

DEMONSTRATING CONTINUOUS RISK REDUCTION

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Measurement of risk at large industrial sites has generally been achieved through analysis of hazard scenarios which allows facilities to calculate theoretical individual risk and societal risk levels for comparison with specified criteria. This has provided plants with a measure of their 'inherent risk levels'.

Operations management are increasingly demanding that plants measure and report their risk levels on a regular basis with the rightful expectation that these facilities demonstrate a downward trend in risk levels as a function of time. 'Inherent risk' levels alone do not commonly allow facilities to make such a demonstration on a frequent basis, as they will only change significantly as a result of major engineering or personnel changes over the course of multiple years. Risk management personnel are therefore being required to employ alternative risk indicators, in addition to inherent risk, in order to construct multi-component risk measures that are better able to reflect short-term variations.

This paper describes the approach BP Trinidad and Tobago is taking to address this need based on the construction of a risk measure which combines indicators based on inherent risk (long term risk level), plant conditions (integrity status of plant and safety systems) and leading indicators (status of risk control measures in place to protect against identified hazards).

This paper first summarises the risk measures that are calculated to represent inherent risk. The shortcomings of these measures, and QRA in general, for helping management make decisions regarding risk reduction activity on a day to day basis is then discussed. The final section of the paper presents the authors thoughts on one approach that can be adopted to track risk reduction on a regular basis and thus better inform management regarding the effectiveness of risk reduction activity.

QUANTIFIED RISK ASSESSMENT MEASURES

Engineers and scientists employed as risk management professionals commonly express numerical measures of risk in one of two ways; either as Individual Risk or as Societal or Group Risk. The former is the risk experienced by an individual person, the latter is the risk experienced by the whole group of people exposed to the hazard. Both may be produced as an output of an analytical, quantitative risk assessment (QRA) for an industrial site or facility. Both may be regarded as a measure of the 'inherent risk' associated with operating that site or facility.

Individual risk has been formally defined by Jones (1992) as the frequency at which an individual may be expected to sustain a given level of harm from the realisation of specified hazards. It is usually taken to be the risk of death, and usually expressed on an annual basis. It is most commonly expressed in terms of the risk experienced by an individual worker (or member of the public), taking into account the amount of time they are likely to spend in the area impacted by the particular hazards and the approximate break-down of their movements within these 'hazard zones'. An alternative, less widely adopted means of representing individual risk is on the basis of location; i.e. the risk experienced by a theoretical person who remains in the same position for 24 hours, 365 days a year. This measure is usually employed for constructing isopleths for points of constant risk exposure (risk contours).

Societal risk is defined by Spouge (1999) as the risk experienced in a given time period by the whole group of personnel exposed. It reflects the severity of the hazard and the number of people in proximity to it. It is usually taken to refer to the risk of death, and usually expressed on an annual basis. Societal risk may be expressed in one of two ways. The simplest measure is an 'annual fatality rate' attributable to the site or facility. A more informative measure is a tabular or graphical representation of the relationship between the frequency and the number of people suffering a given level of harm from the realisation of specified hazards. The most common form of this second measure is the FN curve. FN curves are frequency-fatality plots, showing the cumulative frequencies (F) of events involving *N or more* fatalities.

Used collectively these QRA outputs are, potentially, a valuable tool for managing risk. QRAs require an analyst to build a numerical model of a site or facility. Failure rate data from historic archives is used to estimate how often the plant will experience a failure, this may be a leak of flammable or toxic substance, or other hazardous occurrence. Consequence modelling then assesses the results of a release, based on expected plant operating parameters and flammable, radioactive or toxic properties. The overall risk picture is completed by taking into account the geographic and chronologic distribution of vulnerable, populations and, in the case of flammable compounds, potential ignition sources.

This structured means of estimating exposure to particular risks is the greatest strength of a QRA. As a tool for making rational, informed judgements on potential risk-reduction measures it is unique. It identifies tangible linkages between plant operations and the risks experienced by vulnerable populations. However it does have its shortcomings.

