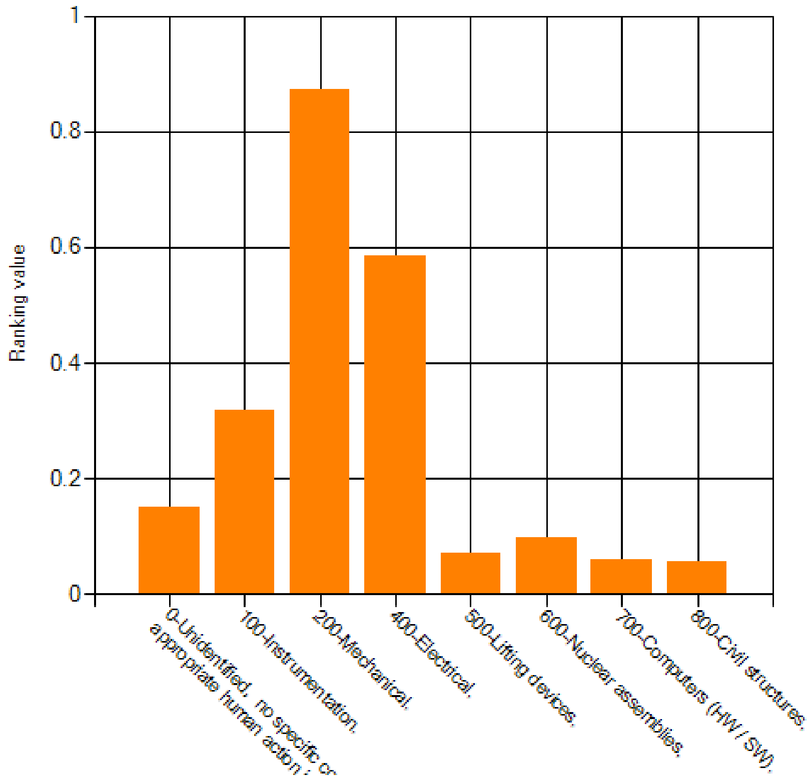


Figure 4 Ranking results for Components group

3.3 Ranking confidence (uncertainty and sensitivity) analysis

In order to use the results from any model it is important so have an estimate about confidence. This could be provided with a sensitivity and uncertainty assessment.

In this model uncertainty is coming from the initial events reports, their database characterization and the ranking indexes weights determination. The model results are sensitive to the ranking indexes quantification and pairwise comparison. The model described in this report has, in this phase, selected uncertainty and sensitivity, accounting true uncertainty and sensitivity quantification of ranking influenced by ranking indexes changes. This is considered sufficient to identify the robustness of the resulting ranking.

Uncertainty is considered by repeating the ranking after increasing and decreasing the AHP derived weighting values for all seven ranking indexes. This also creates 14 additional rankings. If for example the uncertainty value is ***u*** (e.g. 33%) then new weights for the ranking index ***j*** are $w_j \bullet (1+u)$ and $w_j \bullet (1-u)$. Other RIs weights then have to be corrected by ***c*** following the restriction that the sum of all weights has to be equal to 1. The following equation is for the case of increased weighting value for the ranking index ***i***, and it is similar for the decreasing case:

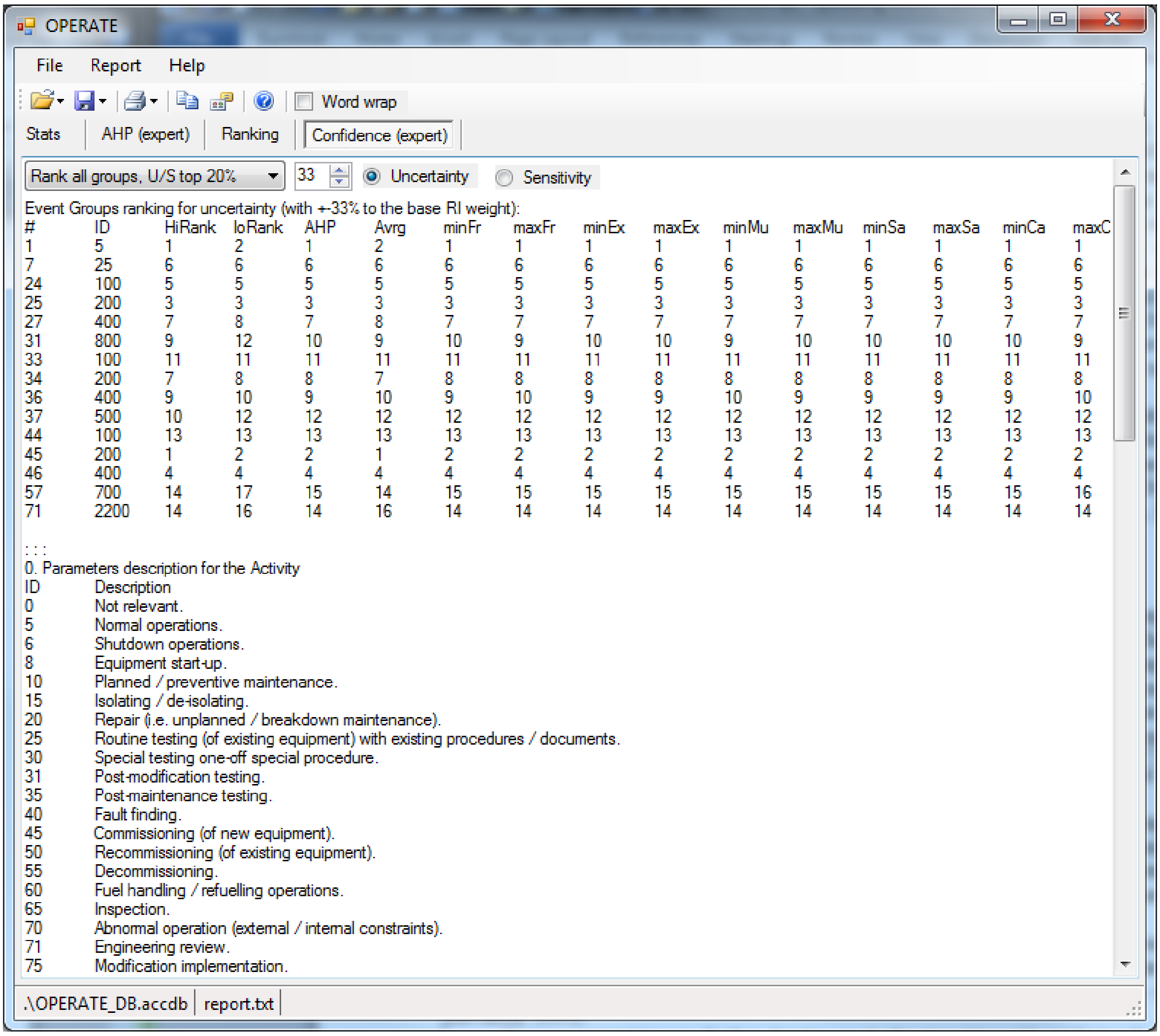
$$1 = \mathrm{w}_i \times (1 + u) + c \times \sum_{j=1, j\neq i}^{7} \mathrm{w}_j \quad (4)$$

$$c = \frac{1 - \mathrm{w}_i \times (1+u)}{1 - \mathrm{w}_i} \qquad (5)$$

Sensitivity of ranking order is considered by repeating the ranking after setting the AHP derived weighting values to the selected extreme value for all seven ranking indexes. These will also create 14 additional rankings. If for example the sensitivity value is ***s*** (e.g. 0.33) then the new weights for the ranking index ***j*** are ***s*** and (1-***s***)/10. The weights for the other ranking indexes are then set to the remaining averaged value for each case as (1- ***s***)/6 and [1-(1-***s***)/10]/6 respectively.

One additional ranking is performed with all RI weightings set to value 1/7 for both the uncertainty and sensitivity assessment. With the ranking based on the AHP weighting this makes a total of 16 uncertainty and sensitivity assessments. The uncertainty and sensitivity results could be at first judged only from the maximal and minimal ranking position achieved for all groups and then if needed they could be judged in detail by looking for the ranking index weighting changes with the most significant influence.

This approach is perhaps sufficient at the beginning but it is clearly rather limited because the AHP consistency index is not verified for the new weightings and the number of variations is far from exhaustive. Further improvements could be planned for the future based on the results from more practical applications. Figure 5 shows the tool screen for the Top 20% ranked. The full report for one group is presented in Appendix 8.4.3.



Event Groups ranking for uncertainty (with +-33% to the base RI weight):

#	ID	HiRank	loRank	AHP	Avrg	minFr	maxFr	minEx	maxEx	minMu	maxMu	minSa	maxSa	minCa	maxC
1	5	1	2	1	2	1	1	1	1	1	1	1	1	1	1
7	25	6	6	6	6	6	6	6	6	6	6	6	6	6	6
24	100	5	5	5	5	5	5	5	5	5	5	5	5	5	5
25	200	3	3	3	3	3	3	3	3	3	3	3	3	3	3
27	400	7	8	7	8	7	7	7	7	7	7	7	7	7	7
31	800	9	12	10	9	10	9	10	10	9	10	10	10	10	9
33	100	11	11	11	11	11	11	11	11	11	11	11	11	11	11
34	200	7	8	8	7	8	8	8	8	8	8	8	8	8	8
36	400	9	10	9	10	9	10	9	9	10	9	9	9	9	10
37	500	10	12	12	12	12	12	12	12	12	12	12	12	12	12
44	100	13	13	13	13	13	13	13	13	13	13	13	13	13	13
45	200	1	2	2	1	2	2	2	2	2	2	2	2	2	2
46	400	4	4	4	4	4	4	4	4	4	4	4	4	4	4
57	700	14	17	15	14	15	15	15	15	15	15	15	15	15	16
71	2200	14	16	14	16	14	14	14	14	14	14	14	14	14	14

: : :

0. Parameters description for the Activity

ID	Description
0	Not relevant.
5	Normal operations.
6	Shutdown operations.
8	Equipment start-up.
10	Planned / preventive maintenance.
15	Isolating / de-isolating.
20	Repair (i.e. unplanned / breakdown maintenance).
25	Routine testing (of existing equipment) with existing procedures / documents.
30	Special testing one-off special procedure.
31	Post-modification testing.
35	Post-maintenance testing.
40	Fault finding.
45	Commissioning (of new equipment).
50	Recommissioning (of existing equipment).
55	Decommissioning.
60	Fuel handling / refuelling operations.
65	Inspection.
70	Abnormal operation (external / internal constraints).
71	Engineering review.
75	Modification implementation.

Figure 5 Example for Confidence part of the tool – results for sensitivity of Top 20% ranking

3.4 Ranking tool application

While relying on the database with the characterized events and implementing the AHP method, a special tool is developed in order to allow interactive event groups ranking. The tool is developed using Microsoft Visual Studio and named OPERATE (Operating events ranking tool). There are four parts (i.e. Statistical, AHP, Ranking and Confidence) in the tool with many textual and graphical on-screen and reporting capabilities. The Statistics part presents 19 reports for all parameters describing the events in the database. Figure 2 illustrates this part of the tool with one report.

In the 'AHP (expert)' part of the tool the pairwise comparison is performed as an input to the weighting determination with the AHP quantification. Figure 3 presents default values which the user can change, allowing to form a different judgment. If the comparison is changed so that the AHP consistency check is not satisfied, this will be visible at the bottom of the screen and the consistency ratio becomes red for values >0.10 (as described in the previous section). Here 'expert' is meant that the AHP comparison should be changed only by the user who is well aware of the whole methodology.

The ranking part presents results for all five groupings, separately and together, based on the AHP determined weightings for the ranking indexes. The screen and reports present numerical and graphical ranking results with background data (e.g. ranking indexes, weightings and values). Ranking is determined for each group inside the grouping and across all groups, Figure 4.

The uncertainty and sensitivity assessment is presented in the 'Confidence (expert)' part. Here the user is able to see the ranking results for sixteen selected assessments, as described in the previous section, for each grouping for uncertainty and sensitivity. The default value is 33% and the user can change that between 0 and 100%. On the total level the uncertainty and sensitivity assessment is also possible for the top 20% groups (15 in total). Figure 5 presents the tool's screen illustration for this part. The uncertainty and sensitivity results are helpful to spot the potential for further refining of the ranking indexes weights or perhaps for expanding the list of the most important groups if the uncertainty is large or the sensitivity significant.

Each part of the tool is accessible independently in a flexible way. However, the idea is that the user can easily go back and forth in order to improve the whole picture and make a final ranking and an overall assessment. The results from all parts of the tool are available as text and graphic in order to allow further assessment and easy reporting. In that way it is easily possible to do some additional assessment (e.g. ranking with completely arbitrary ranking indexes weights) or to present combined results in different ways which are not supported by the tool (e.g. frequency data together ranking results).

The appendix contains much more examples of the tool's different parts with result from the event database used for the demonstration.

4 Results

Five years of U.S. NRC LERs from 2007 to 2011 were used as an input for the ranking method testing (U.S. NRC, 2013). In total 1453 events were characterized, grouped and ranked. Considering the events grouping according to 5 parameters (see section 3.2.1), the uncertainty and sensitivity assessment and the large number of statistical reports available from the tool, this report presents the most important results and is at the same time an illustration of the method.

The next section presents selected results and the following section provides for discussion regarding the method and the findings.

4.1 Selected results

After applying the ranking method with AHP weightings, ranking results are available for all 5 grouping parameters and they can be viewed together since all the total ranking values are normalized. All the results presented are based on the default AHP values as shown on Figure 3. According to the default comparison the most important ranking index is Extension (weighting = 0.28) and the least important is Frequency (weighting = 0.05). Other ranking indexes have weightings between 0.11 and 0.18. The consistency ratio is equal to 0.085, which is acceptable.

The top 20 groups between all groupings are presented in Figure 6 (higher ranking = higher rank). The graph also presents the contribution from each ranking index (after applied weighting). Even though the comparison of groups ranking among different groupings is questionable, this presentation is selected because it shows a compact overview for all results. The respective grouping name and group description is provided in Table 7. The top ranked group is 0.5 (Activity - Normal operation) with ranking value 0.95, and the second top ranked group is 3.200 (Components - Mechanical) with ranking value 0.87.

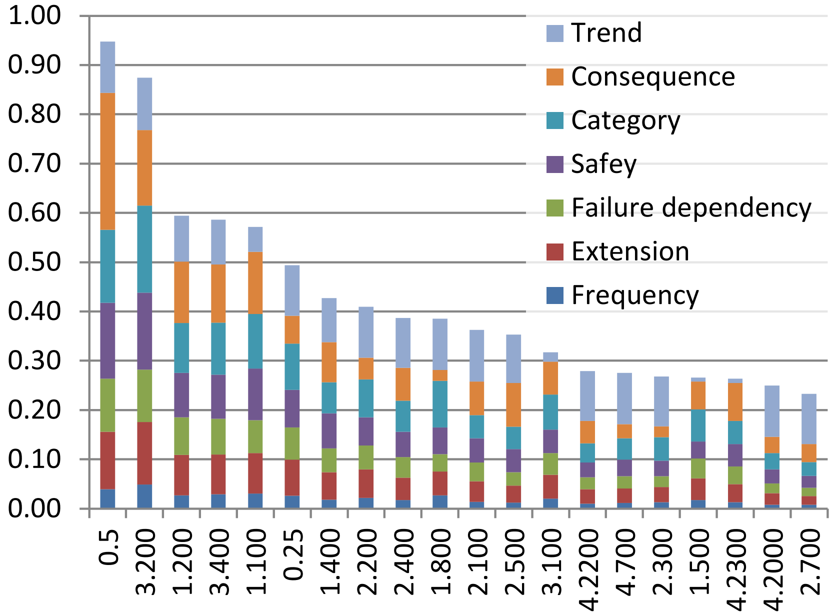


Figure 6 Ranking values for the top 20 groups (described in Table 7) with contributions from all RIs.

The total ranking and the ranking values (in %) are also provided in Table 7 with additional information about ranking in the respected groupings and ranking(s) from the uncertainty assessment. Uncertainty is performed for the 33% change. The results are presented with groups together with respective grouping. All five groups are represented with respective most important groups. Only six groups have changed ranking from the uncertainty assessment for their groups ranking, in the same way as with the AHP weightings. For example group 4.700 (Root cause – Written procedures and documents) is ranked in respective groupings with AHP weighting as the 2nd and uncertainty assessment is resulting with the highest rank as the 1st and lowest as the 3rd. Group 4.700 is the 15th in the total rank. More detailed results are available for the uncertainty assessment where ranking weighting change related to ranking change could be identified. For example Figure 3 shows a total ranking change from the same 33% uncertainty assessment.

Table 7 Ranking results – top 20 groups ranking with AHP and 33% uncertainty ranking indexes weighting

TR	**RV%**	**GR, AHP** / 33% Uncertainty	**Grouping**	**Group description**
1	95	**1** / same	**0. Activity**	5 Normal operations.
6	49	**2** / same		25 Routine testing with existing procedures / documents.
3	59	**1** / same	**1. Direct cause**	200 Electrical deficiency.
5	57	**2** / same		100 Mechanical deficiency.
7	43	**3** / same		400 Hydraulic and pneumatic deficiency.
10	39	**4** / same		800 Human factor.
17	27	**5** / same		500 Control and Instrumentation deficiency.
8	41	**1** / same	**2. System**	200 Reactor auxiliary systems.
9	39	**2** / same		400 Electrical systems.
11	36	**3** / 3-4		100 Primary reactor systems.
12	35	**4** / 3-4		500 Feedwater, steam, condensate and power conversion sys.

16	27	**5** / same		300 Essential auxiliary systems.
20	23	**6** / same		700 Instrumentation and control systems.
2	87	**1** / same	**3. Component**	200 Mechanical components.
4	59	**2** / same		400 Electrical components.
13	32	**3** / same		100 Instrumentation components.
14	28	**1** / 1-2	**4. Root cause / Causal factor**	2200 Maintenance, testing and surveillances.
15	28	**2** / 1-3		700 Written procedures and documents.
18	26	**3** / 1-4		2300 Design configuration and analysis.
19	25	**4** / 3-4		2000 Equipment performance.

TR – Total ranking with AHP weighting values. RV – Ranking value in %.

GR – Ranking for separate grouping with AHP and 33% uncertainty ranking indexes weighting

As for insights, it could be inferred which groups are very important (Table 7). Among 23 'Activity' groups (i.e. Normal operation; and Routine testing, with ranking values 95% and 49% respectively) two are distinctly more important because the 3rd ranked group has a ranking value of 26%. Four groups for 'Direct causes' (Electrical, Mechanical, Hydraulic/pneumatic deficiencies and Human factor) are at the top with ranking values between 59% and 39%. The four groups for Systems (Reactor auxiliary, Electrical, Primary reactor and Secondary) are even more closely ranked with ranking values between 41% and 35%. The two groups of components (Mechanical and Electrical) are distinctly more important with ranking values of 87% and 59%. Finally, one Root cause (Written procedures and documents) and three 'Causal factors' groups (Maintenance, testing and surveillance; Design configuration analysis; and Equipment performance) are more important (with ranking values between 28% and 25%) than the rest of groups (next ranked group has a ranking value of 18%).

Besides the ranking results there are also some interesting results available from the statistical part derived from the characterized events database. For example the distribution of the number of events over time on different scales: during the year, week or day. During the year average number of events per month is 24 where three months (April, May and October) have ~25% more events and other three months (July, August and December) have ~25% less events than average A more detailed presentation of these results is left out of this report for brevity.

4.2 Discussion

The numerical results provide transparent information about the relative importance of different event groups on the basis of the importance of selected ranking indexes. The graphical presentation of ranking results shows how close some ranking results are. For example, the first two ranked groups are clearly separated from the next three etc. (Figure 6). This might also be reflected in the ranking changes resulting from uncertainty or sensitivity assessment and a final conclusion about the group importance should reflect this. For example most of the groups from the 11th place (for total ranking) and afterward are affected from uncertainty assessment with 1 or 2 ranks change (Table 7).

