Methodology for the establishment of pipeline performance indicators

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INTRODUCTION

The purpose of this paper is to establish a methodology to assess the adequate performance indicators to check the effectiveness of the companies’ PIMS “Pipeline Integrity Management System” covering natural gas transmission pipelines.

The working procedure throughout this paper is as follows:

• Draw up the inventory of possible failure causes;
• Carry out root failure cause analysis for each of the failure causes;
• Express the results from the root cause analysis in terms of performance indicators/performance elements.

Under the root cause analysis the main controls, called performance indicators, are on the one hand “prevention” measures to avoid pipeline failure and on the other hand “detection” tools to identify potential pipeline damage.

The various measures in support of “prevention” and “detection” are called performance elements e.g. cathodic protection, surveys, patrolling etc. Furthermore under “prevention”, design and construction characteristics of pipelines are additional performance indicators with supporting performance elements, such as: pipeline cover and material choice.

Incident frequency is a substantial reactive performance indicator to tune and improve the companies’ PIMS, in particular the performance indicators for “prevention” and “detection”.

The application of national, European or International standards and industry codes for design, construction, maintenance and operation of natural gas pipelines constitutes a basic performance indicator under the companies’ management system.

Management continuity and control is improved by review of systems and procedures. A major element in successful management is keeping records about system performance and monitoring performance. This enables safety improvements to be implemented by analysing causes of incidents, trends and common mode failures and learning from these experiences by amending critical performance indicators such as management, technical or control aspects to prevent the recurrence of such incidents.

SCOPE

The scope of this report is limited to inland transmission pipelines excluding their stations as defined under EN 1594:
• processed, non-toxic and non-corrosive natural gas according to ISO 13686 in inland systems;
• maximum operating pressure (MOP) over 16 bar;
• not located within industrial premises.

**POTENTIAL FAILURE CAUSES**

The potential pipeline main failure causes derived from the EGIG incident database (European Gas Incident Data Group) are classified into 4 categories:

1. external interference (third party damage);
2. corrosion:
   - external;
   - internal;
   - SCC/HCC/others;
3. construction defects/material defects;
4. others:
   - overload;
   - overpressure;
   - welding on pipeline in operation;
   - fatigue;
   - settlement/landslide/mining subsidence/crossing of faults (earthquake);
   - erosion;
   - pipeline moving;
   - temperature;
   - lightening impact.

It should be noted that the potential failure causes listed above do not apply in full to the complete pipeline system because in certain areas they do not exist or they represent a very low failure frequency; therefore a case by case approach is recommended.

**ROOT ANALYSIS OF EACH OF THE POTENTIAL FAILURE CAUSES**

For each of the potential failure causes mentioned above root cause analysis has been carried out.

To establish the root cause failure diagram, for example third party interference, the main cause of pipeline damage, the following procedure has been applied (see figure 1):

- what prevents third party damage;
- damage that not directly leads to failure, how is this detected;
- the damage and the failure concern the pipeline.
In the subject failure cause diagram all potential measures called "performance elements" have been identified. Not necessarily all of these measures have to be applied to achieve the adequate “prevention” or “detection” policy, a case by case approach is recommended.

The following example is corrosion outside (see fig. 2)

**Figure 1 - Root cause analysis third party damage**

Note: Remote sensing in development (resolution not sufficient yet).

**Figure 2 – External corrosion**
Another example is settlement/landslide/mining subsidence/crossing of faults (earthquake)

Figure 3 - Settlement/landslide/mining subsidence/crossing of faults (earthquake)

**ROOT CAUSE ANALYSIS UNDER TRIPOD MODEL**

For the purpose of this work the TRIPOD method was used to manage the performance indicators in a fast way, but also other methods can be used.

In terms of TRIPOD “prevention” and “detection” are called respectively “controls” and “defences”. Controls are managerial while design is more static and is called a “defence”. For further explanation see also annex 1.

The schemes of figure 1, figure 2 and figure 3 given above, are converted into the appropriate TRIPOD root cause format, a model that has been used in this paper and which was developed by the Leiden University and the Manchester University ordered by Shell.
The TRIPOD scheme concerning third party damage is shown in figure 4, external corrosion in figure 5 and settlement/landslide etc. in figure 6.