SHORTCOMINGS WITH QRA AS A MONITOR OF CONTINUOUS RISK REDUCTION

Individual Risk and Societal Risk should be regarded as complementary. Used in isolation, they both have shortcomings. Individual risk does not give any indication of the scale of a particular incident that the person is exposed to. It is, by definition, a measure of the annual risk exposure of a single person. It makes no distinction between them being exposed to a relatively small incident that affects them, and them alone, or a relatively large incident that affects multiple other persons. Societal risk reflects the level of risk exposure for a population. It is not an effective tool as far as managing the risk exposure of particular worker groups is concerned, however. If, at a particular site, one worker group spends all their time in a blast-proof, fire-rated control room and another worker group spends all their time out amongst process vessels and pipe-work, societal risk would be representative of the exposure levels of the overall population and give no indication of the risk levels experienced by the most exposed individual.

A comparable view was expressed by the UK Health & Safety Executive (1989);

> *QRA is an element that cannot be ignored in decision making about risk since it is the only discipline capable, however imperfectly, of enabling a number to be applied and comparisons of a sort to be made, other than of a purely qualitative kind. That said, the numerical element must be viewed with great caution and treated as only one parameter in an essentially judgemental exercise.*

This endorsement is clearly not without reservations and the limitations of QRA, and the 'inherent risk' measures that result from it, have been widely discussed.

One major criticism is that it presents a theoretical 'snapshot' of risk at a 'point in time', and some practitioners will assert that this risk picture is valid for the entire lifetime of the plant or facility. The validity of the picture will vary dependent upon the quality of the inputs and the frequency with which the model is updated. As an example, in the UK, offshore operators must undertake a through review of the Operational Safety Case for their installations which details the findings of the QRA every 5 years or whenever they consider themselves to be completing major structural changes to their installations. This reflects the fact that the QRAs are not expected to be highly dynamic analysis tools.

Elsewhere in the world there is often no regulatory requirement for reviewing QRAs and the reports will often lie dormant for the duration of a facility's life. There may not even be a study completed for that phase of the platform life when risk is at its highest; during drilling and well intervention activity. Even if the model is frequently updated, the constraints placed upon the model by the necessarily generic input data must be taken into account. The statistical validity of failure rate frequencies employed in QRAs is dependent upon them being drawn from large sample populations. British offshore QRA practitioners will generally refer to analyses of the HSE's OIR12 database for their failure rate data, for instance. This records all leaks from platforms on the UK Continental Shelf since 1992. Whilst the extensive reporting of leaks in this database ensures that such analyses provide a good average leak rate for British facilities, across the entirety of their operating lifetimes they fail to successfully account for fluctuations in leak rate during different phases in a facility's operating life.

Reliability analysis have shown that plant failures are unevenly distributed throughout the lifetime of a facility, with a heightened probability of failure during commissioning, start-up and the initial months of a facility's operating life and, once again, during the final years of a facilities life. Similarly, QRAs are not suited to dynamically reflecting failures to carry out adequate fabric maintenance at a facility (data from a British source will inevitably reflect an average level of fabric maintenance associated with a British facility and levels of fabric maintenance will vary significantly across the UK sector and elsewhere in the world). Neither can they reflect failures to follow operating procedures that may have significant negative implications for Integrity Management (IM) at a particular facility. Even if QRAs were capable of reflecting such things, the time taken to go from acknowledging such a failure and reporting it and then working out how to demonstrate this failure as a statistical measure and incorporate it into the QRA would be very extensive, if it were even possible. To try and use QRA in this way would be to misinterpret it's purpose which, as already identified, is to provide a statistical measure of the 'inherent risk' associated with operating a particular facility.

THE NEED FOR A TECHNIQUE TO SUPPLEMENT QRA

Risk management professionals are increasingly being asked to identify tools which can be used to monitor and report 'major accident risk' levels (i.e. risks associated with incidents which may result in multiple fatalities) frequently throughout the lifetime of a facility, in order to demonstrate 'Continuous Risk Reduction'. Senior managers are familiar with such reporting for HSE risks, through the comprehensive recording and analysis of occupational risks, and may misguidedly believe a useful, dynamic record of inherent risk can be reported with comparable frequency. Such reporting of 'slips, trips and falls' is an effective measure of the success of HSE management programmes but this reactive reporting only highlights what is happening at one end of the 'risk spectrum'. It reports on the high-frequency, low-consequence events. Whilst no manager wants to report reactively on HSE risks they want, much less, to report on an event that might happen once every thousand years in the theoretical operating life of a facility, but that results in 10 or 20 fatalities. For an offshore facility, however, occupational risks will commonly only represent around a quarter of the platform risk. The remainder of the risk is associated with the major accident risks; the low-frequency, high consequence events.