The uncertainty and sensitivity assessment, as implemented, shows that ranking results are stable. However, as mentioned before, an additional 15 variations are not checked for AHP consistency and they are far from being exhaustive. This remains for potential future investigation. Perhaps in the future some cross-verification between different experts might be useful for characterization or identification of critical parameters if they exist.

An important issue is related to the events characterization consistency verification. This was not done in the present work. However, it seems that the distribution of dominant event groups is similar to other approaches performed independently (Revuelta, 2004).

It seems promising to further develop the tool's functionality with an analysis of events which are present in more than one high-ranked group from different groupings. This way, events with potential for further investigation might be reduced and selected in a more appropriate way.

All ranking results together with numerous statistical reports and tool interactivity seem to offer a rich and informative solution which can complement and enhance the operating experience feedback creation process.

5 Further development

The method presented is applicable to any set of events from the operating experience of nuclear power plants. It is important to realise that the specification of the events characterisation has to be the same on the application as on the database side. This means that either some different database has to be adjusted or the tool has to be modified. This requires a certain effort before any analysis is possible. The level of required effort depends on the discrepancies between the characterisation currently implemented in the tool and the specification of the new database. There is a potential to further develop the tool to make it easier to adapt to a different database specification. However that should be seen as a question specific to any new potential application.

The other potential change in the tool is related to the ranking method, because the current application is only one possible implementation of the base method for events grouping and ranking. The method itself could be improved and the specific implementation could be changed. This is a general source of potential future changes to the application.

Some more specific potential changes for future development are listed here:

1. Options for the user to save specific settings (e.g. AHP comparison and uncertainty values).
2. Using a different uncertainty quantification approach (e.g. exhausting whole acceptable space for the RI comparison values etc.)..
3. More detailed and customised reporting (e.g. more graphics, yearly data, only the first parameter for System, Components and Root Cause & Causal Factors).
4. The events data characterisation and input could be further improved (including full WANO detailed characterisation for large database with many events) depending on the application and the user preferences and data sources (as mentioned before).
5. Weighting values for ranking indexes for more than one expert opinion with combined results.
6. Formulas for ranking indexes calculation could be changed with fixed or flexible options.
7. New parameters, ranking indexes or grouping could be introduced. This depends on the characterisation and could be useful for different databases.
8. Automatic events data import from the tool and other data processing improvements including data mining.
9. In cooperation with WANO: assessing their vast collection of events.

All these potential future developments could be interrelated or separate projects which require a more detailed description and specification. They all require tool changes and some of them require database changes or even additional event characterisation.

A list of statistical reports and ways of grouping could be optional, but for the first implementation the full selection is implemented.

6 Conclusion

A statistical tool for operating events database reporting with a method for grouping and ranking event groups using AHP method for determining the importance of ranking indexes is demonstrated with five year of real experience. The statistical tool has a total of nineteen reports. The ranking approach developed provides traceable ways of prioritizing event groups on the basis of the contribution from seven ranking indexes for five different event groupings. The implemented methodology also includes uncertainty and sensitivity assessment regarding the influence of ranking indexes weighting changes on the ranking results. The results presented from the analysis and assessment of the real events from nuclear power plants operation illustrate the described ranking approach and give insight into the potential benefits for the further practical application of this tool.

The future work could be oriented towards additional applications and demonstrations of the methodology on different databases and towards further methodology development. Additional demonstrations will help the operating experience feedback development and the methodology testing. The most important elements for development seem to be in the area of event characterisation and confidence. As of characterisation advancement it seems interesting to test the method on the more detailed groupings and identification of events which are at the cross-section of high ranked groups from different groupings. A more complete uncertainty and sensitivity assessment could be accomplished with consistency index checking and a more complete set of variations assessment.

This effort demonstrates that more elaborate event characterisation provides numerous interesting and valuable statistical reports and that a quantitative event groups ranking application seems a promising complementary tool in the process of creating operating experience feedback. The methodology presented and the tool implementation seem to demonstrate a potential for events exploration, education and identification of the most important groups for further detailed investigation.

With a developed interactive application this presents a valuable tool for learning about events and making informed conclusions and decisions regarding further investigation prioritization in the area of better and safer operation of nuclear power plants.

7 References

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8 Appendix

Additional more detailed information for different parts of methodology and tool development and results is provided in this Appendix.

8.1 Events characterisation

This section provides some details about the process of events characterisation.

Data source for first demonstration set of events was chosen based on the availability, completeness and significance. Suitable and dependable source was found in the US NRC LER database which is available online. Five years of nuclear power plants LER events was selected for characterisation and use in the OPERATE. The following is practical description of characterisation process.

Selected years are from 2007 to 2011. Characterisation was performed by four EC JRC IET – NRSA experts with parallel approach (i.e. each year was split in four parts).

Table 8 Number of characterised US NRC LER data and assigned experts per quarters

Year / Quarter	2007	2008	2009	2010	2011
1st	64, R	64, A	79, A	79, A	81, A
2nd	65, D	65, D	80, D	80, D	85, D
3rd	65, R	66, R	80, S	80, S	79, S
4th	70, R	67, R	82, R	78, R	79, R
Total	**264**	**261**	**321**	**317**	

A – Arcadio; D – Dusko; R – Radian; S – Samir

Characterisation was managed in the way that all events were listed in the MS Excel spread sheet with columns for each parameter. Attribute code was incorporated as dropdown list with checking capability for validation. However, validation was not covering missing entries. Cancelled events were assigned with 0 value for the Category column. Two tables bellow are documenting characterisation results in this regard. First one provides total level statistics, and second table lists specific events which are identified for reconsideration.

These quarterly characterisation tables were first checked for problems, aggregated in to the respected year table, integrated for all years in to the final table which is imported in to the database.

Events in 2007 which happened before (i.e. 6 LERs in 2006) were disregarded. The same was for all other years. This is because only five years is characterised and these events are in the year which is not characterised. This issue will be resolved fully after characterisation expands to the years before 2007. So, all LERs before 2007 were just deleted from the database for this initial evaluation.

Counting of irregularities was done for each years table at the bottom of respected column. There was ten events which were outside the scope of analysed time frame (i.e. before 2007). All but two were from 2006, and one from 2002 and 2000. They were not included in the database. This is not significant.

Total considered number might not be precise because of these events before 2007.

Table 9 Number of special events – not considered and other

Year	**2007**	**2008**	**2009**	**2010**	**2011**
Total	264	261	321	317	324
Not considered	8	2	2	6	9
Events before	6/6	0/4	2/13	0/12	0/18
WO Time	**88**	**85**	**108**	**140**	**91**
W0&"" SD_OE	183	173	217	196	161
W- SD_OE	79	66	71	75	21
WO SD_OE	5	1	2	1	11
WO RC_CF	**0**	**10**	**13**	**8**	**5**
Total considered	**244**	**259**(?)	**316**	**311**	**315**

(?)Check what to do about some root causes and causal factors characterisation missing for some LERs (e.g. 2008 Arcadio, 9 events).

Table 10 List of special events – not considered and other

Event	Expert	Issue
133-2010-001	Arcadio	Dummy values left in! Missing info for the Humboldt Bay. (USPlantsNew4DB.xls)
219-2011-001	Arcadio	Dummy values left in!
220-2011-002	Arcadio	Missing component! (-> temporary set to 0!)
237-2008-002	Arcadio	Assigned component 300 does not exist.
237-2009-007	Arcadio	'cause unknoown'
237-2009-008	Arcadio	'cause unknoown'
237-2009-901	Arcadio	'root cause unknoown'
244-2008-901	Arcadio	'root cause not identified'
244-2011-001	Arcadio	Assigned component 300 does not exist.
244-2011-002	Arcadio	Assigned component 300 does not exist.
247-2008-002	Arcadio	'root cause not identified'
247-2009-004	Arcadio	'root cause unknoown'
247-2010-004	Arcadio	'root cause unknoown'
247-2010-006	Arcadio	'root cause unknoown'
249-2008-001	Arcadio	' cause not identified'
249-2009-901	Arcadio	'root cause not identified'
249-2010-003	Arcadio	'root cause not be determined'
251-2008-003	Arcadio	'root cause unclear'
251-2010-008	Arcadio	Missing component! (-> temporary set to 0!)
255-2008-001	Arcadio	Missing Component designation! (-> temporary set to 0!)
255-2008-003	Arcadio	'root cause not identified'
255-2008-004	Arcadio	'root cause unclear'
255-2011-003	Arcadio	'lack of info' Missing component! (-> temporary set to 0!)
255-2011-004	Arcadio	Missing component! (-> temporary set to 0!)
255-2011-005	Arcadio	Assigned component 300 does not exist.
259-2009-006	Arcadio	'root cause not identified'
260-2010-003	Arcadio	'root cause unknoown'
263-2009-003	Arcadio	Component1 empty with filled in other two components designations!
263-2009-901	Arcadio	'root cause not identified'
263-2011-001	Arcadio	No data -> set to 0 category
263-2011-002	Arcadio	No data -> set to 0 category
266-2008-001	Arcadio	'root cause not identified'
270-2008-001	Arcadio	'root cause not identified'
271-2010-901	Arcadio	'root cause unknoown'
272-2009-001	Arcadio	'root cause not identified'
275-2009-002	Arcadio	'root cause not identified'
275-2011-003	Arcadio	Changed category from 8 to 0 because this is Japan Thoku earthquake warning.
277-2008-901	Arcadio	'LER not found' -> assigned 0 Category
277-2008-901	Arcadio	'LER not found'
277-2008-902	Arcadio	'root cause not identified'
277-2010-003	Arcadio	'root cause unknoown'
278-2009-001	Arcadio	'root cause not identified'
278-2009-901	Arcadio	'root cause not identified'
280-2008-002	Arcadio	'root cause not identified'
280-2008-901	Arcadio	'root cause under investigation'
285-2009-003	Dusko	Cancelation letter
285-2011-001	Dusko	'cancelation letter'
285-2011-003	Dusko	Assigned component 300 does not exist.
285-2011-008	Dusko	'non-existent'
295-2007-001	Dusko	Missing info for the Zion-1. This is updated from new table USPlantsNew4DB.xls
296-2010-001	Dusko	Missing Component designation! (-> temporary set to 0!)
296-2010-004	Dusko	Missing Component designation! (-> temporary set to 0!)
298-2007-901	Dusko	'Not available' -> assigned 0 Category
301-2011-003	Dusko	Assigned component 300 does not exist.
305-2007-003	Dusko	'Cancellation letter' -> assigned 0 Category
324-2007-004	Dusko	'Cancellation letter' -> assigned 0 Category
325-2007-901	Dusko	'Not available' -> assigned 0 Category
327-2011-002	Samir	'cancelation letter'
335-2009-003	Samir	'not relevant'
336-2011-003	Samir	Assigned component 300 does not exist.
446-2010-001	Radian	Assigned component 300 does not exist.
456-2011-003	Radian	'cancelled' but category was 7 -> changed to 0
482-2011-001	Radian	'cancelled' but category was 7 -> changed to 0
482-2011-002	Radian	Assigned component 300 does not exist.
482-2011-003	Radian	'cancelled' but category was 7 -> changed to 0
Several LERs	Arcadio	root cause not identified with filled in value!?

8.2 Events parameters and attributes

Different sources could be used for the event database and it is important to determine and select a preferable set of parameters with defined attributes. These parameters provide consistent event information and are used for different processing. The final list of parameters is presented here, with all the attributes as implemented in the OPERATE database and application. The main source for this list was the Clearinghouse experience, the WANO coding scheme, IRS [5] and NRC LER system. This list is neither comprehensive nor ideal because there are many different questions and possible applications, and therefore any solution has certain advantages for main objectives/purposes but might also unavoidably lack something. Therefore this list is made having in mind different views, flexibility for applications and real practical possibility to find respected values for most of attributes. It is clear that similarity of the coding scheme with the other most respectable systems (i.e. IRS and WANO) allows data exchange. However, because of certain differences regarding some values and format, direct exchange of data is not possible without developing an additional application functionality.

It is important also to recognise multiple attributes assignment and some overlap between parameters. This is resolved partly by allowing for selected parameters to have multiple entry, e.g. up to three entries for: *Consequence, System, Component, and Root cause/Causal factors*.

The final number of attributes was reduced to the most important subgroups in order to make them not too detailed and therefore easier for characterisation. This has resulted in a compromise solution for some parameters with a too large number of attributes in referenced systems (i.e. IRS and WANO) where only a subgroup level of attributes is applied, i.e. for: *Group, Direct cause, Consequences, System, Component, Root cause/Causal factor*.

It is very important to fill all parameters because further processing depends on this. For all parameters with a possibility of multiple (up to three) values at least one should be entered.

Table 11 Parameters for the events characterisation with respected attributes

Parameter	Attributes	Multy.
Event	Unique event id in the database: LER NUMBER	1
Title	Event title from the source or created (about 10 words)	-
Plant	CODE from the PLANTS tab (e.g. US-222)	1
Vendor	**B&W, CE, GE, WH, FRAM**, …	1
Reactor type	**BWR, PWR**, …	1
Op. Commercially	Date when commercially operation started (auto filled)	
Country	**US**, FR, GE, RU, GB, FI, … (filled in automatically)	
Description	Available from the source (filled in automatically)	-
Date	Local **date** when event occurred with format (filled in autom.)	1
Time	Local **time** when event occurred with 24h format: **hh:mm:ss**	1
SD/O ext. duration	Number of **hours** of shutdown or outage extension caused by event in fractions (e.g. **8.3**). Negative sign is used when this value is not known and only roughly judged (e.g. -**120**).	1
Category Broad event categorization.	**0** Cancelled, incomplete or otherwise irrelevant event **1** Severe or unusual plant transient **2** Safety system malfunctions or improper operations **3** Major equipment damage **4** Excessive radiation exposure or severe personnel injury **5** Unexpected or uncontrolled release of radioactivity that exceeds on-site or offsite regulatory limits **6** Fuel handling or storage events **7** Deficiencies of design, analysis, fabrication, construction, installation, operation, configuration management, man-machine interface, testing, maintenance, procedure, or training **8** Other events involving plant safety or reliability	1
Status (of the reactor at the time the event occurred or was detected)	**110** Steady power operation **120** Start up operations - reactor critical but < 30% power **130** Increasing power - 30% to 100% **135** Decreasing power - 100% to 0% **140** Hot standby - sub critical and coolant temperature at normal operating temperature **150** Hot shutdown - sub critical coolant temperature < normal operating temperature **155** Cold shutdown- sub critical and coolant temp. < 93°C **160** Refuelling op. or open vessel - all or some fuel inside the core **165** Refuelling operations or open vessel -fuel out of the core **170** Mid loop operation (PWR) **180** Not relevant	1
Activity (that was being performed at the time the event occurred or was detected)	**0** Not relevant **5** Normal operations **6** Shutdown operations **8** Equipment start-up **10** Planned / preventive maintenance **15** Isolating / de-isolating **20** Repair (i.e. unplanned / breakdown maintenance) **25** Routine testing (of existing equipment) with existing procedures/documents **30** Special testing one-off special procedure **31** Post-modification testing **35** Post-maintenance testing **40** Fault finding **45** Commissioning (of new equipment) **50** Recommissioning (of existing equipment) **55** Decommissioning **60** Fuel handling / refuelling operations **65** Inspection **70** Abnormal operation (external/ internal constraints) **71** Engineering review **75** Modification implementation **90** Training **95** Actions taken under emergency conditions **99** Other	1

Parameter	Attributes		Multy.
Group (of staff most involved in, or likely to learn from the event, Table)	**100** Maintenance, general. **200** Operations, general. **300** Technical and engineering, general. **400** Management and administration, general		1*
Direct cause	**0** Unknown. **100** Mechanical deficiency. **200** Electrical deficiency. **300** Chemical or core physics deficiency. **400** Hydraulic and pneumatic deficiency. **500** Control and Instrumentation deficiency. **600** Environmental - inside the plant, abnormal conditions. **700** Environmental - external the plant, abnormal conditions. **800** Human factor.		1
Multiple (failure/error/ plant)	**0** Unknown dependency, **1** Single independent, **2** Multiple independent, **3** Multiple dependent, common cause/mode		1
Safety (relevance)	**0** No safety relevance **1** Low safety relevance **2** High safety relevance		1
Consequences (of the event, see table with some examples)	**1** Degraded plant operating conditions **2** Plant transient **3** Equipment damage; Fires; Steam generator tube leak **4** Degradation of safety systems **5** Uncontrolled release of radioactivity	**6** Unforeseen personnel exposure **7** Personal injuries **8** Degradation of a safety barrier **9** Other **10** Non-consequential or near miss	**Y** up to **3**
Systems (malfunctioning, failed, affected and degraded, see table with detail list of all systems)	**0** None of the specified or unidentified. **100** Primary reactor systems. **200** Reactor auxiliray systems. **300** Essencial auxiliary systems. **400** Electrical systems. **500** Feedwater, steam, condensate and power conversion systems.	**600** Heating, ventilation and air conditioning systems. **700** Instrumentation and control systems. **800** Service auxiliary systems. **900** Structural systems. **950** Waste management systems.	**Y** up to **3**
Components (malfunctioning, failed, affected, degraded)	**100** Instrumentation. **200** Mechanical. **400** Electrical. **500** Lifting devices. **600** Nuclear assemblies. **700** Computers (HW / SW).	**800** Civil structures. **0** Unidentified, no specific component involved or where in-appropriate human action is the direct cause of the event.	**Y** up to **3**
Root/Casal (Root causes/ Causal factors. <u>Human perf. rel.:</u> 100-1000 <u>Managmnt related:</u> 1100-1800 <u>Equipment rel.:</u> 2000-2300)	**100** Verbal communication. **200** Personnel work practices. **300** Personnel work scheduling. **400** Environmental conditions. **500** Man-machine interface. **600** Training / qualification. **700** Written procedures and documents. **800** Supervisory methods. **900** Work organization. **1000** Personal factors. **1100** Management direction. **1200** Communication or coordination. **1300** Management monitoring and assessment.	**1400** Decision process. **1500** Allocation of resources. **1600** Change management. **1700** Organisational / safety culture. **1800** Management of contigencies. **2000** Design configuration and analysis. **2100** Equipment specification, manufacture, and construction. **2200** Maintenance, testing and surveillances. **2300** Equipment performance.	**Y** up to **3**

& WC – Coding from WANO Operating Experience Programme Reference Manual

* Group(s) are treated as multiple parameter in the WANO reporting.

Table 12 Database parameters summary and main use

Parameter	Description	Used to: Group	Used to: Rank
Event	unique event id	-	-
Plant	Code of the plant	-	-
Vendor	Supplier of the nuclear and stem side	-	-
Reactor	type	-	-
Comm. Op.	Date when commercial operation started	-	Y^
Date	when event happened	-	Y*
Time	time when event happened	-	-
SD/O ext.	duration of shutdown or outage caused by event	-	Y
Category	broad event categorization, 1-8 (8)	-	Y
Status	of the reactors when event occurred, 110-180 (11)	-	-
Activity	performed when event occurred or detected, 0-99 (23)	Y	-
Group	staff involved, or likely to learn from event, 100-400 (4)	-	-
Dir. cause	of the event, 0-800 (9)	Y	-
Multiple	number of affected plants/ comp./systems/functions (4)	-	Y
Safety	estimated conditional safety relevance after event (3)	-	Y@
Consequences	caused by event, 1-10 (10)	-	Y3
Systems	malfunctioning, failed, affected and degraded, 0-900 (10)	Y3	-
Components	malfunctioning, failed, affected and degraded, 0-600 (7)	Y3	-
Root cause/ Casual factor	multiple characterisation, 100-2300 (20)	Y3	-
Frequency	Calculated ratio of events in group to total		Y#
Description~	of the event	-	-
Country~	Location	-	-

#	The calculated frequency from the number of related events, after grouping, is also used for ranking.
&	The reactor type would be used for subgrouping (i.e. to select only one type).
*	The date is going to be used for trending calculation which is used for ranking.
@	The safety relevance is important: it should be judged if explicit information is not available.
^	The age of a plant is could be used as a ranking factor (older worse or similar)
~	Not included in the OPERATE application. Available from the database for future use.
Note:	All parameters are used for sorting and reporting.

Table 13 **Database parameters details regarding database structure and values**

Parameter	Values	Type
Event	e.g. "219-2011-001"	nchar 12
Plant	e.g. "US-219"	nchar 6
Vendor	i.e. "B&W", "CE", "GE", "WH"	nchar 8
Rtype	i.e. "BWR", "PWR"	nchar 4
OpCom	e.g. "1969-12" *	?date
Date	i.e. "22/11/2011"	date
Time	i.e. "14:50"	time
SD_O_ext	e.g. 8.3, -120	real
Category	0, 1, 2, 3, 4, 5, 6, 7, 8	tinyint
Status	110, 120, 130, 135, 140, 150, 155, 160, 165, 170, 180	tinyint
Activity	0, 5, 6, 8, 10, 15, 20, 25, 30, 31, 35, 40, 45, 50, 55, 60, 65, 70, 71, 75, 90, 95, 99	tinyint
Group	100, 200, 300, 400	smallint
D_cause	0, 100, 200, 300, 400, 500, 600, 700, 800	smallint
Multiple	0, 1, 2, 3	tinyint
Safety	0, 1, 2	tinyint
Cons1, Cons**2,** Cons**3**	1, 2, 3, 4, 5, 6, 7, 8, 9, 10	tinyint
SYS1, SYS**2,** SYS**3**	0, 100, 200, 300, 400, 500, 600, 700, 800, 900, 950	smallint
Comp1, Comp**2,** Comp**3**	0, 100, 200 , 400, 500, 600, 700	smallint
RC_Case1, RC_Case**2,** RC_Case**3**	100, 200, 300, 400, 500, 600, 700, 800, 900, 1000, 1100, 1200, 1300, 1400, 1500, 1600, 1700, 1800, 2000, 2100, 2200, 2300	smallint

Table 14 Detailed list of parameters with respected sub parameters from the WANO coding scheme

Direct Cause (The failure, action, omission or condition which immediately produced, or led to, the event, WANO 5.8)

0100 MECHANICAL DEFICIENCY
0101 Deformation, distortion, spurious movement, loosening, displacement, loose parts,
0102 Corrosion, erosion, fouling
0103 Overloading (including mechanical stress and overspeed)
0104 Fatigue
0105 Leak
0106 Break, rupture, crack, weld failure
0107 Blockage, restriction, obstruction, binding, foreign material
0108 Wear, fretting, lubrication problem
0109 Vibration

0200 ELECTRICAL DEFICIENCY
0201 Short circuit, arcing
0202 Overheating
0203 Over voltage
0204 Under voltage, voltage breakdown
0205 Failure to change state
0206 Bad contact, disconnection
0207 Circuit failure, open circuit
0208 Ground fault
0209 Faulty insulation

0300 CHEMICAL or CORE PHYSICS DEFICIENCY
0301 Uncontrolled chemical reaction
0302 Core physics problems
0303 Poor chemistry or inadequate chemical control
0304 Chemical contamination, deposition

0400 HYDRAULIC AND PNEUMATIC DEFICIENCY
0401 Water hammer, abnormal pressure, pressure fluctuations, over pressure
0402 Loss of pressure
0403 Loss of fluid flow
0404 Cavitation
0405 Gas binding
0406 Vibration due to fluid flow
0407 Moisture in air systems

0500 CONTROL AND INSTRUMENTATION DEFICIENCY
0501 Oscillation
0502 False response, loss of signal, spurious signal
0503 Set point drift, parameter drift
0504 Computer hardware deficiency (including auto control loops)
0505 Computer software deficiency (including auto control loops)

0600 ENVIRONMENTAL (ABNORMAL CONDITIONS INSIDE THE PLANT)
0601 Fire, burning, smoke, explosion
0602 Dropped load, high energy impacts, missiles
0603 Water ingress, flooding
0604 High temperature
0605 Radiation, contamination and irradiation of parts
0606 Pressure
0607 Humidity
0608 Low temperature (including freezing)

0700 ENVIRONMENTAL (EXTERNAL TO THE PLANT)
0701 Lightning strikes
0702 Flooding
0703 Wind loading I storm
0704 Earthquake
0705 Ambient temperature high
0706 Ambient temperature low (freezing)
0707 Heavy rain or snow

0800 HUMAN FACTORS (* See definitions below)
0801 Slip or lapse
0802 Mistake
0803 Violation
0804 Sabotage

0000 UNKNOWN
0001 Unidentifiable
0002 Not yet identified

*** Human Factors Definitions**

Slip or lapse - Unconscious unintended action or failure to act, resulting from attention failure or memory failure in routine activity. In spite of a good understanding of the system, the process, the procedure, the specific context, and the intention to perform the task correctly, an unconscious, unintended action or failure to act occurs, or a wrong reflex or inappropriate instinctive action took place.

Mistake - Intended action resulting in undesired outcome in the problem solving activity. The person made wrong action because he did not understand the system, the procedure, the specific context, the prescribed task etc.

Violation - In spite of a good understanding of the system, the process, the procedure and the specific context – the person intentionally breaks known rules, prescriptions,... without malevolent intention.
Sabotage - Intentional breaking of known rules, prescriptions,... with malevolent intention.

Consequences of the event (WANO 5.2)

Code	Description	Definition/Examples
01	Degraded plant operating conditions	Dilution transients, Breach of Technical Specifications
02	Plant transient	The number of which is limited in plant life such as scrams, safety injection etc.
03	Equipment damage; Fires; Steam generator tube leak	Major or safety related equipment
04	Degradation of safety systems	Reactor protection systems, Shutdown cooling systems, Safeguard systems, Emergency power systems, Ultimate heat sink systems, Fire protection systems
05	Uncontrolled release of radioactivity	
06	Unforeseen personnel exposure	
07	Personal injuries	
08	Degradation of a safety barrier	Fuel cladding, Primary boundary *, Containment integrity
09	Other	Availability of the plant
10	Non-consequential or near miss	For precursor occurrences nuclear safety or plant reliability consequences

* Excluding steam generator tube leaks classified under equipment damage. Tube ruptures are classified under 08.

Systems (malfunctioning, failed, affected and degraded, WANO 5.3

Code	Description
100	**PRIMARY REACTOR SYSTEMS**
110	Reactor core
120	Control rod (including drives and special power supply
130	Reactor vessel and internals
140	Moderator and auxiliaries (PHWR)
150	Reactor coolant system
160	Pressure control (includes primary safety r
170	Recirculation (BWR)
180	Steam generator, boiler, steam drum
190	At power fuel handing systems (PHWR, GCR, RBMK)
195	Annulus gas systems (PHWR, RBMK)
200	**REACTOR AUXILIARY SYSTEMS**
210	Reactor core isolation cooling (BWR)
215	Auxiliary and emergency feedwater
220	Emergency poisoning function
	Stand-by liquid control (BWR)
	Residual heat removal
	Chemical and volume control (PWR)
	Emergency core cooling
	Main steam pressure safety I relief valves (for reactors with secondary loops)
	Core flooding accumulator (PWR)
	Gas clean-up system (PHWR, RBMK, LMFBR)
	Failed fuel detection
300	**ESSENTIAL AUXILIARY SYSTEMS**
	Component cooling water
	Essential raw cooling or service water
	Essential auxiliary steam (GCR)
	C02 injection and storage (GCR)
	Essential compressed air
	Borated or refuelling water storage
	Condensate storage
	Spent fuel pool or refuelling pool cooling and cleanup
	Containment isolation
	Main stearn/feedwater isolation function
	Containment spray and ice condenser
	Containment pressure suppression (not including spray)
	Containment combustible gas control

400 **ELECTRICAL SYSTEMS**
High voltage AC (greater than 15kV including off-site power)
Medium voltage AC (600 V to 15 kV)
Low voltage AC (less than 600 V, mainly 480 V)
AC & DC supplies to vital instrumentation, control and computers
DC power supplies
Emergency power generation and auxiliaries
Security and access control
Communication and alarm annunciation

500 **FEEDWATER, STEAM, CONDENSATE AND POWER CONVERSION SYSTEMS**
Main steam and auxiliaries (including auxiliary steam)
Turbo-generator and auxiliaries
Main condenser and auxiliaries (including off gas systems)
Turbine by-pass
Condensate and feedwater
Condensate demineraliser
Circulating water or condenser cooling water (including raw & service water cooling)

600 **HEATING, VENTILATION AND AIR CONDITIONING S**
10 Primary reactor containment building HVAC ventilation
15 Primary containment vacuum and pressure relief
20 Secondary containment recirculation, exhaust and gas treatment
25 Dry well or wet well ventilation, purge and inerted
30 Nuclear or reactor auxiliary building ventilation
35 Control building ventilation, main control room ventilation
40 Fuel building ventilation
45 Turbine building ventilation
50 Emergency generator building ventilation
60 Miscellaneous structures ventilation
65 Chilled water
70 Plant stack
75 Seismic / bunkered emergency control building ventilation

700 **INSTRUMENTATION AND CONTROL SYSTEMS**
10 Plant / process com2uter (including main and auxiliary computer
15 Fire detection
20 Environment monitoring
25 Turbo-generator instrumentation and control
30 Plant monitoring (including main control room equipment & rem functions)
35 In-core and ex-core neutron monitoring
40 Leak monitoring
45 Radiation monitoring (in the plant and of workers)
50 Reactor power control
51 Reactor protection
55 Recirculating flow control (BWR)
60 Feedwater control
65 Engineered safety features actuation (including emergency system
70 Non-nuclear instrumentation

800 **SERVICE AUXILIARY SYSTEMS**
10 Sampling
20 Control and service air (non-essential), compressed gas
30 Demineralised water
40 Material and equipment handling (including cranes, tools & lifting
50 Nuclear fuel handling and storage
60 Fire protection
70 Chemical additive injection and make-up
80 Sodium heating systems

900 **STRUCTURAL SYSTEMS**
910 Primary reactor containment building
915 Secondary reactor containment building or vacuum building (PHWR)
920 Reactor or nuclear auxiliary building
922 Control building
925 Emergency generator building
928 Fuel building (including wet and dry storage buildings)
930 Turbine building
932 Waste management building
935 Pumping stations
938 Back-up ultimate heat sink building
940 Cooling towers
945 Switchyard (open I enclosed)
946 Seismic I bunkered emergency control building

950 **WASTE MANAGEMENT SYSTEMS**
955 Liquid radwaste
960 Solid radwaste
962 Gaseous radwaste
965 Non-radioactive waste (liquid, solid and gaseous)
968 Steam generator blowdown (secondary side)
970 Plant drainage (floor, roof, etc.)
972 Equipment drainage (including vents)
975 Suppression pool cleanup (BWR)
980 Reactor water cleanup (BWR)

000 **NONE of the above systems or unidentified**

Components (malfunctioning, failed, affected, degraded, WANO 5.4)

Code Description

100 INSTRUMENTATION
110 Neutron flux (detectors, ion chambers, associated components)
120 Pressure
121 Temperature
122 Level
123 Flow
124 Speed measurement
130 Radiation I contamination
140 Concentration
150 Position
160 Dew point, moisture
170 Fire detectors
180 Hydrogen detectors
190 Electrical (current, voltage, power ...)

200 MECHANICAL
210 Pumps, compressors, fans
220 Turbines (steam, gas, hydro), engines (diesel, petrol, etc.)
230 Valves (incl. safety, check, relief & solenoid), valve operators, controllers, dampers (incl. fire dampers), seals and packing, flanges, orifices, drain traps, diaphragm rupture disks
240 Heat exchangers (heaters, coolers, condensers, boilers), heat exchanger tube plugs
250 Tanks, pressure vessels, accumulators (e.g. reactor vessel and internals, accumulators)
260 Tubes, pipes, ducts
270 Fittings, couplings (incl. transmissions & gearboxes), hangers, supports, bearings, snubbers
280 Strainers, screens, filters, ion exchange columns
290 Penetrations/doors (personnel and equipment access, fuel handling)
295 Fuel storage racks, fuel storage casks and fuel transport containers

400 ELECTRICAL
410 Switchyard equipment (switchgear, transformers, buses, reactors, arresters, line isolators)
420 Circuit breakers, power breakers, fuses
430 Motors (for pumps, fans, compressors, motor generators, ...)
440 Generators of emergency and standby power
450 Main generator and auxiliaries
460 Relays, connectors, hand switches, push buttons, contacts
470 Wiring, logic circuitry, controllers, starters, cables
480 Alarms

500 LIFTING DEVICES

600 NUCLEAR ASSEMBLIES
610 Absorber assemblies
620 Fuel assemblies (block type, cluster type and spherical fuel elements are included)
630 Breeder assemblies
640 Flow restrictor (assemblies)
650 Burnable absorber assemblies
660 Reflector assemblies
665 Moderator assemblies
670 Neutron sources
680 Shielding equipment
685 Special assemblies
690 Control rods

700 COMPUTERS
710 Computer hardware
720 Computer software

000 UNIDENTIFIED or no specific component involved
(This code to be used where inappropriate human action is the direct cause of the event).

Groupe (of staff most involved in, or likely to learn from the event, WANO 5.7)

Code Description

100 MAINTENANCE general
110 Shift
120 Electrical
130 Instrument
140 Mechanical
150 Fuel route
160 Civil
170 Work planning or scheduling
200 OPERATIONS general
210 Shift - Control room operators
220 Shift- Field operators
230 Day
240 Fuel route
300 TECHNICAL AND ENGINEERING general
301 System engineering
302 Project engineering
310 Chemistry
320 Plant performance
330 Reactor physics
340 Mechanical
350 Instrument
360 Electrical
370 Health physics
380 Emergency planning
390 Industrial safety
400 MANAGEMENT AND ADMINISTRATION general
410 Planning
420 Contractors
430 QA
440 Training
450 Document production
460 Security
470 Procurement
480 Stores
490 All groups

Root Cause and Causal Factor Codes (WANO 5.9)

ROOT CAUSE: The fundamental cause(s) that, if corrected, will prevent recurrence of an unusual event or adverse condition.

CAUSAL FACTOR: Causes that, if corrected, would not of themselves have prevented the event, but are important enough to be recognised as needing corrective action to improve the quality of the process or the product.

HUMAN PERFORMANCE RELATED (OJ TO 10**), MANAGEMENT RELATED (11** TO 19**), EQUIPMENT RELATED (20 **TO 23 **)**

0100 VERBAL COMMUNICATIONS
0101 Shift hand-over inadequate
0102 Pre-job briefing inadequate I not performed
0103 Message misunderstood I misinterpreted
0104 Communications equipment inadequate or not available
0105 Receiver not listening
0106 Communications incorrect I inadequate
0107 Internal team communication inadequate
0108 Inter-team communication inadequate
0109 Supervisor not notified of problem
0200 PERSONNEL WORK PRACTICES
0201 Self checking not used or ineffectively applied
0202 System alignment I isolation not verified
0203 Required procedures, drawings, or other references not used
0204 Administrative controls circumvented or intentionally not performed
0205 Conditions not verified prior to work
0206 Task not adequately researched prior to start
0207 Unauthorised material substitution
0208 Inadvertent bumping, stepping on, or damage to equipment
0209 Radiological I ALARA work practices not followed
0210 Inattention to detail
0211 Independent checking not used or ineffectively applied
0212 Unsafe working practices applied
0213 Personal protective equipment not used I worn
0214 Improper tools I equipment used
0215 Failure to maintain written logs
0216 Inappropriate habits developed through group pressure I culture
0217 Lack of questioning attitude
0300 PERSONNEL WORK SCHEDULING
0301 Excessive overtime
0302 Called in during unsociable hours
0303 Working continuously for considerable number of hours
0304 Working without rest day for considerable time
0305 Frequent changes of shift
0306 Time pressure to complete task
0307 Unfamiliar work cycle
0400 ENVIRONMENTAL CONDITIONS
0401 Lighting inadequate
0402 Housekeeping inadequate
0403 Temperature too hot I cold
0404 Excessive noise level
0405 High humidity
0406 High radiation

0407 Cramped work space
0408 Distractions

0500 MAN-MACHINE INTERFACE

0501 Label missing I inadequate
0502 Interface design inappropriate for task
0503 Controls provided not adequate
0504 Alarms provided not adequate
0505 Alarm masking I cancelling
0506 Too many standing alarms
0507 Too many incoming alarms
0508 Indications provided not adequate

0600 TRAINING I QUALIFICATION

0601 Training not provided on how to perform a task
0602 Training not provided on how to use special equipment or tools
0603 Training not provided on relevant system(s) I components
0604 Training not based on current plant requirements
0605 Demonstration of task proficiency not required prior to qualification
0606 Insufficient refresher training
0607 Training not attended
0608 Training standard not adequate
0609 Training not provided to required level of competence for task
0610 Training not provided in personnel work practice
0611 Shortfall in on-iob training I experience
0612 Inadequate definition of required qualifications

0700 WRITTEN PROCEDURES AND DOCUMENTS

0701 No document available
0702 Technically incorrect
0703 Technically incomplete
0704 Cautionary information not included
0705 Not up to date with plant design
0706 Not formally stated
0707 Unclear or complex wording
0708 Format deficiencies
0709 User aids deficient I not provided
0710 Inadequate technical review process
0711 Responsibility for following procedure not stated
0712 Inadequate safety assessment provided

0800 SUPERVISORY METHODS

0801 Duties and tasks not clearly explained
0802 Progress not adequately monitored
0803 Supervision levels not decided prior to task
0804 Supervisor too involved in tasks
0805 Inappropriate balance between timescale and standards
0806 Standards not adequately communicated
0807 Control of contractors inadequate
0808 Frequent task re-allocation
0809 Inappropriate selection of staff for task
0810 Safety aspects of task not emphasised

0900 WORK ORGANISATION

0901 Planning done without site visit
0902 Special conditions or requirements not identified
0903 Co-ordination of all relevant on-site departments not achieved
0904 Work initiated prior to ensuring all skills, parts, tools, instruments, etc., are available
0905 Job walk through not performed
0906 Work package did not address all administrative requirements
0907 Scheduling conflicts not identified
0908 Task or routine not assigned
0909 Too few workers allocated to task
0910 Too few workers of the correct trade I specialisation
0911 Co-ordination of relevant on-site and off-site departments not achieved
0912 Planning of parallel tasks inadequate

1000 PERSONAL FACTORS

1001 Fatigue
1002 Stress I perceived lack of time I boredom
1003 Skill of the craft less than adequate I not familiar with job performance standards

1100 MANAGEMENT DIRECTION

1110 Policies, official guidance (standards), expectations, administrative controls:- not developed
1120 Policies, official guidance (standards), expectations, administrative controls:- not enforced
1130 Policies, official guidance (standards), expectations, administrative controls:- not adequate (not strict enough, confusing or incomplete)

1200 COMMUNICATION OR CO-ORDINATION

1210 Policies, official guidance (standards), expectations, administrative controls not communicated effectively within the organisation
1220 Familiarity of workers with relevant policies and/or official guidance not verified
1230 Inadequate coordination/communication between departments
1240 Coordination/communication not sufficiently promoted by management
1250 Inadequate communication between management and plant staff, inadequate feedback from plant staff to management, employee concerns fail to reach management attention
1260 No prompt responses to employee concerns

1300 MANAGEMENT MONITORING AND ASSESSMENT

1310 Inadequate level of management involvement
1320 Inadequate establishment/support of programs or processes
1330 Inadequate monitoring of the effectiveness of programs or processes
1340 Inadequate monitoring of results of decisions/assignments
1350 Inadequate assessment of the effectiveness of corrective actions
1360 Inadequate assessment of personnel behaviour and performance

1400 DECISION PROCESS

1410 Officially designated responsibilities and accountabilities unclear
1420 Decision process too lengthy/time consuming
1430 Decisions based on insufficient information
1440 Risks and consequences of decision not identified or assessed before decision made
1450 Management objectives did not encompass known problems
1460 Management objective did not reflect a relevant constraint
1470 Inadequate operating experience feedback process (corrective actions not defined,