As already indicated, 'Inherent Risk' measures such as Individual Risk and Societal Risk are one proactive means of measuring how effectively 'major accident risks' are being managed through good design, and QRA is, potentially, a very effective tool for allowing informed decisions to be made on the relatively significance of various different risks drivers. If a QRA is only to be valuably updated every five years or so, however, there is a demand for a more wide-ranging selection of dynamic, proactive indicators of major accident risk potential that managers can use to monitor 'Continuous Risk Reduction'. bpTT has identified a range of these measures that broadly fall into one or other of two categories. The first are measures of 'plant condition' (the integrity status of plant and safety systems) and the second are 'leading indicators' (measures of the status of risk control measures in place to protect against identified hazards).

'Continuous Risk Reduction' is a phrase increasingly being employed within risk management literature as a supplement to demonstrating ALARP. In the UK this demonstration of ALARP has generally been by means of cost benefit analysis. The cost of implementing potential safeguards will be balanced against their probabilistic potential to avert certain incidents with associated levels of plant damage. Alternatively, the comparison may be made against the expected number of fatalities associated with these incidents, using a formula which includes a suggested figure for the value of a human life. This method (if employed as intended) imposes a moral responsibility upon an operator to spend the calculated sum each year on mitigation measures to prevent the identified hazards being realised but certain safeguards will be shown to be disproportionately expensive. Whilst such analyses have been widely undertaken by risk management professionals in the UK they are increasingly passing out of favour as it has been used on occasions to justify not implementing safety measures which have previously been considered industry good practice.

As the ALARP demonstration falls out of favour operators are increasingly being asked to demonstrate 'Continuous Risk Reduction' instead. Relative to the established ALARP demonstration this still remains a rather nebulous concept. Nevertheless, risk management professionals are being asked to identify tools that can prove that such a process is in place. For the reasons identified above, QRA may not necessarily be the most appropriate tool for making this case, if applied in exclusion.

AN APPROACH TO DEMONSTRATING CONTINUOUS RISK REDUCTION ON A DAY TO DAY BASIS

In the long term Continuous Risk Reduction has to be demonstrated by an ongoing reduction in inherent risk measures such as Individual Risk and societal risk. However, these measures, in isolation, are insufficient as a management reporting tool to ensure appropriate focus on CRR. The reason is that the processes for generating these risk measures in most organisations only require updates infrequently, e.g. 3–5 years, or when a major design modification is implemented.

Additional measures are required which can be monitored on a more regular basis.

What should these measures be? Consider the following.

The management of hazards is based on a series of safeguards or barriers which either prevent a hazardous situation arising or mitigate against the consequences of the Hazardous situation should it arise, see Figure 1.

If barriers are in place to protect against all causes of hazardous events and their consequences, there should be zero residual inherent risk. In reality, there is a level of residual risk which is due to a degree of unreliability in each barrier. Conversely, improvements to the reliability of barriers will reduce the level of residual risk. Measuring the status of barriers is therefore a possible contributor to a CRR indicator. "Leading" indicators such as barrier performance status have the advantages that they can be measured and reported on a regular basis, say every month.

There is a large gap between the status of barriers and inherent risk levels. The harm, which the inherent risk values represent, is frequently preceded by a degradation of conditions, e.g. an increase in the amount of corrosion in hydrocarbon containing equipment. Monitoring a series of conditions or "lagging" indicators can also usefully feature in monitoring CRR.

Immediate improvements in the reliability of leading Indicators should translate in time to an improvement in lagging indicators which in time should translate to a reduction in inherent risk values, see Figure 2.