Inadequate or not implemented promptly, root causes of known problems not addressed)
1480 Improvement campaigns ineffective

1500 ALLOCATION OF RESOURCES

1510 Insufficient resources allocated for identified objectives (includes resources such as training, supervision, documentation, tools, materials, and equipment)

1600 CHANGE MANAGEMENT

1610 Need for change, further change not identified
1620 Change not implemented in adequate timescale
1630 Inadequate resourcing of change
1640 Consequences of change not adequately assessed
1650 Change-related training/briefing inadequate
1660 Change-related documentation alteration inadequate
1670 Change-related equipment provision inadequate
1680 Results of change not monitored for correctness

1700 ORGANISATIONAL/SAFETY CULTURE

1710 Punitive responses to genuine slips or mistakes
1720 Lack of blame-free reporting culture
1730 Staff do not have "do it right the first time" attitude
1740 Taking of short-cuts allowed/tolerated
1750 Low morale among plant staff
1760 Recurrent violation of rules
1770 General lack of questioning attitude
1780 Lack of conservative approach in control room
1790 Lack of teamwork in control room

1800 MANAGEMENT OF CONTINGENCIES

1810 Organisation unprepared to handle unforeseen events
1820 No management oversight of problem-solving by workers for unforeseen events
1830 Weaknesses in emergency preparedness
1840 Weaknesses in contingency planning

2000 DESIGN C ONFIGURATION AND ANALYSIS

2001 Original design inadequate
2002 Design documentation I prints inadequate
2003 Design analysis deficiency
2004 Component selection inadequate
2005 Material selection inadequate
2006 Unauthorised or unreviewed modification
2007 Inadequate review of design changes
2008 Field walk through input to design inadequate
2009 Historical design does not meet current requirements
2010 Inappropriate reliance on human action
2011 Deficiency in engineering of modification

2100 EQUIPMENT SPECIFICATION, MANUFACTURE, AND CONSTRUCTION

2101 Material used inadequate
2102 Manufacturer fabrication I construction inadequate
2103 Specifications provided to manufacturer inadequate
2104 Substitute parts I material used during installation
2105 Lack of proper tools I materials used do not meet specifications
2106 Installation workmanship inadequate
2107 QA requirements not used or met during procurement process
2108 Equipment installed does not meet all codes I requirements
2109 Post procurement requirements not used I performed

2200 **MAINTENANCE I TESTING I SURVEILLANCES**

2201 Corrective maintenance did not correct problems
2202 Other problems noted during the performance of maintenance I testing not corrected
2203 Preventive maintenance inadequate
2204 Maintenance performed incorrectly
2205 Testing not performed as required
2206 Post-maintenance testing inadequate
2207 Post-modification testing inadequate
2208 Retest requirements not specified
2209 Retest delayed
2210 Test acceptance criteria inadequate
2211 Test results review inadequate
2212 Surveillance schedule not followed
2213 Situational surveillance not performed
2214 Required surveillance I test not scheduled
2215 Equipment outside acceptance criteria
2216 Incorrect parts I consumables installed I used
2217 Failure to exclude foreign material
2218 Incorrect restoration of plant following maintenance I isolation I testing

2300 **EQUIPMENT PERFORMANCE**

2301 Equipment operated outside of design specifications
2302 Ageing of component
2303 Known problems not corrected
2304 Degraded sub-component contributed to failure
2305 Component monitoring inadequate
2306 Component beyond expected lifetime
2307 Externally damaging condition not properly evaluated or correlated
2308 Equipment erosion I corrosion
2309 Failed within expected lifetime

8.3 Database structure

This section provides the detailed description of the Microsoft Access database.

H:\Desktop\OPERATE_DBx.accdb **12 June 2014**

Table: OPERATE

Properties

DatasheetGridlinesTh	-1	DateCreated:	03/09/2013 19:06:15
DefaultView:	2	DisplayViewsOnShar	1
FilterOnLoad:	False	GUID:	{guid {0BB49770-ECDA-4C98-AA75-
HideNewField:	False	LastUpdated:	24/01/2014 09:29:05
NameMap:	Long binary data	OrderBy:	[OPERATE].[Date]
OrderByOn:	True	OrderByOnLoad:	True
Orientation:	Left-to-Right	PublishToWeb:	1
RecordCount:	1479	ThemeFontIndex:	-1
TotalsRow:	False	Updatable:	True

Columns

Name	Type	Size
LER	Text	12
Plant	Text	6
Vendor	Text	8
Rtype	Text	4
OpComm	Text	8
Date	Date/Time	8
Time	Date/Time	8
SD_O_ext	Double	8
CATEGORY	Integer	2
STATUS	Integer	2
ACTIVITY	Integer	2
GROUP	Integer	2
D_CAUSE	Integer	2
MULTY	Integer	2
SAFETY	Integer	2
CONS1	Integer	2
Cons2	Integer	2
Cons3	Integer	2
SYS1	Integer	2
SYS2	Integer	2
SYS3	Integer	2
COMP1	Integer	2
COMP2	Integer	2
COMP3	Integer	2
RC_C1	Integer	2
RC_C2	Integer	2
RC_C3	Integer	2

Table Indexes

Name		Number of
LER		1
Fields:		
LER	Ascending	

Table: Activity

Properties

PublishToWeb:	1	RecordCount:	23
ThemeFontIndex:	1	TotalsRow:	False
Updatable:	True		

Columns

Name	Type	Size
ID	Byte	1
Description	Text	124

Table Indexes

Name	Number of	
PrimaryKey	1	
Fields:	ID	Ascending

Table: Category

Properties

PublishToWeb:	1	RecordCount:	9
ThemeFontIndex:	1	TotalsRow:	False
Updatable:	True		

Columns

Name	Type	Size
ID	Byte	1
Description	Text	124

Table Indexes

Name	Number of	
PrimaryKey	1	
Fields:	ID	Ascending

Table: Component

Properties

PublishToWeb:	1	RecordCount:	8
ThemeFontIndex:	1	TotalsRow:	False
Updatable:	True		

Columns

Name	Type	Size
ID	Integer	2
Description	Text	124

Table Indexes

Name	Number of	
PrimaryKey	1	
Fields:	ID	Ascending

Table: Consequence

Properties

PublishToWeb:	1	RecordCount:	10
ThemeFontIndex:	1	TotalsRow:	False
Updatable:	True		

Columns

Name	Type	Size
ID	Byte	1
Description	Text	124

Table Indexes

Name	Number of

PrimaryKey	1	
Fields:	ID	Ascending

Table: D_Cause

Properties

PublishToWeb:	1	RecordCount:	9
ThemeFontIndex:	1	TotalsRow:	False
Updatable:	True		

Columns

Name	Type	Size
ID	Integer	2
Description	Text	124

Table Indexes

Name	Number of	
PrimaryKey	1	
Fields:	ID	Ascending

Table: Group

Properties

PublishToWeb:	1	RecordCount:	4
ThemeFontIndex:	1	TotalsRow:	False
Updatable:	True		

Columns

Name	Type	Size
ID	Integer	2
Description	Text	124

Table Indexes

Name	Number of	
PrimaryKey	1	
Fields:	ID	Ascending

Table: Multiple

Properties

PublishToWeb:	1	RecordCount:	4
ThemeFontIndex:	1	TotalsRow:	False
Updatable:	True		

Columns

Name	Type	Size
ID	Byte	1
Description	Text	124

Table Indexes

Name	Number of	
PrimaryKey	1	
Fields:	ID	Ascending

Table: Plant

Properties

PublishToWeb:	1	RecordCount:	118
ThemeFontIndex:	-1	TotalsRow:	False
Updatable:	True		

Columns

Name	Type	Size
ID	Integer	2
Description	Text	255
ID0	Text	255
Plant	Text	255
Type	Text	255
Model	Text	255
COUNTRY	Text	255
Pt_MW	Double	8
Pe_MW	Double	8
Peg_MW	Double	8
Status	Text	255
Vendor	Text	255
Grid	Date/Time	8
Commercial	Date/Time	8
Shutdown	Date/Time	8

Table Indexes

Name		Number of	
Grid		1	
Fields:	Grid		Ascending
ID		1	
Fields:	ID		Ascending
ID0		1	
Fields:	ID0		Ascending

Table: RC_Causal

Properties

PublishToWeb:	1	RecordCount:	22
ThemeFontIndex:	1	TotalsRow:	False
Updatable:	True		

Columns

Name	Type	Size
ID	Integer	2
Description	Text	124

Table Indexes

Name		Number of	
PrimaryKey		1	
Fields:	ID		Ascending

Table: Safety

Properties

PublishToWeb:	1	RecordCount:	3
ThemeFontIndex:	1	TotalsRow:	False
Updatable:	True		

Columns

Name	Type	Size
ID	Byte	1
Description	Text	124

Table Indexes

Name	Number of

Name	Number of	
PrimaryKey	1	
Fields:	ID	Ascending

Table: Status

Properties

PublishToWeb:	1	RecordCount:	11
ThemeFontIndex:	1	TotalsRow:	False
Updatable:	True		

Columns

Name	Type	Size
ID	Integer	2
Description	Text	124

Table Indexes

Name		Number of	
PrimaryKey		1	
Fields:	ID		Ascending

Table: System

Properties

PublishToWeb:	1	RecordCount:	11
ThemeFontIndex:	1	TotalsRow:	False
Updatable:	True		

Columns

Name	Type	Size
ID	Integer	2
Description	Text	124

Table Indexes

Name		Number of	
PrimaryKey		1	
Fields:	ID		Ascending

Table: Vendor

Properties

Orientation:	Left-to-Right	PublishToWeb:	1
RecordCount:	6	ThemeFontIndex:	1
TotalsRow:	False	Updatable:	True

Columns

Name	Type	Size
Code	Text	8
Vendor	Text	25
ID	Long Integer	4
Description	Text	255

Table Indexes

Name		Number of	
ID		1	
Fields:	ID		Ascending
PrimaryKey		1	
Fields:	Code		Ascending

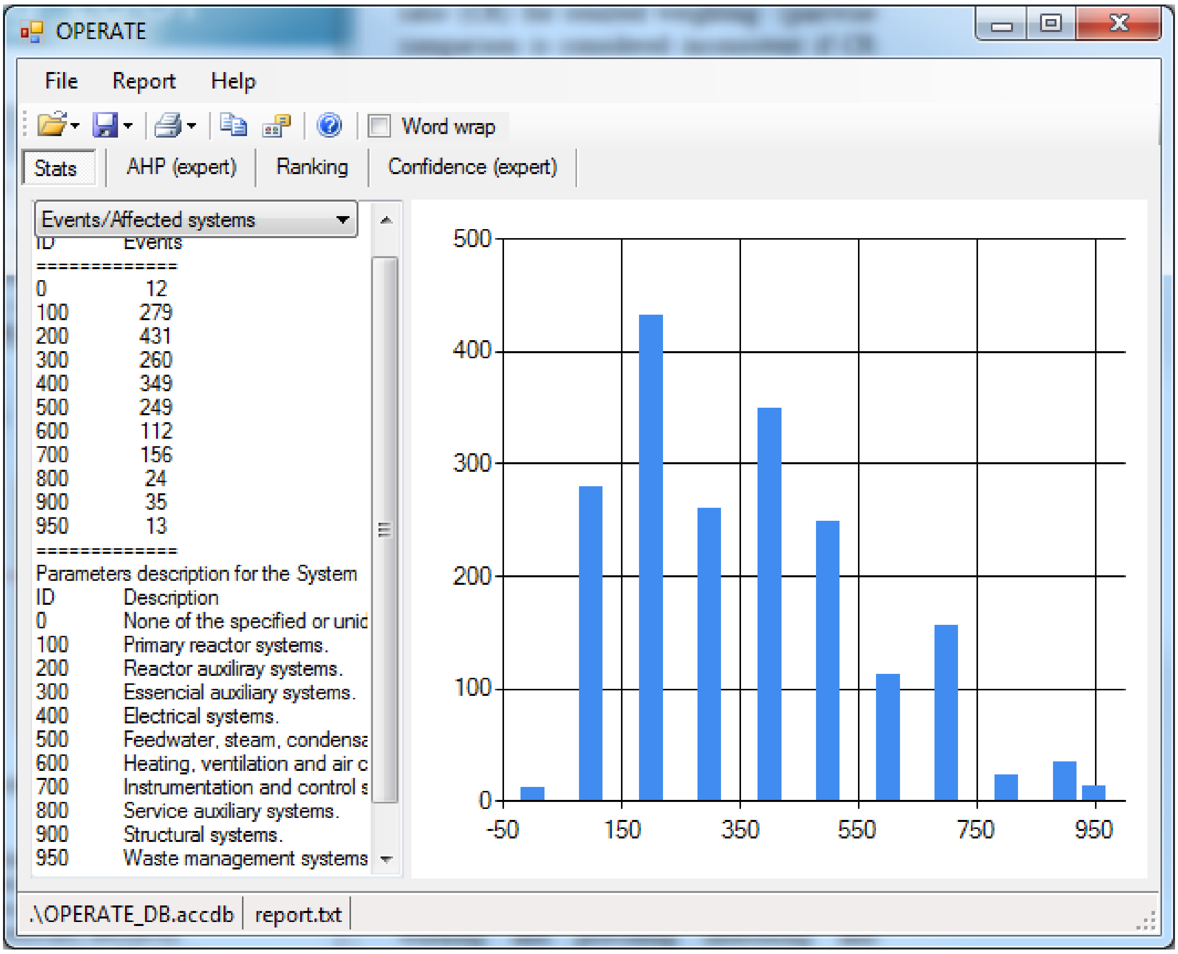
8.4 Tool and results illustrations

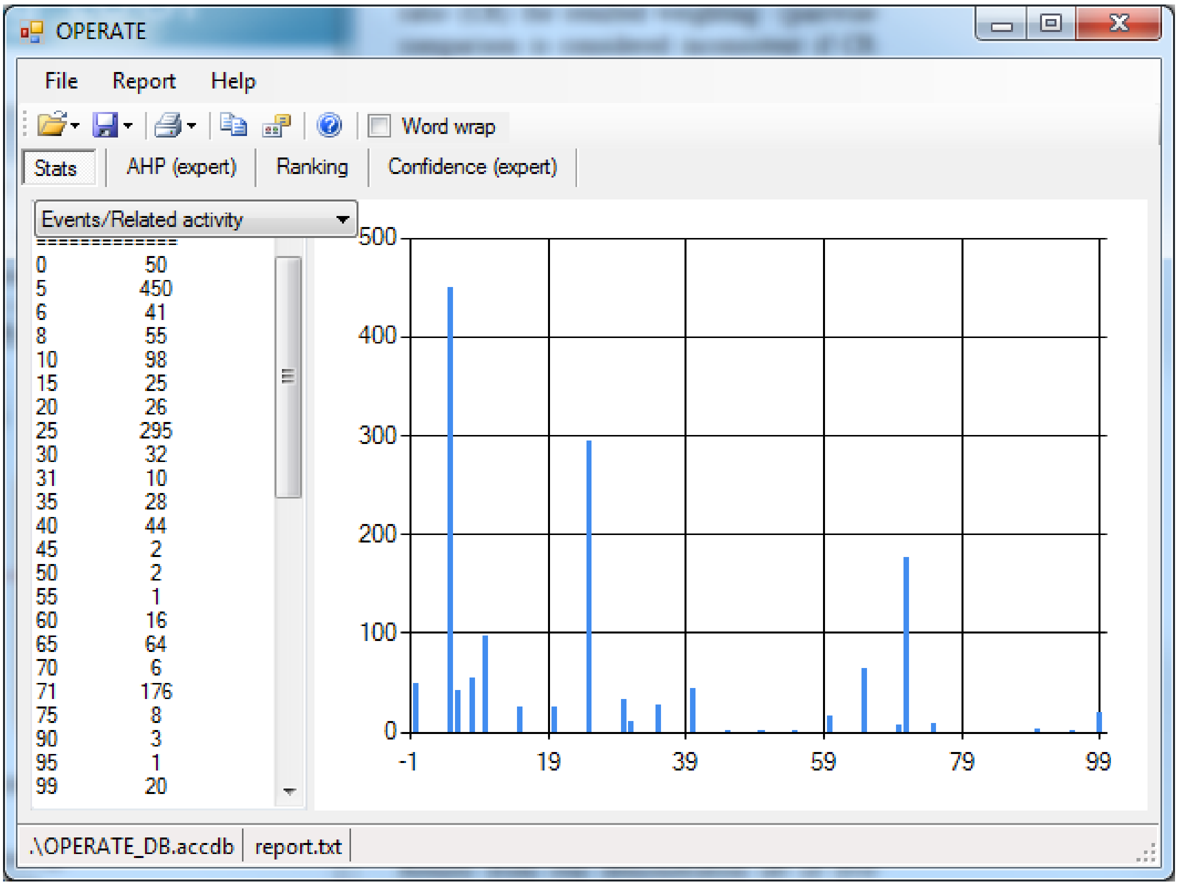
This section is presenting more detailed results and tool illustrations.

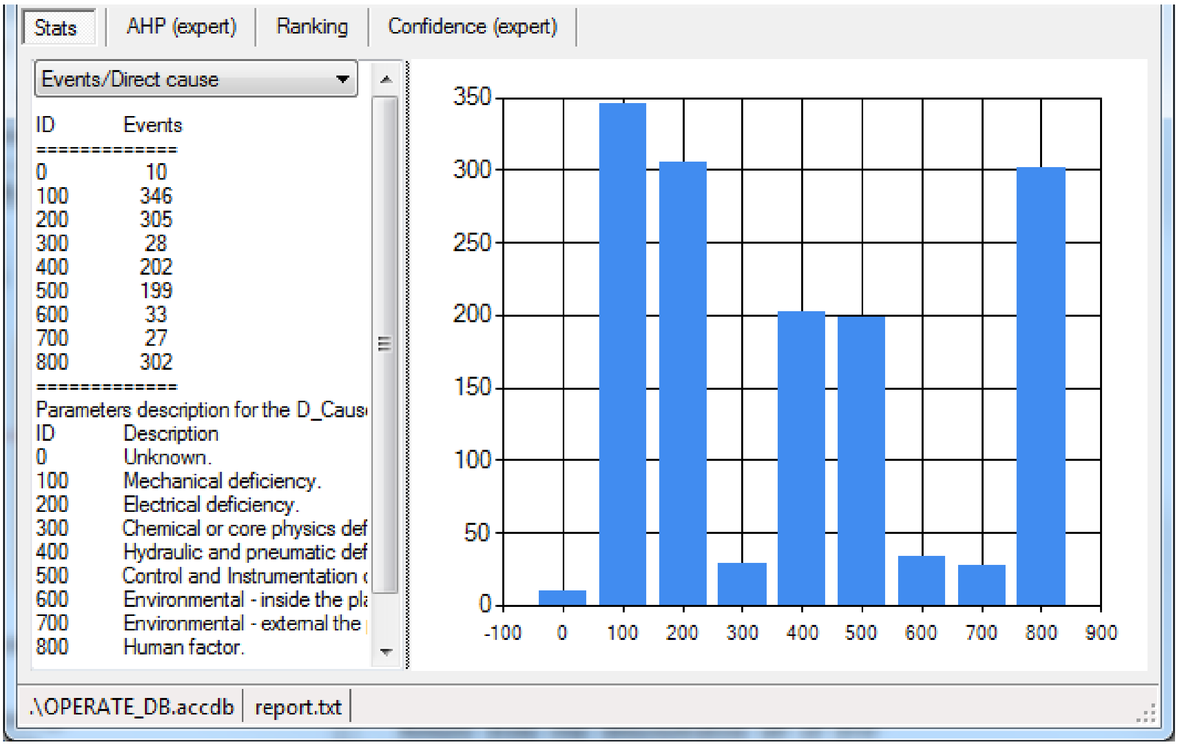
The following subsections are illustrating all the statistical reports, all the groups ranking results, and the complete confidence (uncertainty and sensitivity) results for one event group.