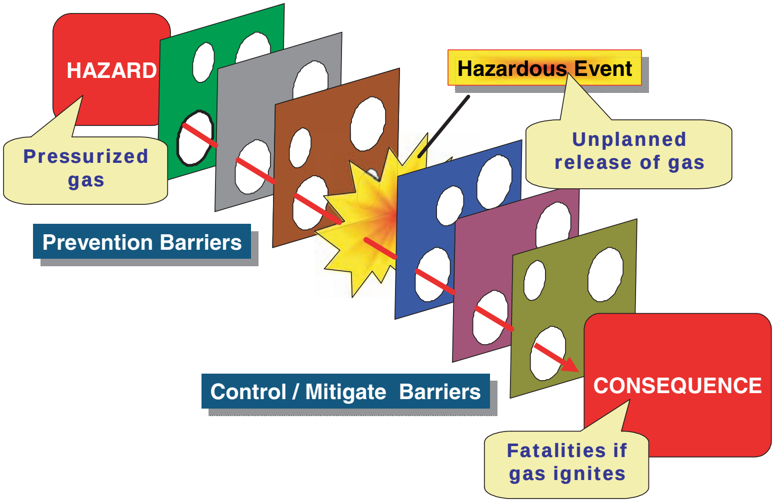


Figure 1. Hazard management barriers

A combination of inherent risk measures, leading and lagging indicators is considered as one possible approach to developing a CRR indicator capable of being updated on a regular basis. This approach has been adopted by bp Trinidad and Tobago.

BPTT CRR MEASUREMENT APPROACH

INHERENT RISK MEASURES

Two point measures of inherent risk are calculated within bpTT, The Potential Loss of Life (PLL) and the Individual Risk Per Annum (IRPA). Selecting either measure in isolation as a metric for demonstrating CRR could be misleading as discussed previously.

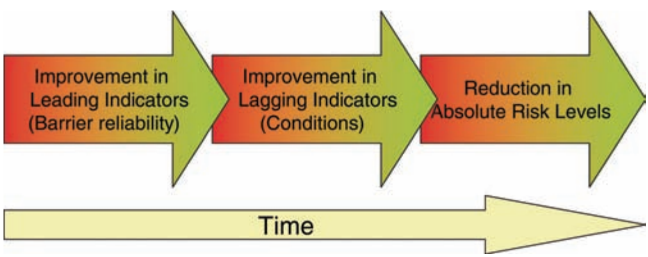


Figure 2. CRR factors timeline

CRR must demonstrate a reduction in both a PLL and IRPA value. For this reason both PLL and IRPA values have been included in the CRR measurement process.

bpTT has a number of offshore platforms and onshore processing facilities. The PLL and IRPA values vary for each platform and facility. For the purposes of measuring CRR the mean average value across all the platforms and facilities has been calculated. The advantage of this approach is that when a new platform is installed and starts to produce no sudden jump in this indicator occurs as would be the case if the PLL and IRPA values were added together.

LEADING INDICATOR MEASURES

bpTT is in the process of implementing an Integrity management Standard and the leading indicators were selected to reflect each element of the Integrity Management Standard.

The leading indicators cover the key aspects of a hazard management system:

- Status of documentation and operating procedures
- Status of competency
- Status of hazard management awareness
- Status of inspection and maintenance
- Status of management of change

The adopted list of leading indicators is listed in Table 1.

To demonstrate a trend it is important that the leading indicators are couched in terms that are comparable over time and measured on a consistent basis. For this reason where possible the leading indicators were based on % completion of an item rather than "number of tasks outstanding" etc. e.g. *"percentage of IM engineers and practitioners assessed as competent"*. In all cases a high percentage completion represents a larger contribution to risk reduction than a low percentage complete.

Where it was not possible to phrase a leading indicator in this form a scaling approach was adopted to translate, say, a number of outstanding items to an equivalent % complete. For example, the measure *"Number of outstanding critical work orders"* uses the scale listed in Table 2. If in a given reporting period the number of outstanding work orders is, say, 78 the equivalent percentage complete is recorded as 50% based on the scaling in Table 2.

Not all the barriers that the leading indicators measure necessarily have the same impact on risk levels. A small improvement in one barrier may have a much larger impact on reducing risk than an equivalent improvement in another barrier. To account for this each leading indicator was allocated a relative weighting, see Table 1, derived by a team approach of risk management and integrity management professionals within bpTT, e.g. from Table 1 it can be seen that the team developing the tool considered *"Number of outstanding critical work orders"*, if small, contributed significantly more to risk reduction than a high "*percentage completion of non safety critical work orders"* (20 weighting against a 5 weighting).

Translating the percentage completions and weightings to a risk reduction measure is described later in the paper.

Table 1. Leading indicators

Leading indicators	Weighting
Percent Design/Construction/Operations documents with appropriate level of EA/TA review	5
Percent Operations/Maintenance Technicians assessed as competent	20
Percent IM engineers and Practitioners assessed as competent	10
Percentage Contractors with approved competency management systems	20
Percent of assets/sites with current hazard registers	5
Percentage of (on time) closure of actions from risk assessments and hazard evaluations	20
Percentage of current hazard evaluations/risk assessment (completed according to schedule)	10
Percentage PM Plan Attainment (non SCE)	5
Number of outstanding PR1 WOs (non SCE) (20/100/100+)	20
Percentage Completion of inspection and tests (All Systems – non SCE)	5
Percentage completion SCE PMs	10
No of shortfalls against functional specification for safety critical protective systems during testing and actual demands on system (20/100/100+)	20
Percentage Compliance with high risk to STPs	15
Percent SOPs certified (by OPS Leadership) as up to date, accurate, accessible and being followed	15
Percent MOCs compliance	15
Percentage CM&ER plans current and in place	10
Percentage ER drills conducted according to schedule and lesson learned entered in Tr@ction	10

Table 2. Number of outstanding critical work orders scale

No of outstanding critical work orders	Equivalent % complete
<20	90%
21–99	50%
>100	20%

LAGGING INDICATOR MEASURES

Three lagging indicators representing conditions which have the greatest impact on risk levels were selected, again, based on the views of a team of specialists, see Table 3.

Hydrocarbon leaks pose one of the biggest threats to personnel on bpTT platforms and facilities. The status of the leading indicators as described previously has a large influence on this measure, hence its inclusion as a lagging indicator.

Excursions outside process design limits and Integrity management related incidents e.g. identification of pipes with excessive corrosion do not impact risk levels directly. However, they are "near misses" and as such are meaningful indicators of conditions, hence their inclusion as lagging indicators.

When a new platform comes on stream the number of unplanned releases may go up slightly because of the additional process facilities now operational, yet the "risk" posed by process releases on the existing facilities has not changed. To avoid these lagging indicators painting an unrealistic picture of conditions, the indicators were worded as average values per facility per time period, e.g. the total number of unplanned hydrocarbon releases divided by the number of facilities per reporting period.

As can be seen the lagging indicators are not percentage completed items as are the majority of the leading indicators. Scaling values had therefore to be developed for the lagging indicators, see Table 4. The scaling is used as follows. If, say, a particular asset has 6 platforms and there are 3 leaks during the reporting period the average number of leaks per platform is 0.5. This translates to a leaks measure of 5 using the scale in Table 4. Similarly, if there are 12 Integrity management (IM) related incidents in the same period (average 2 per facility) the IM measure, the IM measure is 4 using the scale in Table 4.

Table 3. Lagging indicators

Lagging indicators
Average number of unplanned hydrocarbon releases per facility per reporting period
Average number of excursions outside process design limits per facility per reporting period
Average number of Integrity management related incidents per facility per reporting period

Table 4. Lagging indicator scales

	Leaks		IM incidents		Process deviations	
	Scale	No.	Scale	No.	Scale	No.
Upper	1	10	1	10	1	10
Lower	0	0	0	0	0	0