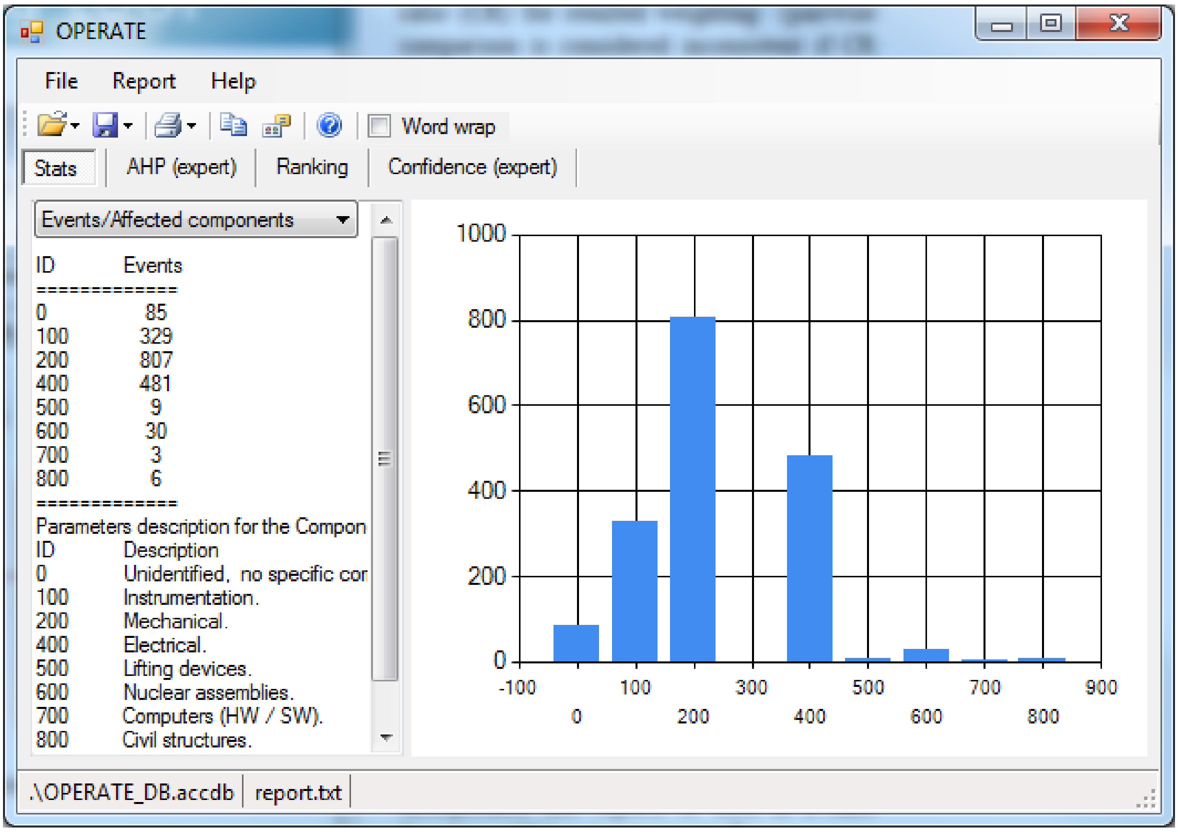
8.4.1 Illustration for all the available statistical reports

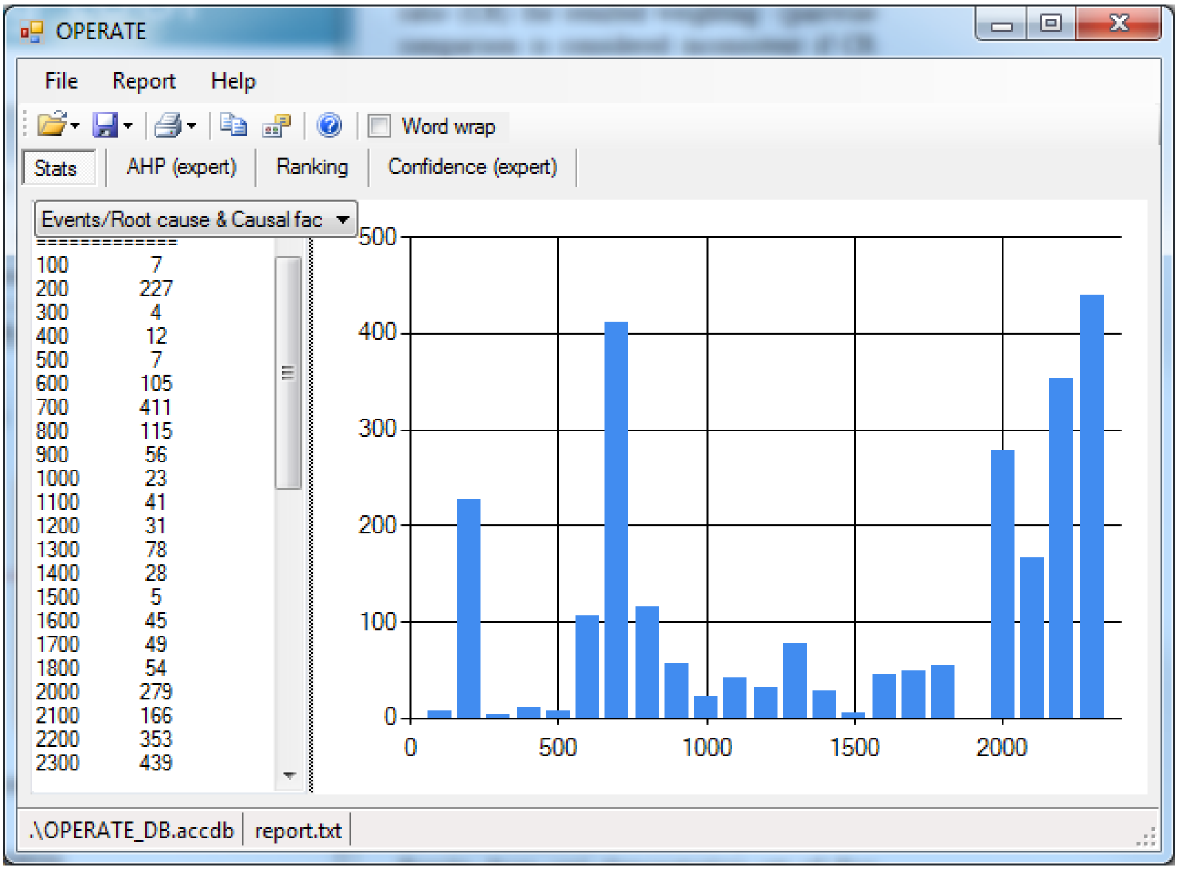
This is the illustration for all the available reports. For the attributes where an ID description is not visible on the figure it can be found in this Appendix inside the previous subsection.

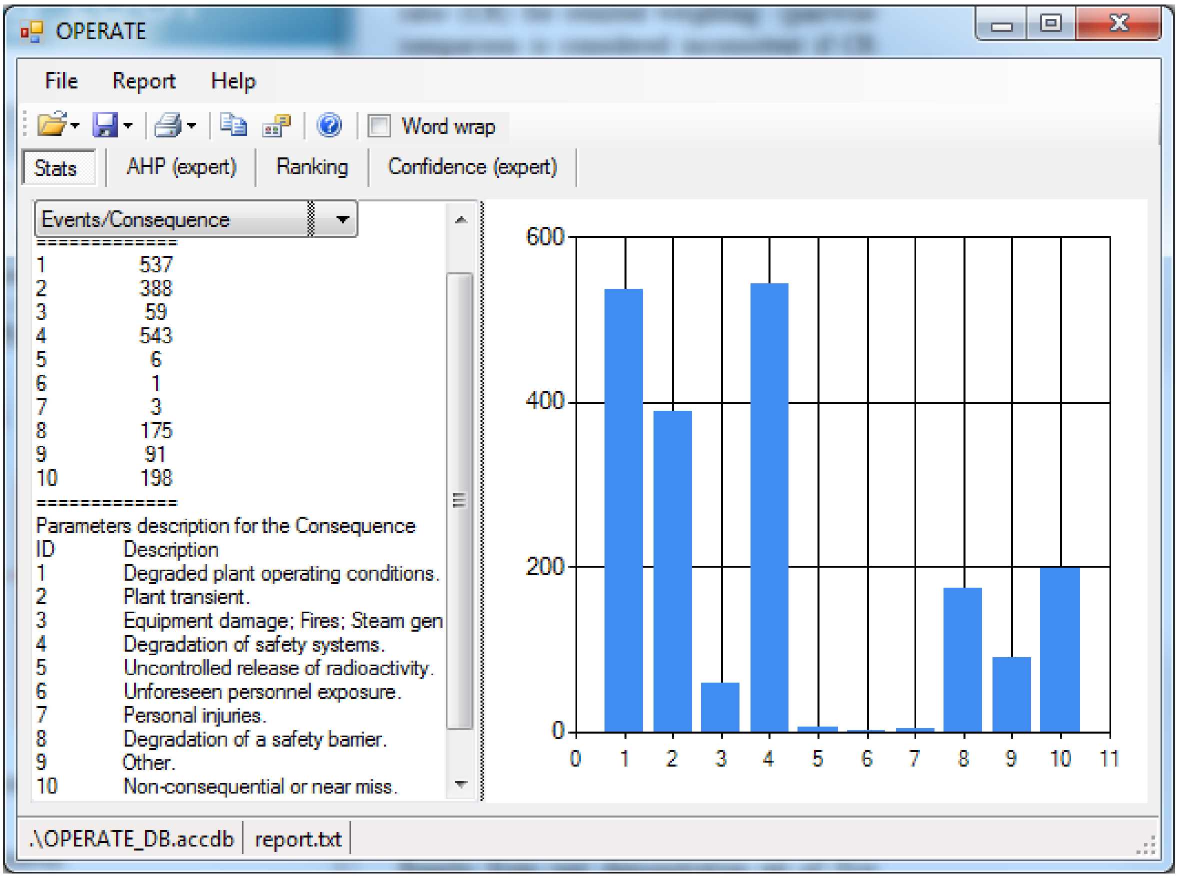


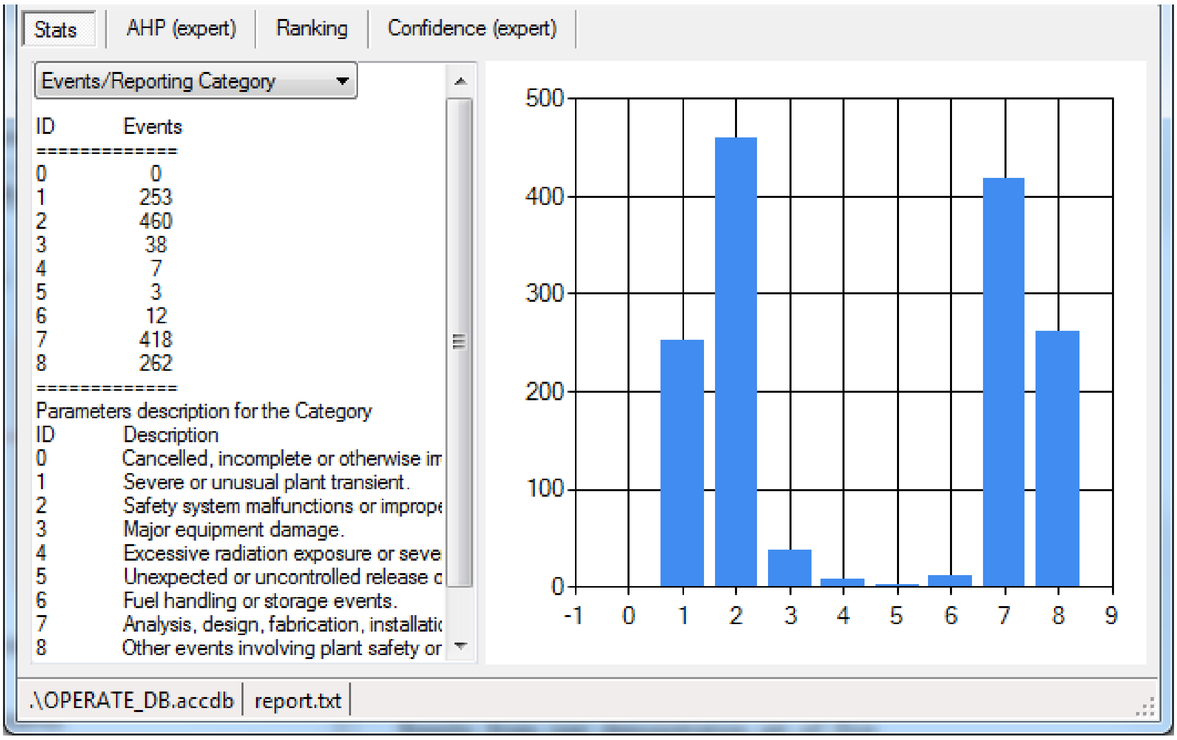

OPERATE
File
Report
Help
Word wrap
Stats
AHP (expert)
Ranking
Confidence (expert)
Events/Related activity
=============
0 50
5 450
6 41
8 55
10 98
15 25
20 26
25 295
30 32
31 10
35 28
40 44
45 2
50 2
55 1
60 16
65 64
70 6
71 176
75 8
90 3
95 1
99 20
500
400
300
200
100
0
-1
19
39
59
79
99
.\OPERATE_DB.accdb
report.txt

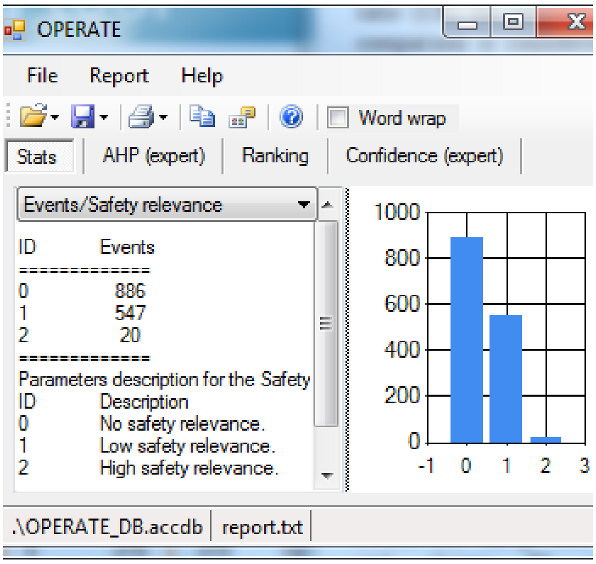

Stats
AHP (expert)
Ranking
Confidence (expert)
Events/Direct cause
ID Events
=============
0 10
100 346
200 305
300 28
400 202
500 199
600 33
700 27
800 302
=============
Parameters description for the D_Caus
ID Description
0 Unknown.
100 Mechanical deficiency.
200 Electrical deficiency.
300 Chemical or core physics def
400 Hydraulic and pneumatic def
500 Control and Instrumentation
600 Environmental - inside the pl
700 Environmental - external the
800 Human factor.
350
300
250
200
150
100
50
0
-100
0
100
200
300
400
500
600
700
800
900
.\OPERATE_DB.accdb
report.txt

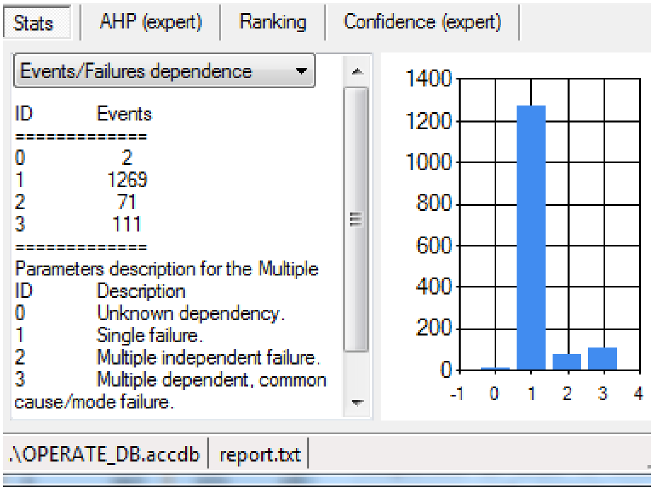

OPERATE
File Report Help
Word wrap
Stats AHP (expert) Ranking Confidence (expert)
Events/Affected components
ID Events
=============
0 85
100 329
200 807
400 481
500 9
600 30
700 3
800 6
=============
Parameters description for the Compon
ID Description
0 Unidentified, no specific cor
100 Instrumentation.
200 Mechanical.
400 Electrical.
500 Lifting devices.
600 Nuclear assemblies.
700 Computers (HW / SW).
800 Civil structures.
1000 800 600 400 200 0
-100 0 100 200 300 400 500 600 700 800 900
.\OPERATE_DB.accdb report.txt

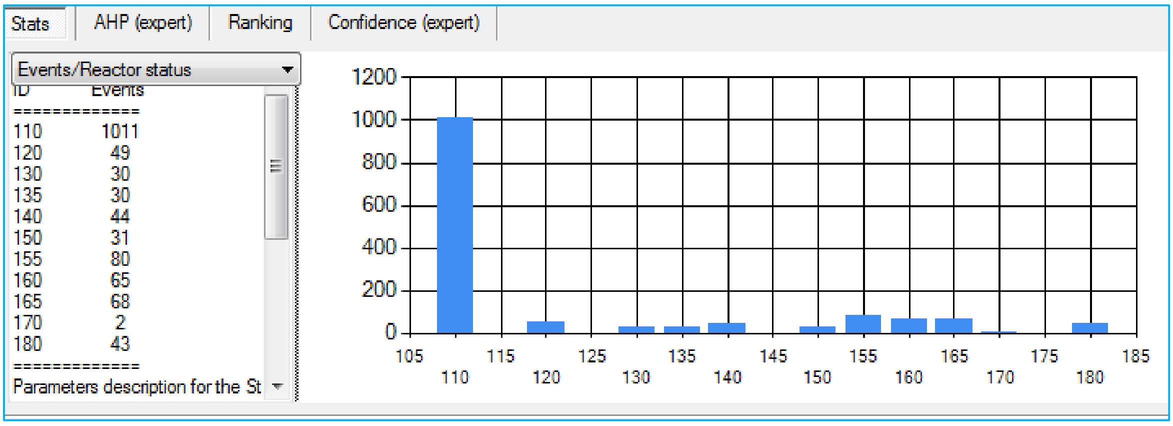

OPERATE
File Report Help
Word wrap
Stats AHP (expert) Ranking Confidence (expert)
Events/Root cause & Causal fac
=============
100 7
200 227
300 4
400 12
500 7
600 105
700 411
800 115
900 56
1000 23
1100 41
1200 31
1300 78
1400 28
1500 5
1600 45
1700 49
1800 54
2000 279
2100 166
2200 353
2300 439
500 400 300 200 100 0
0 500 1000 1500 2000
.\OPERATE_DB.accdb report.txt