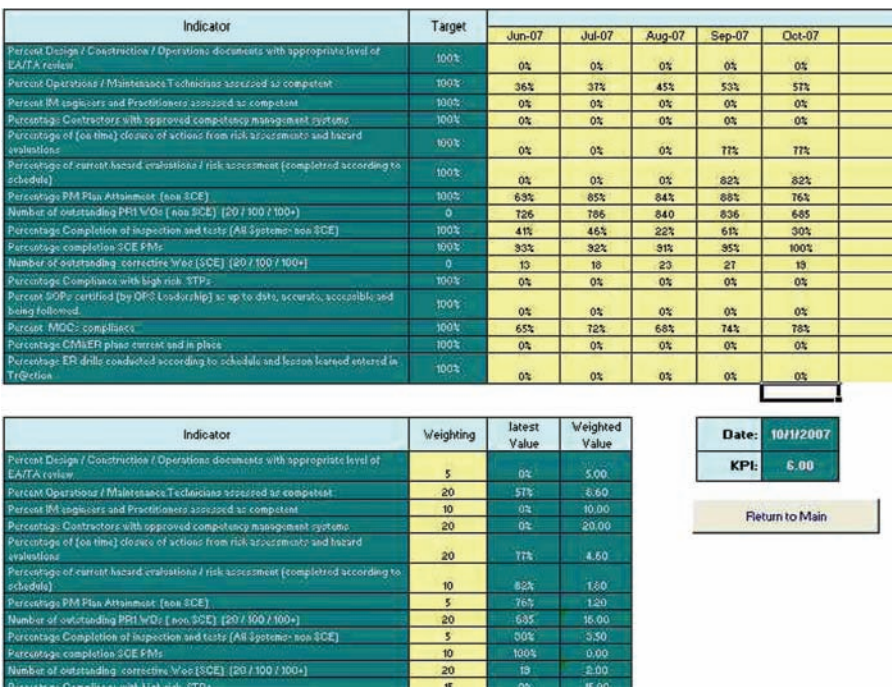
COMBINING OF MEASURES TO PRODUCE THE CRR MEASURE

The inherent risk measure, leading and lagging indicators are then combined to produce a single CRR indicator which can be trended with time.

Each of the three indicators has been scaled to provide a 1–10 score. The scaling factors have been generated by using knowledge of good and bad indicators from within the business sector that bpTT operates, e.g. an IRPA value of 1×10^{-3}/year is considered the upper limit of acceptability with the UK offshore oil industry and an IRPA Value of 1×10^{-5}/year is considered extremely low within the same industry. These two values are used as two points on the 1–10 scale. The scaling factors have then been developed from them. A similar approach has been taken to the PLL values.

Scaling of the leading indicators was simpler to achieve as they were all couched in terms of % complete (or scaled to an equivalent). The scaling was then a case of setting 100% complete as a low value on the scale and 0% complete as the 10 value on the scale.

For the lagging indictors a similar approach to scaling as for the inherent risk measures was adopted by comparison with known good and bad performance within the industry for the lagging indicators, see Table 4.



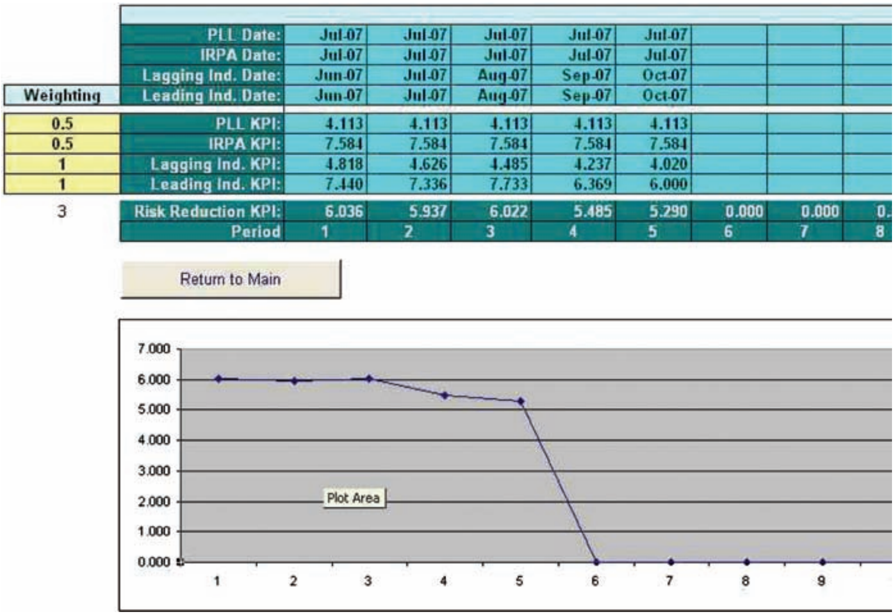
Indicator	Target	Jun-07	Jul-07	Aug-07	Sep-07	Oct-07
Percent Design / Construction / Operations documents with appropriate level of EA/TA review	100%	0%	0%	0%	0%	0%
Percent Operations / Maintenance Technicians assessed as competent	100%	36%	37%	45%	53%	57%
Percent IM engineers and Practitioners assessed as competent	100%	0%	0%	0%	0%	0%
Percentage Contractors with approved competency management systems	100%	0%	0%	0%	0%	0%
Percentage of (on time) closure of actions from risk assessments and hazard evaluations	100%	0%	0%	0%	77%	77%
Percentage of current hazard evaluations / risk assessment (completed according to schedule)	100%	0%	0%	0%	82%	82%
Percentage PM Plan Attainment (non SCE)	100%	69%	85%	84%	88%	76%
Number of outstanding PR1 WOs (non SCE) (20 / 100 / 100+)	0	726	786	840	836	685
Percentage Completion of inspection and tests (All Systems- non SCE)	100%	41%	46%	22%	61%	30%
Percentage completion SCE PMs	100%	93%	92%	91%	95%	100%
Number of outstanding corrective Wos (SCE) (20 / 100 / 100+)	0	13	18	23	27	19
Percentage Compliance with high risk STPs	100%	0%	0%	0%	0%	0%
Percent SOPs certified (by OPS Leadership) as up to date, accurate, accessible and being followed.	100%	0%	0%	0%	0%	0%
Percent MOCs compliance	100%	65%	72%	68%	74%	78%
Percentage CM&ER plans current and in place	100%	0%	0%	0%	0%	0%
Percentage ER drills conducted according to schedule and lesson learned entered in Tr@ction	100%	0%	0%	0%	0%	0%

Indicator	Weighting	latest Value	Weighted Value
Percent Design / Construction / Operations documents with appropriate level of EA/TA review	5	0%	5.00
Percent Operations / Maintenance Technicians assessed as competent	20	57%	8.60
Percent IM engineers and Practitioners assessed as competent	10	0%	10.00
Percentage Contractors with approved competency management systems	20	0%	20.00
Percentage of (on time) closure of actions from risk assessments and hazard evaluations	20	77%	4.60
Percentage of current hazard evaluations / risk assessment (completed according to schedule)	10	82%	1.80
Percentage PM Plan Attainment (non SCE)	5	76%	1.20
Number of outstanding PR1 WOs (non SCE) (20 / 100 / 100+)	20	685	16.00
Percentage Completion of inspection and tests (All Systems- non SCE)	5	30%	3.50
Percentage completion SCE PMs	10	100%	0.00
Number of outstanding corrective Wos (SCE) (20 / 100 / 100+)	20	19	2.00

Date:	10/1/2007
KPI:	6.00

Return to Main

Figure 3. CRR Tool typical data entry sheet



	PLL Date:	Jul-07	Jul-07	Jul-07	Jul-07	Jul-07			
	IRPA Date:	Jul-07	Jul-07	Jul-07	Jul-07	Jul-07			
	Lagging Ind. Date:	Jun-07	Jul-07	Aug-07	Sep-07	Oct-07			
Weighting	Leading Ind. Date:	Jun-07	Jul-07	Aug-07	Sep-07	Oct-07			
0.5	PLL KPI:	4.113	4.113	4.113	4.113	4.113			
0.5	IRPA KPI:	7.584	7.584	7.584	7.584	7.584			
1	Lagging Ind. KPI:	4.818	4.626	4.485	4.237	4.020			
1	Leading Ind. KPI:	7.440	7.336	7.733	6.369	6.000			
3	Risk Reduction KPI:	6.036	5.937	6.022	5.485	5.290	0.000	0.000	0.
	Period	1	2	3	4	5	6	7	8

Figure 4. CRR trend line sheet

CRR TOOL

To facilitate the generation of the CRR indicator a spreadsheet template has been developed which generates a new point on the CRR trend graph each time a set of data is entered. The spreadsheet template consists of 4 sheets, one for each of the three sets of indicators, see Figure 3 as an example, and the fourth summarising the data and generating the CRR trend graph, see Figure 4.

CONCLUSION

The paper has discussed the need for a method of measuring continuous risk reduction on a regular basis. The shortcomings of the use QRA results in isolation have been discussed. A simple method of producing a continuous risk reduction indicator based on a combination of inherent risk values, leading and lagging indicators has been described when implemented gives management an indicator of status of their risk reduction journey. It is important to recognise that the indicator described is only an indicator; it is not an actual measure of risk.

The only actual measures are the PLL and IRPA values.

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