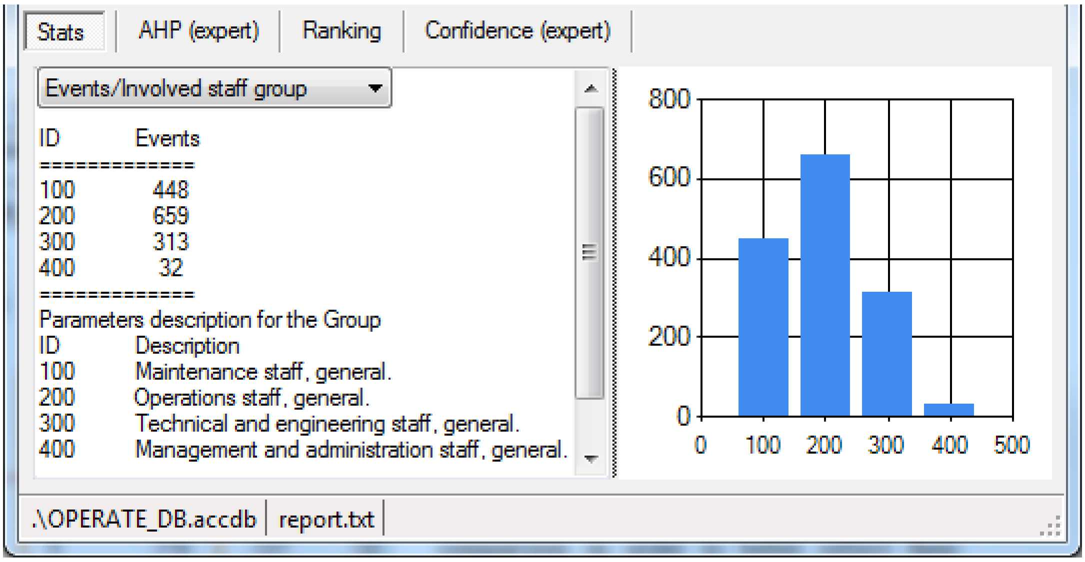

OPERATE
File
Report
Help
Word wrap
Stats
AHP (expert)
Ranking
Confidence (expert)
Events/Consequence
=============
1 537
2 388
3 59
4 543
5 6
6 1
7 3
8 175
9 91
10 198
=============
Parameters description for the Consequence
ID Description
1 Degraded plant operating conditions.
2 Plant transient.
3 Equipment damage; Fires; Steam gen
4 Degradation of safety systems.
5 Uncontrolled release of radioactivity.
6 Unforeseen personnel exposure.
7 Personal injuries.
8 Degradation of a safety barrier.
9 Other.
10 Non-consequential or near miss.
600
400
200
0
0 1 2 3 4 5 6 7 8 9 10 11
.\OPERATE_DB.accdb
report.txt

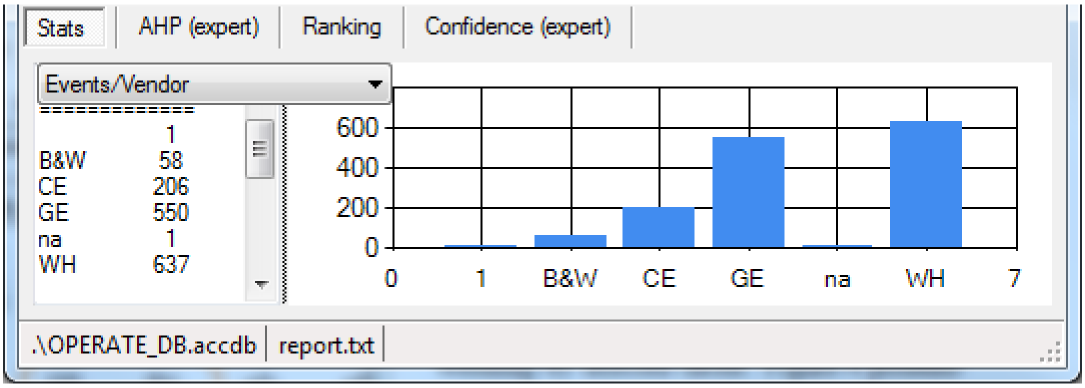

Stats
AHP (expert)
Ranking
Confidence (expert)
Events/Reporting Category
ID Events
=============
0 0
1 253
2 460
3 38
4 7
5 3
6 12
7 418
8 262
=============
Parameters description for the Category
ID Description
0 Cancelled, incomplete or otherwise im
1 Severe or unusual plant transient.
2 Safety system malfunctions or imprope
3 Major equipment damage.
4 Excessive radiation exposure or seve
5 Unexpected or uncontrolled release c
6 Fuel handling or storage events.
7 Analysis, design, fabrication, installatic
8 Other events involving plant safety or
500
400
300
200
100
0
-1 0 1 2 3 4 5 6 7 8 9
.\OPERATE_DB.accdb
report.txt

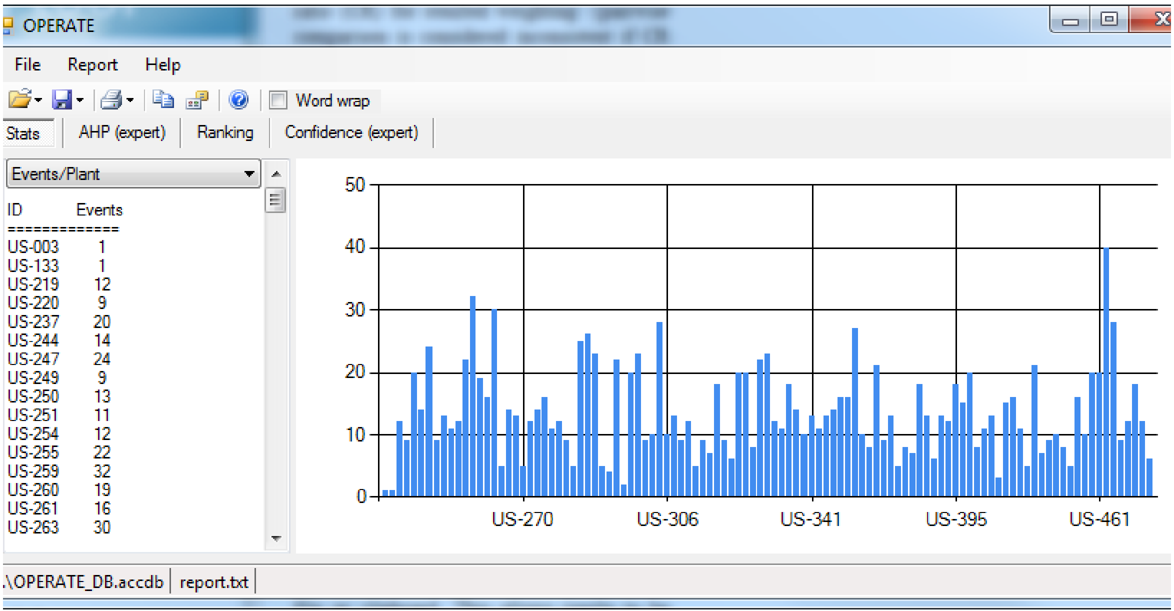

OPERATE
File
Report
Help
Word wrap
Stats
AHP (expert)
Ranking
Confidence (expert)
Events/Safety relevance
ID Events
=============
0 886
1 547
2 20
=============
Parameters description for the Safety
ID Description
0 No safety relevance.
1 Low safety relevance.
2 High safety relevance.
.\OPERATE_DB.accdb
report.txt

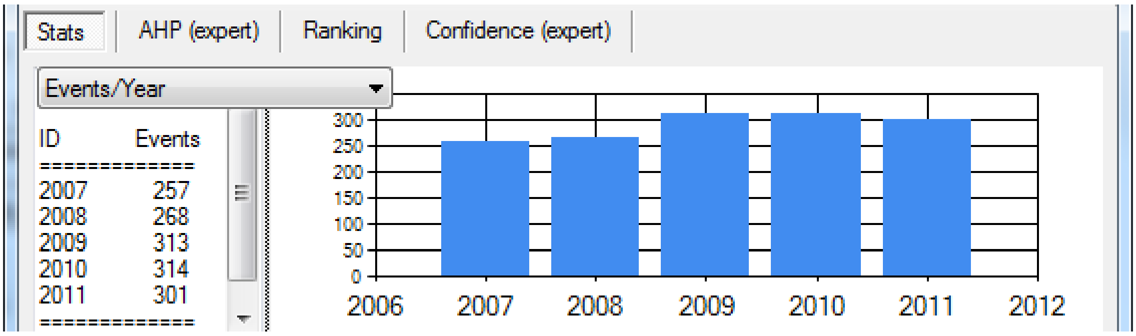

Stats
AHP (expert)
Ranking
Confidence (expert)
Events/Failures dependence
ID Events
=============
0 2
1 1269
2 71
3 111
=============
Parameters description for the Multiple
ID Description
0 Unknown dependency.
1 Single failure.
2 Multiple independent failure.
3 Multiple dependent, common cause/mode failure.
.\OPERATE_DB.accdb
report.txt

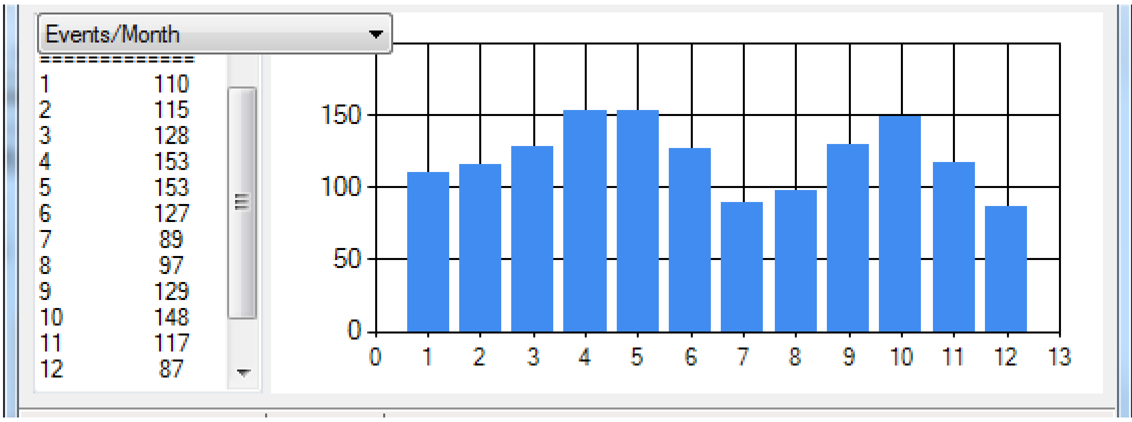

Stats
AHP (expert)
Ranking
Confidence (expert)
Events/Reactor status
ID Events
=============
110 1011
120 49
130 30
135 30
140 44
150 31
155 80
160 65
165 68
170 2
180 43
=============
Parameters description for the St

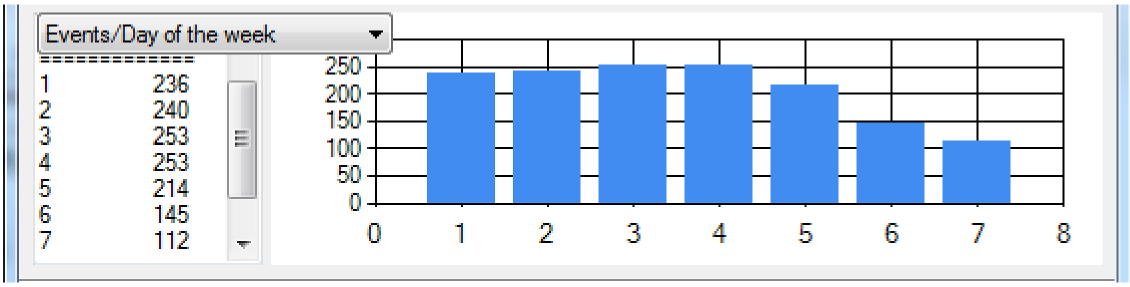

Stats
AHP (expert)
Ranking
Confidence (expert)
Events/Involved staff group
ID Events
=============
100 448
200 659
300 313
400 32
=============
Parameters description for the Group
ID Description
100 Maintenance staff, general.
200 Operations staff, general.
300 Technical and engineering staff, general.
400 Management and administration staff, general.
.\OPERATE_DB.accdb
report.txt

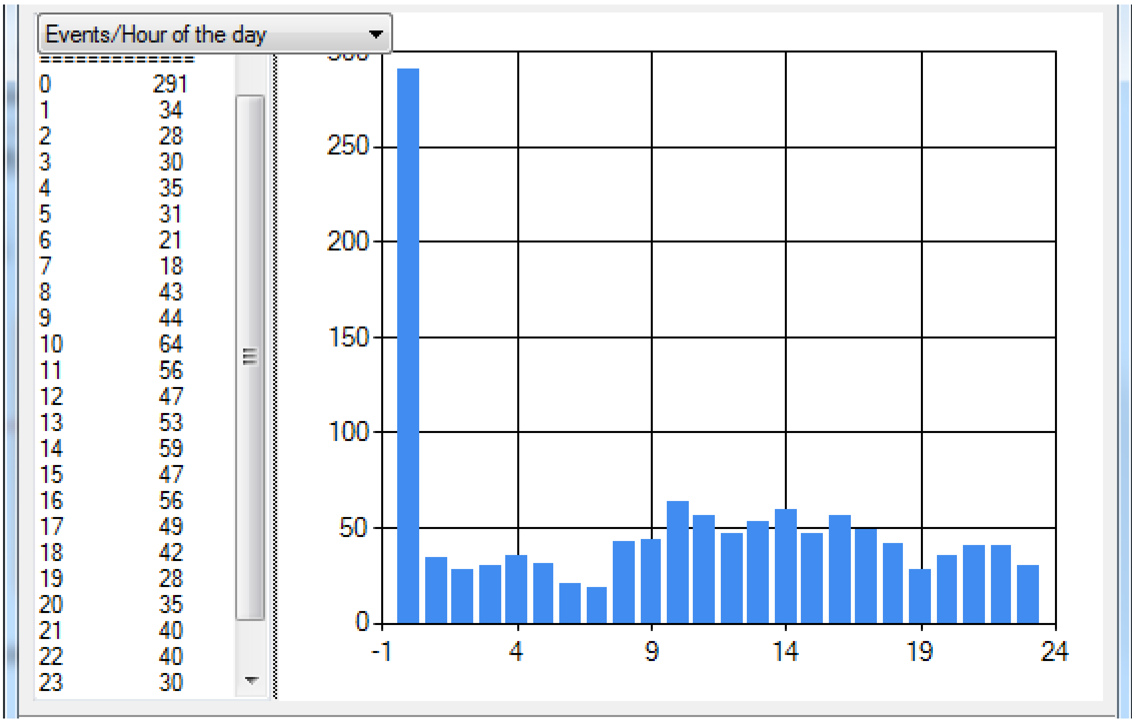

Stats
AHP (expert)
Ranking
Confidence (expert)
Events/Vendor
=============
1
B&W 58
CE 206
GE 550
na 1
WH 637
600
400
200
0
0
1
B&W
CE
GE
na
WH
7
.\OPERATE_DB.accdb
report.txt

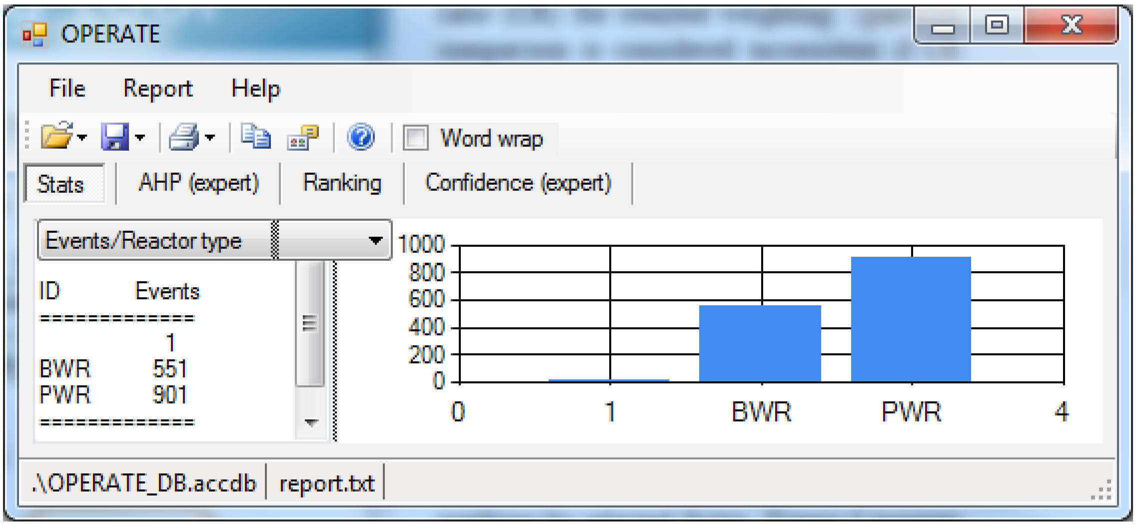

OPERATE
File
Report
Help
Word wrap
Stats
AHP (expert)
Ranking
Confidence (expert)
Events/Plant
ID Events
============
US-003 1
US-133 1
US-219 12
US-220 9
US-237 20
US-244 14
US-247 24
US-249 9
US-250 13
US-251 11
US-254 12
US-255 22
US-259 32
US-260 19
US-261 16
US-263 30
50
40
30
20
10
0
US-270
US-306
US-341
US-395
US-461
.\OPERATE_DB.accdb
report.txt

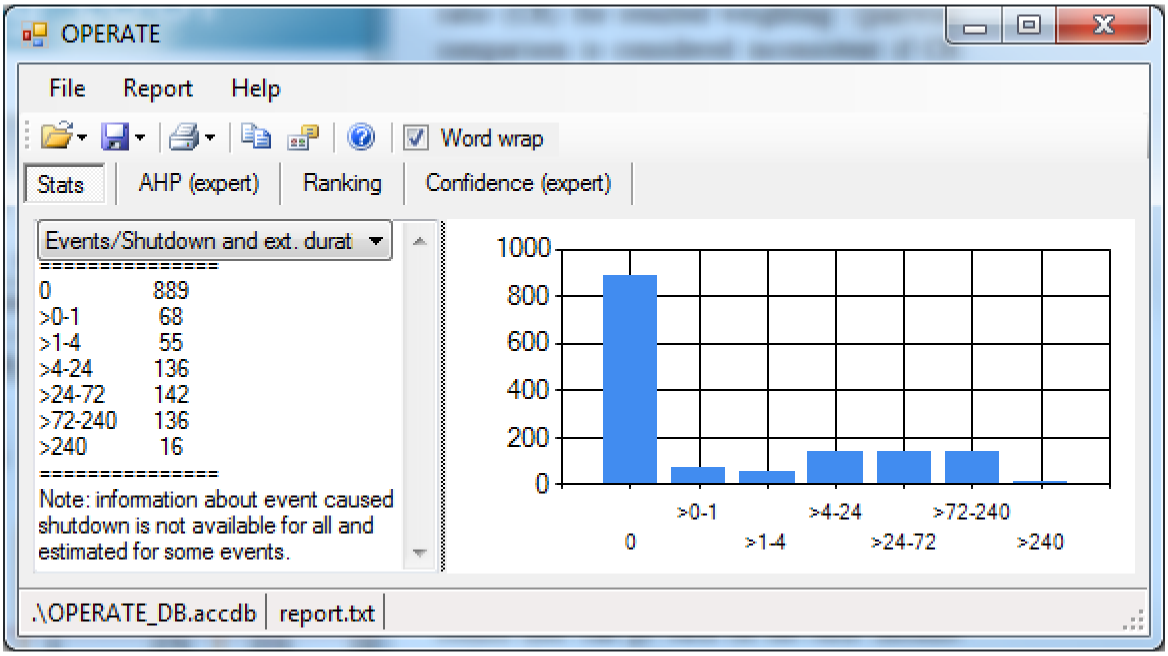

Stats
AHP (expert)
Ranking
Confidence (expert)
Events/Year
ID Events
=============
2007 257
2008 268
2009 313
2010 314
2011 301
=============
300
250
200
150
100
50
0
2006
2007
2008
2009
2010
2011
2012


Events/Month
=============
1 110
2 115
3 128
4 153
5 153
6 127
7 89
8 97
9 129
10 148
11 117
12 87
0 50 100 150
0 1 2 3 4 5 6 7 8 9 10 11 12 13


Events/Day of the week
=============
1 236
2 240
3 253
4 253
5 214
6 145
7 112
0 50 100 150 200 250
0 1 2 3 4 5 6 7 8

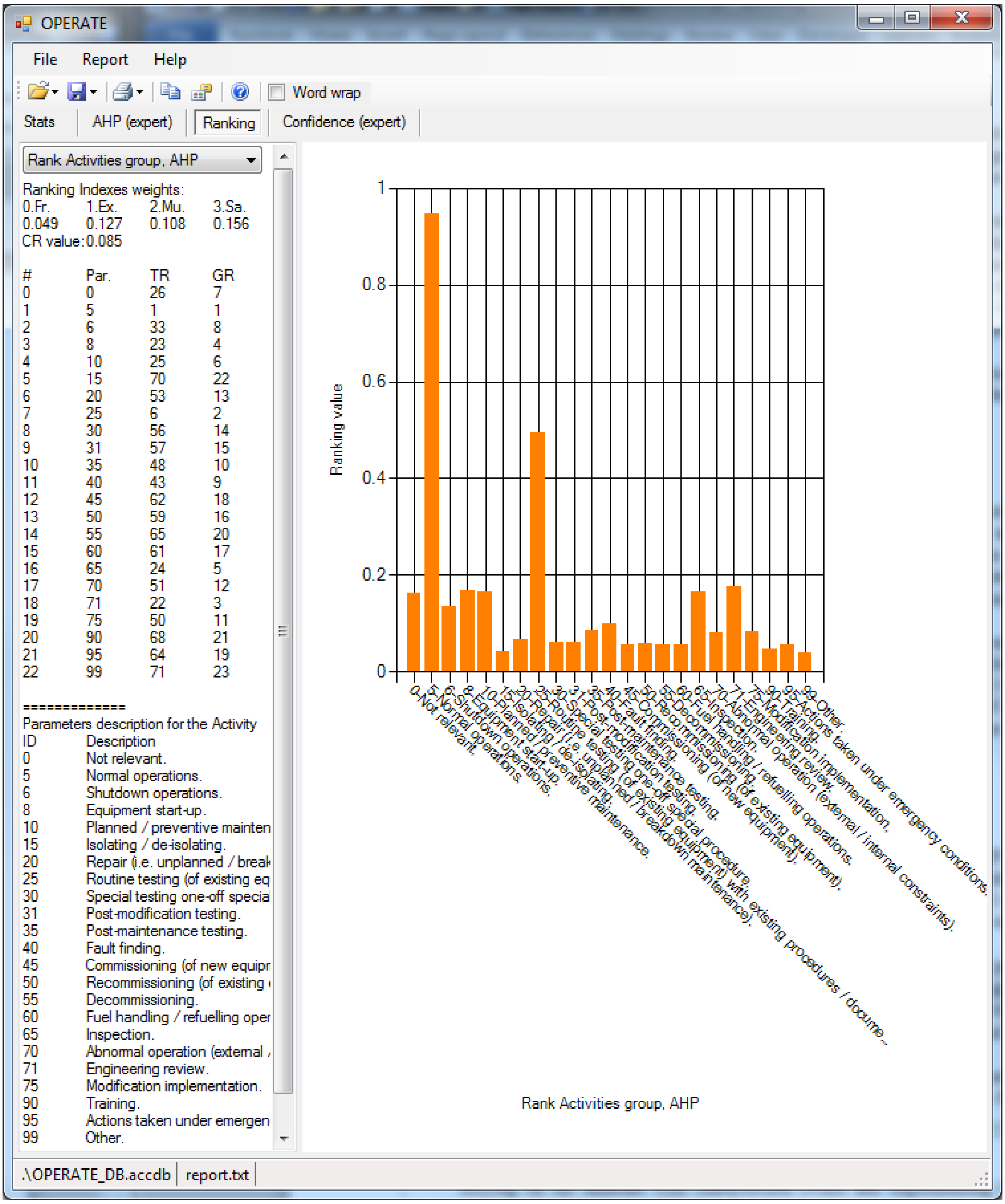

Events/Hour of the day
=============
0 291
1 34
2 28
3 30
4 35
5 31
6 21
7 18
8 43
9 44
10 64
11 56
12 47
13 53
14 59
15 47
16 56
17 49
18 42
19 28
20 35
21 40
22 40
23 30
0 50 100 150 200 250
-1 4 9 14 19 24

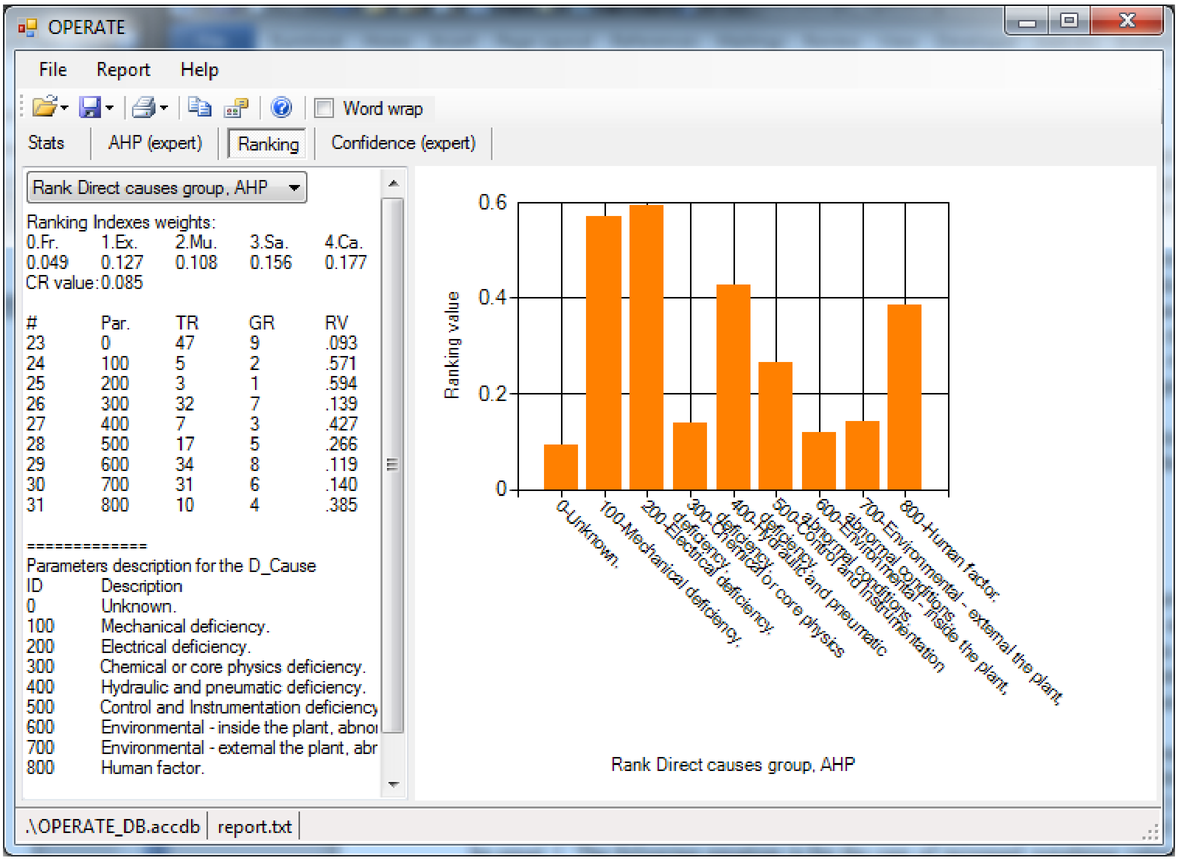

OPERATE
File
Report
Help
Word wrap
Stats
AHP (expert)
Ranking
Confidence (expert)
Events/Reactor type
ID Events
=============
1
BWR 551
PWR 901
=============
1000
800
600
400
200
0
0
1
BWR
PWR
4
.\OPERATE_DB.accdb
report.txt

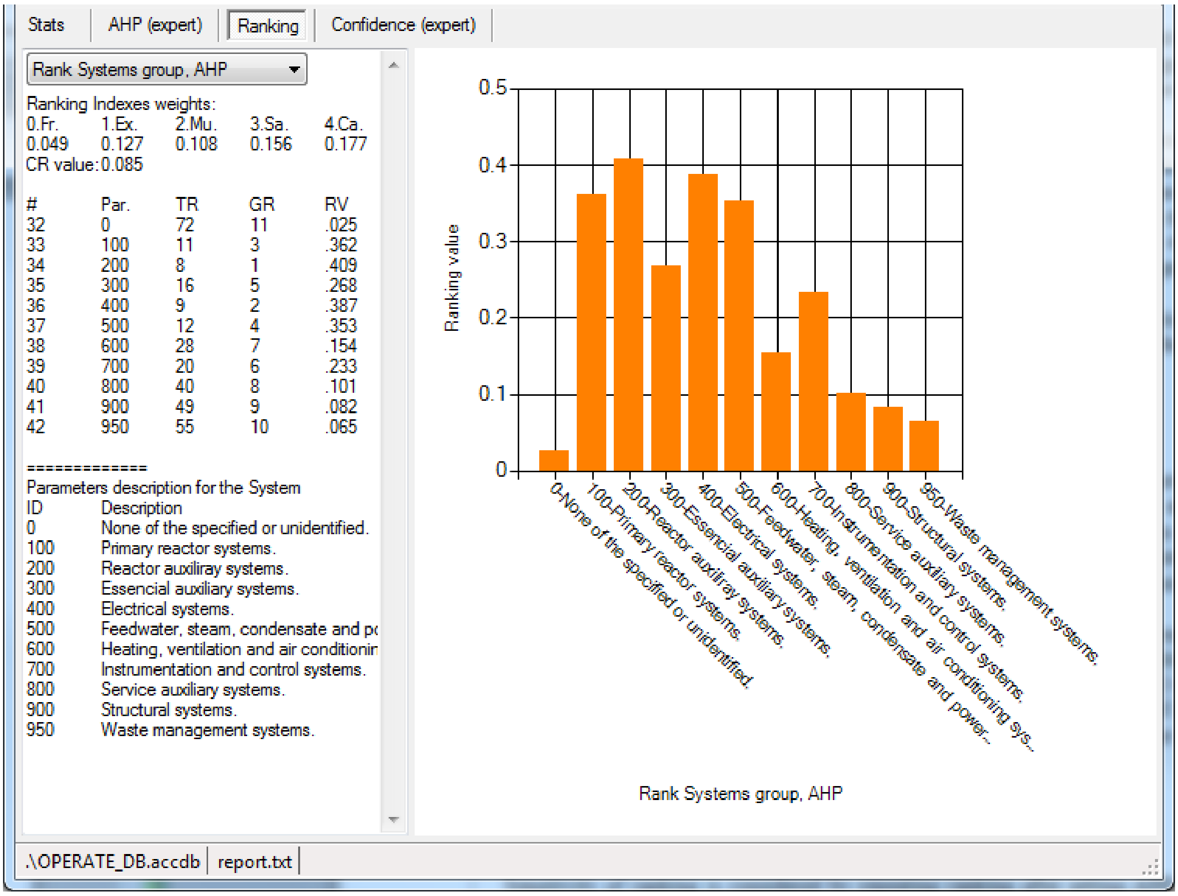

OPERATE
File
Report
Help
Word wrap
Stats
AHP (expert)
Ranking
Confidence (expert)
Events/Shutdown and ext. durat
===============
0 889
>0-1 68
>1-4 55
>4-24 136
>24-72 142
>72-240 136
>240 16
===============
Note: information about event caused shutdown is not available for all and estimated for some events.
1000
800
600
400
200
0
0
>0-1
>1-4
>4-24
>24-72
>72-240
>240
.\OPERATE_DB.accdb
report.txt

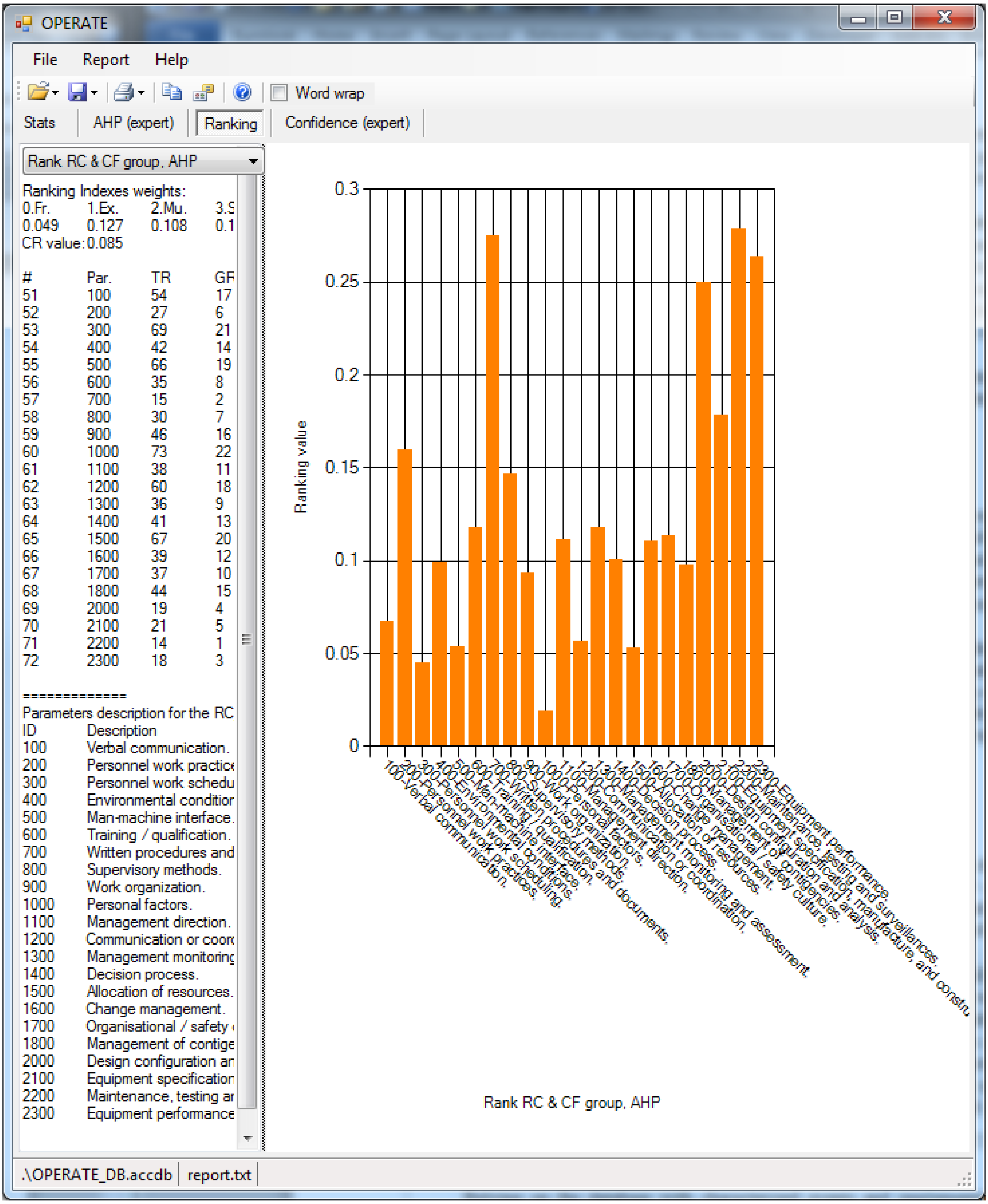
8.4.2 Illustration for all the groups rankings

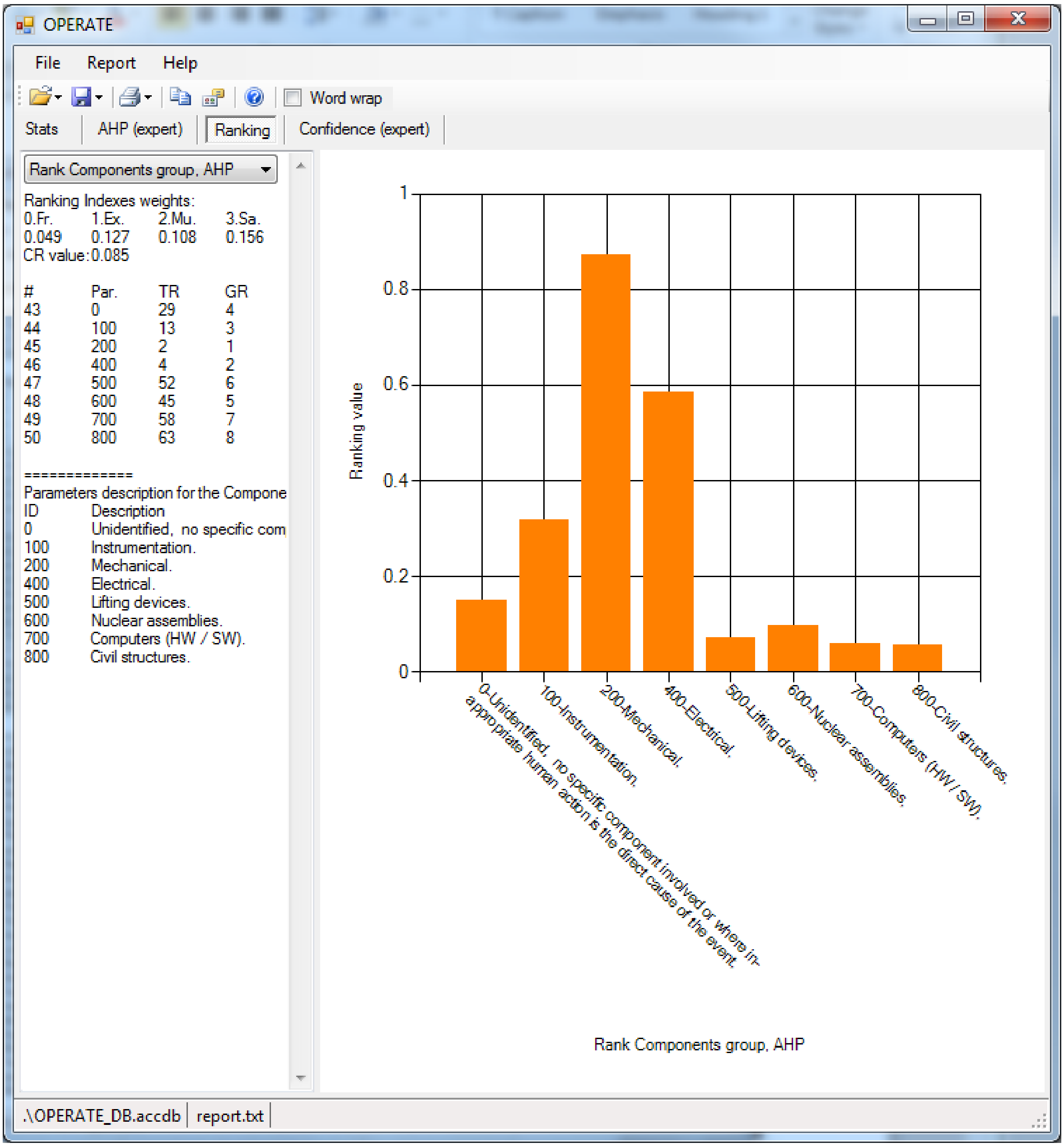
This is the illustration for all the groups ranking reports. For the attributes where an ID description is not visible on the figure it can be found in this Appendix inside the previous subsection.

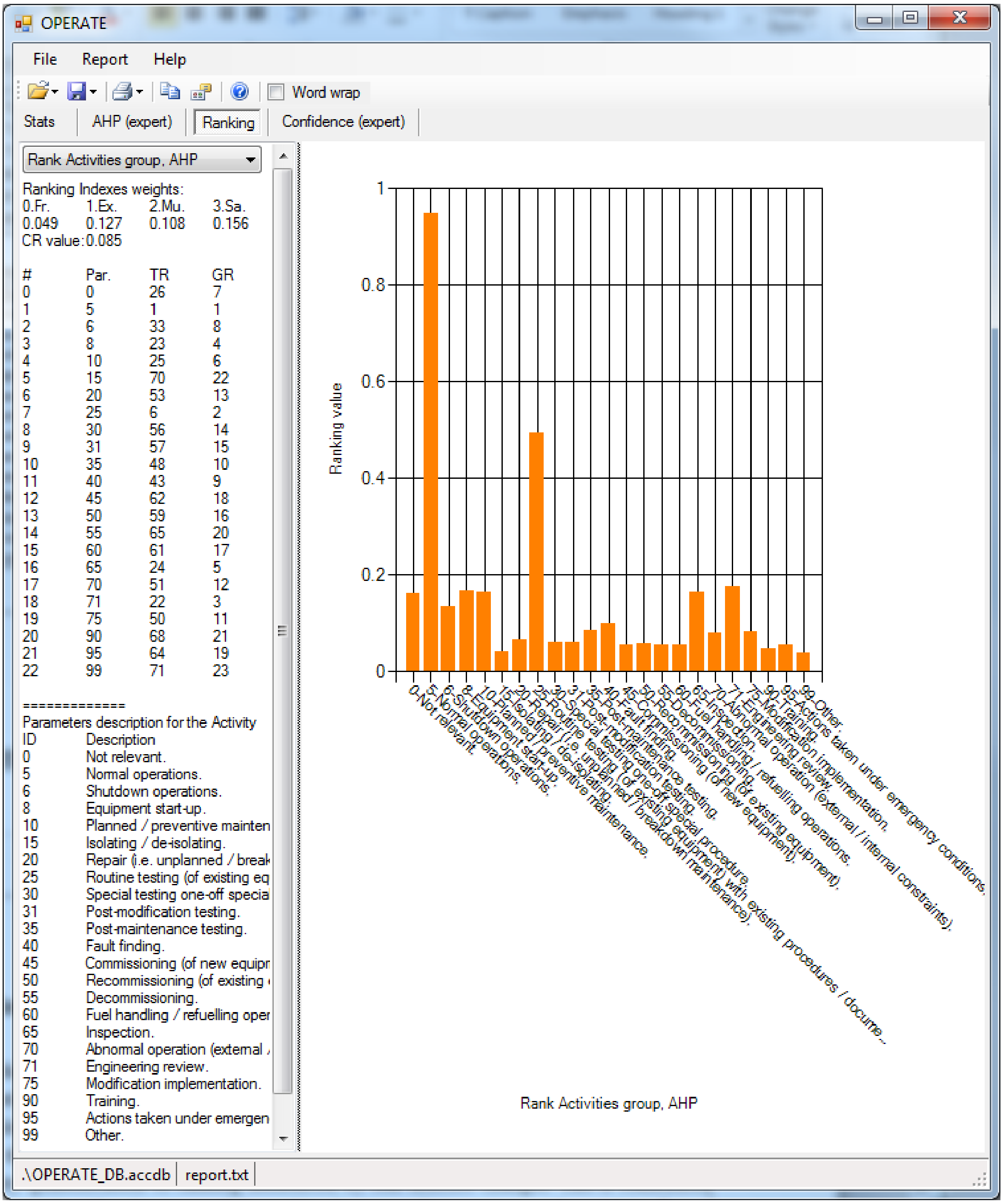



OPERATE
File Report Help
Word wrap
Stats AHP (expert) Ranking Confidence (expert)
Rank Direct causes group, AHP
Ranking Indexes weights:
0.Fr. 1.Ex. 2.Mu. 3.Sa. 4.Ca.
0.049 0.127 0.108 0.156 0.177
CR value:0.085
Par. TR GR RV
23 0 47 9 .093
24 100 5 2 .571
25 200 3 1 .594
26 300 32 7 .139
27 400 7 3 .427
28 500 17 5 .266
29 600 34 8 .119
30 700 31 6 .140
31 800 10 4 .385
=============
Parameters description for the D_Cause
ID Description
0 Unknown.
100 Mechanical deficiency.
200 Electrical deficiency.
300 Chemical or core physics deficiency.
400 Hydraulic and pneumatic deficiency.
500 Control and Instrumentation deficiency
600 Environmental - inside the plant, abno
700 Environmental - external the plant, abr
800 Human factor.
Ranking value
0.6
0.4
0.2
0
0-Unknown.
100-Mechanical deficiency.
200-Electrical deficiency.
300-Chemical or core physics deficiency.
400-Hydraulic and pneumatic deficiency.
500-Control and Instrumentation
600-Environmental - inside the plant, abnormal conditions
700-Environmental - external the plant, abnormal conditions
800-Human factor.
Rank Direct causes group, AHP
.\OPERATE_DB.accdb report.txt


Stats AHP (expert) Ranking Confidence (expert)
Rank Systems group, AHP
Ranking Indexes weights:
0.Fr. 1.Ex. 2.Mu. 3.Sa. 4.Ca.
0.049 0.127 0.108 0.156 0.177
CR value:0.085
Par. TR GR RV
32 0 72 11 .025
33 100 11 3 .362
34 200 8 1 .409
35 300 16 5 .268
36 400 9 2 .387
37 500 12 4 .353
38 600 28 7 .154
39 700 20 6 .233
40 800 40 8 .101
41 900 49 9 .082
42 950 55 10 .065
=============
Parameters description for the System
ID Description
0 None of the specified or unidentified.
100 Primary reactor systems.
200 Reactor auxiliray systems.
300 Essencial auxiliary systems.
400 Electrical systems.
500 Feedwater, steam, condensate and pc
600 Heating, ventilation and air conditionir
700 Instrumentation and control systems.
800 Service auxiliary systems.
900 Structural systems.
950 Waste management systems.
Ranking value
0.5
0.4
0.3
0.2
0.1
0
0-None of the specified or unidentified.
100-Primary reactor systems.
200-Reactor auxiliray systems.
300-Essencial auxiliary systems.
400-Electrical systems.
500-Feedwater, steam, condensate and power...
600-Heating, ventilation and air conditioning sys...
700-Instrumentation and control systems.
800-Service auxiliary systems.
900-Structural systems.
950-Waste management systems.
Rank Systems group, AHP
.\OPERATE_DB.accdb report.txt


OPERATE
File Report Help
Word wrap
Stats AHP (expert) Ranking Confidence (expert)
Rank RC & CF group, AHP
Ranking Indexes weights:
0.Fr. 1.Ex. 2.Mu. 3.S
0.049 0.127 0.108 0.1
CR value: 0.085
Par. TR GF
51 100 54 17
52 200 27 6
53 300 69 21
54 400 42 14
55 500 66 19
56 600 35 8
57 700 15 2
58 800 30 7
59 900 46 16
60 1000 73 22
61 1100 38 11
62 1200 60 18
63 1300 36 9
64 1400 41 13
65 1500 67 20
66 1600 39 12
67 1700 37 10
68 1800 44 15
69 2000 19 4
70 2100 21 5
71 2200 14 1
72 2300 18 3
=============
Parameters description for the RC
ID Description
100 Verbal communication.
200 Personnel work practice
300 Personnel work schedu
400 Environmental conditior
500 Man-machine interface.
600 Training / qualification.
700 Written procedures and
800 Supervisory methods.
900 Work organization.
1000 Personal factors.
1100 Management direction.
1200 Communication or coorc
1300 Management monitoring
1400 Decision process.
1500 Allocation of resources.
1600 Change management.
1700 Organisational / safety
1800 Management of contige
2000 Design configuration ar
2100 Equipment specificatior
2200 Maintenance, testing ar
2300 Equipment performance
Ranking value
0.3
0.25
0.2
0.15
0.1
0.05
0
Rank RC & CF group, AHP
.\OPERATE_DB.accdb report.txt


OPERATE
File Report Help
Word wrap
Stats AHP (expert) Ranking Confidence (expert)
Rank Components group, AHP
Ranking Indexes weights:
0.Fr. 1.Ex. 2.Mu. 3.Sa.
0.049 0.127 0.108 0.156
CR value: 0.085
Par. TR GR
43 0 29 4
44 100 13 3
45 200 2 1
46 400 4 2
47 500 52 6
48 600 45 5
49 700 58 7
50 800 63 8
=============
Parameters description for the Compone
ID Description
0 Unidentified, no specific com
100 Instrumentation.
200 Mechanical.
400 Electrical.
500 Lifting devices.
600 Nuclear assemblies.
700 Computers (HW / SW).
800 Civil structures.
Ranking value
1
0.8
0.6
0.4
0.2
0
0-Unidentified, no specific component involved or where in-appropriate human action is the direct cause of the event.
100-Instrumentation.
200-Mechanical.
400-Electrical.
500-Lifting devices.
600-Nuclear assemblies.
700-Computers (HW / SW).
800-Civil structures.
Rank Components group, AHP
.\OPERATE_DB.accdb
report.txt


OPERATE
File Report Help
Word wrap
Stats AHP (expert) Ranking Confidence (expert)
Rank Activities group, AHP
Ranking Indexes weights:
0.Fr. 1.Ex. 2.Mu. 3.Sa.
0.049 0.127 0.108 0.156
CR value: 0.085
Par. TR GR
0 0 26 7
1 5 1 1
2 6 33 8
3 8 23 4
4 10 25 6
5 15 70 22
6 20 53 13
7 25 6 2
8 30 56 14
9 31 57 15
10 35 48 10
11 40 43 9
12 45 62 18
13 50 59 16
14 55 65 20
15 60 61 17
16 65 24 5
17 70 51 12
18 71 22 3
19 75 50 11
20 90 68 21
21 95 64 19
22 99 71 23
=============
Parameters description for the Activity
ID Description
0 Not relevant.
5 Normal operations.
6 Shutdown operations.
8 Equipment start-up.
10 Planned / preventive mainten
15 Isolating / de-isolating.
20 Repair (i.e. unplanned / break
25 Routine testing (of existing eq
30 Special testing one-off specia
31 Post-modification testing.
35 Post-maintenance testing.
40 Fault finding.
45 Commissioning (of new equipr
50 Recommissioning (of existing
55 Decommissioning.
60 Fuel handling / refuelling oper
65 Inspection.
70 Abnormal operation (external
71 Engineering review.
75 Modification implementation.
90 Training.
95 Actions taken under emergen
99 Other.
Ranking value
1
0.8
0.6
0.4
0.2
0
0.Not relevant.
5.Normal operations.
99.Other.
95.Actions taken under emergency conditions.
Rank Activities group, AHP
.\OPERATE_DB.accdb report.txt

8.4.3 Illustration for the confidence (uncertainty and sensitivity) analysis results

This is the illustration for one whole ranking confidence analysis report. The uncertainty report comes first and then the sensitivity report for the Components grouping with a 33% range.

@Rank Components group, U/S

Event Groups ranking for uncertainty (with +-33% to the base RI weight):

#	ID	HiRank	loRank	AHP	Avrg	minFr	maxFr	minEx	maxEx	minMu	maxMu	minSa	maxSa	minCa	maxCa	minCo	maxCo	minTr	maxTr	Group
43	0	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	3
44	100	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
45	200	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3
46	400	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	3
47	500	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	3
48	600	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	3
49	700	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	3
50	800	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	3

: : :

Parameters description for the Component

ID	Description
0	Unidentified, no specific component involved or where in-appropriate human action is the direct cause of the event.
100	Instrumentation.
200	Mechanical.
400	Electrical.
500	Lifting devices.
600	Nuclear assemblies.
700	Computers (HW / SW).
800	Civil structures.

List of all RI weights used for the uncertainty ranking:

#	Case	0.Fr.	1.Ex.	2.Mu.	3.Sa.	4.Ca.	5.Co.	6.Tr.
0	AHP	0.049	0.127	0.108	0.156	0.177	0.278	0.106
1	Avrg	0.143	0.143	0.143	0.143	0.143	0.143	0.143
2	minFr	0.033	0.129	0.110	0.158	0.180	0.283	0.108
3	maxFr	0.065	0.125	0.106	0.153	0.174	0.273	0.104
4	minEx	0.051	0.085	0.113	0.163	0.185	0.291	0.111
5	maxEx	0.047	0.169	0.103	0.148	0.168	0.264	0.101
6	minMu	0.051	0.132	0.072	0.162	0.184	0.289	0.110
7	maxMu	0.047	0.122	0.143	0.149	0.170	0.267	0.102
8	minSa	0.052	0.135	0.114	0.104	0.187	0.295	0.112
9	maxSa	0.046	0.119	0.101	0.207	0.166	0.261	0.100
10	minCa	0.053	0.136	0.116	0.167	0.118	0.297	0.114
11	maxCa	0.046	0.118	0.100	0.145	0.235	0.258	0.099
12	minCo	0.055	0.143	0.122	0.175	0.199	0.186	0.119
13	maxCo	0.043	0.111	0.094	0.136	0.154	0.369	0.093
14	minTr	0.051	0.132	0.112	0.162	0.184	0.289	0.071
15	maxTr	0.047	0.122	0.104	0.150	0.170	0.267	0.141

@Rank Components group, U/S

Event Groups ranking for sensitivity (with min=.067 max=.33 RI weight):

#	ID	HiRank	loRank	AHP	Avrg	minFr	maxFr	minEx	maxEx	minMu	maxMu	minSa	maxSa	minCa	maxCa	minCo	maxCo	minTr	maxTr	Group
43	0	3	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	3	3
44	100	3	4	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	4	3
45	200	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3
46	400	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	3
47	500	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	3
48	600	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	3
49	700	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	3
50	800	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	3

: : :

Parameters description for the Component

ID	Description
0	Unidentified, no specific component involved or where in-appropriate human action is the direct cause of the event.
100	Instrumentation.
200	Mechanical.
400	Electrical.
500	Lifting devices.
600	Nuclear assemblies.
700	Computers (HW / SW).
800	Civil structures.

List of all RI weights used for the sensitivity ranking:

#	Case	0.Fr.	1.Ex.	2.Mu.	3.Sa.	4.Ca.	5.Co.	6.Tr.
0	AHP	0.049	0.127	0.108	0.156	0.177	0.278	0.106
1	Avrg	0.143	0.143	0.143	0.143	0.143	0.143	0.143
2	minFr	0.067	0.156	0.156	0.156	0.156	0.156	0.156
3	maxFr	0.330	0.112	0.112	0.112	0.112	0.112	0.112
4	minEx	0.156	0.067	0.156	0.156	0.156	0.156	0.156
5	maxEx	0.112	0.330	0.112	0.112	0.112	0.112	0.112
6	minMu	0.156	0.156	0.067	0.156	0.156	0.156	0.156
7	maxMu	0.112	0.112	0.330	0.112	0.112	0.112	0.112
8	minSa	0.156	0.156	0.156	0.067	0.156	0.156	0.156
9	maxSa	0.112	0.112	0.112	0.330	0.112	0.112	0.112
10	minCa	0.156	0.156	0.156	0.156	0.067	0.156	0.156
11	maxCa	0.112	0.112	0.112	0.112	0.330	0.112	0.112
12	minCo	0.156	0.156	0.156	0.156	0.156	0.067	0.156
13	maxCo	0.112	0.112	0.112	0.112	0.112	0.330	0.112
14	minTr	0.156	0.156	0.156	0.156	0.156	0.156	0.067
15	maxTr	0.112	0.112	0.112	0.112	0.112	0.112	0.330

8.5 Implementation details

This section provides some additional details regarding trend ranking index determination and confidence coding implementation.

8.5.1 Trend determination

Usually time series data are not immutable; mostly they reveal various kinds of trends, cycles, and seasonal patterns. Approximating time series data by a single value like mean or median is not suitable. A more suitable strategy for time series data is to derive an approximating function that fits the data without restriction to match the points. In order to remove the subjectivity, some strict criterion must be derived for the fit. The simplest way to do this is to derive a curve that minimizes the misalignment between the data points and the curve. A technique for accomplishing this goal is called least-squares regression. The simplest example of a least-squares approximation is fitting a straight line to a set of paired data:

$$(x_1, y_1), (x_2, y_2), \dots, (x_n, y_n).$$

The equation for the straight line is

$$y = q + px$$

where q and p are coefficients representing the intercept and slope, respectively. The error, or residual, between the model and the real data, is represented by equation:

$$e = y - q - px.$$

Thus, the residual, is the difference between the true value of y and the approximate value predicted by the straight line equation. A strategy for fitting a best line is to minimize the sum of the squares of the residuals.

$$\sum_{i=1}^{n} e_i^2 = \sum_{i=1}^{n} (y_i - q - px_i)^2$$

This strategy has many advantages, including the fact that it yields a unique line for a given set of data. Using the standard technique (differentiation with respect to q and p) for determination of values q and p which minimize the sum of the residuals we get formulas:

$$p = \frac{n\sum x_i y_i - \sum x_i \sum y_i}{n\sum x_i^2 - \left(\sum x_i\right)^2},$$

$$q = \overline{y} - p\overline{x}$$

where $\overline{x}$ and $\overline{y}$ are means of y and x. Any line other than the one computed in a such way results in a larger sum of the residuals. This straight line is unique and in terms of chosen criterion is a best line through the points, and a best linear trend model.

The linear trend model is applied on collected data arranged in groups. For each distinguishing parameter value within the grouping criterion a specific linear trend model is calculated. The first year with parameter data is used as a reference and a linear trend model is calculated as time series data at yearly points after this year. This way we ensure that the value of parameter q is count of events in reference year for thrspecific parameter, and the slope of the linear trend model is trend slope as is expected.

8.5.2 Confidence (uncertainty and sensitivity) implementation

The uncertainty about the relative ranking indexes (RIs) importance was selected as a mean to explore the uncertainty of the event groups ranking. This was implemented in a way to find the boundaries of the RIs relative importance and to calculate the ranking for all relevant combinations. Initially the idea is to have one expert select the RIs relative importance and calculate the min-max relative importance. Presenting all this could provide uncertainty of ranking. This is somehow boundary result which could demonstrate robustness of ranking or it could point to most sensitive assumptions for further expert judgment tuning in order to produce final results and conclusions about event groups importance.

This could be done in the following process: *For all combinations of RI relative importance calculate AHP and for consistent (i.e. CR<0.1) calculate ranking.*

First all the ranking could be evaluated and later only the extreme RI relative importance should be selected in order to calculate the uncertainty on a continuous basis (i.e. in the application). One way of selecting could be to take 14 combinations with maximum and minimum weight value for each RI. How adequate this approach is can be judged only after comparison of uncertainty result is made with complete quantification by propagating uncertainty of all pairwise comparison with acceptable consistency ratio.. Obviously this is a mathematical question, but it might be easier to answer after the results are produced and reviewed.

However, this is a very demanding exercise and an initial solution should be much more practical. Therefore the first implementation will make in addition to the expert based just 15 additional rankings. One ranking will be by using the average (all weights equal, 1/7 weight). Two additional rankings will be made for each ranking index with experience based minimal and maximal weights, keeping other ranking indexes on average. Minimal weights were selected as 0.05 with respected average weights as 0.158. Maximal weight is selected as 1/3 with respected average weights as 1/9.

Inputs:

minRIw - 0.05

maxRIw - 1/3

m4RI - 7x7 mirror matrice with RI relative ratios and methods for dominant eigenvector (i.e. weight) and consistency ratio (CR) calculation.

RIw - 7 vector with RI weights: 0Fr, 1Co, 2Ca, 3Sa, 4Mu, 5Ex, 6Tr

RIwU - 16x7 matrice with RI weights for all uncertainty rankings

m4Rank - 73x12 matrice with rankig for all groups with respected parameters:
0Fr, 1Co, 2Ca, 3Sa, 4Mu, 5Ex, 6Tr, 7Parameter, 8Group, 9RankValue, 10TotalRank, 11GroupRank
RI values are normalised without weighting factors. Weighting is applied only to quantify total ranking value (9)

m4RUnk - 73x32 matrice with total and group ranking for all uncertainty cases: 0-15 for total and (16-31) groups, as follows: 0(16)expert, 1(17)average, 2(18)minFr, 3(19)maxFr, 4(20)minCo, 5(21)maxCo, 6(22)minCa, 7(23)maxCa, 8(24)minSa, 9(25)maxSa, 10(26)minMu, 11(27)maxMu,
12(28)minEx, 13(29)maxEx, 14(30)minTr, 15(31)maxTr,

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