Figure 4 - TRIPOD scheme Third party damage

Figure 5 - TRIPOD scheme External corrosion
Figure 6 - TRIPOD scheme Settlement/landslide/mining subsidence/crossing of faults

Via tables the performance elements are coded, which enhance transparency and control of the measures taken by the pipeline operator. As an example the Tripod schemes concerning third party interference (see table 1 below).

Controls for Prevention:

<table>
<thead>
<tr>
<th>Identifier</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>EI 1: Design</td>
<td>Control Zone</td>
</tr>
<tr>
<td></td>
<td>Markers</td>
</tr>
<tr>
<td></td>
<td>Cover Check Problem Areas</td>
</tr>
<tr>
<td>EI 2: Operation</td>
<td>Notification</td>
</tr>
<tr>
<td></td>
<td>Communication:</td>
</tr>
<tr>
<td></td>
<td>Pipeline Operator- third party</td>
</tr>
<tr>
<td></td>
<td>Pipeline Operator supervision</td>
</tr>
<tr>
<td></td>
<td>Pipeline location</td>
</tr>
<tr>
<td>EI 3: Survey</td>
<td>Periodical Survey</td>
</tr>
<tr>
<td></td>
<td>Aerial Survey</td>
</tr>
<tr>
<td></td>
<td>(remote sensing)</td>
</tr>
</tbody>
</table>
**Defence for Prevention:**

<table>
<thead>
<tr>
<th>EI 4: Design</th>
<th>Markers</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cover</td>
</tr>
<tr>
<td></td>
<td>Protective Measures (e.g. Slabs)</td>
</tr>
<tr>
<td></td>
<td>Wall Thickness</td>
</tr>
</tbody>
</table>

**Controls for Detection:**

<table>
<thead>
<tr>
<th>EI 5: Inspection</th>
<th>Cathodic Protection Survey</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pearson Survey</td>
</tr>
<tr>
<td></td>
<td>Intelligent Pigging</td>
</tr>
<tr>
<td>EI 6: Operator action</td>
<td>Report to Pipeline Operator</td>
</tr>
<tr>
<td></td>
<td>Action by Pipeline Operator</td>
</tr>
<tr>
<td></td>
<td>Repair</td>
</tr>
</tbody>
</table>

**Defence for Detection:**

<table>
<thead>
<tr>
<th>EI 7: Damage Resistance</th>
<th>Material (toughness)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(hoop) stress level</td>
</tr>
</tbody>
</table>

**Table 1 - Performance elements concerning third party damage**

**PERFORMANCE INDICATORS/ PERFORMANCE ELEMENTS**

Cause failure scenarios can only lead to an accident when different "gates", called “defences” (to defend the pipe in a static manner) and “controls” (to control the Management tools) have been passed. When the “gates” are “closed” the accident cannot occur. The individual “gates” are called “Performance Indicators”; while the prevention measures, contributing to the “closing” action of the “gates”, are called “Performance Elements”.

However it is not necessary to apply all “Performance Indicators” or all listed “Performance Elements”, because in certain areas of pipelines they do not exist or represent a very low frequency failure. It is up to the pipeline operator to assess the adequate “performance elements” for each pipeline segment enabling to achieve the pre-set level of safety and integrity of the complete pipeline system, taking into account national legislation or technical rules standards and cultural and historical approaches.

Performance elements are documented in the company operating procedures and instructions.
For some of the “Performance Elements/Indicators” it may be more appropriate to apply a binary approach which can be an inspection declaration or an expert judgement.

Moreover performance indicators can theoretically be expressed in terms of probabilities, provided the probability index for each of the “defences” under the individual performance elements are known. Other performance indicators are more "digital", e.g. the presence of an inspection declaration for design/construction. For specific performance elements for which relevant parameters are partly known an expert judgement is required. Both, expert judgement and the application of acknowledged standards or codes are considered essential tools for compliance with relevant performance indicators.

The re-active performance indicator "incident statistics" is considered as a key indicator to tune and improve the companies’ PIMS in particular the performance elements under the root failure cause analysis.

CONCLUSION

The methodology explained in this paper is based on root failure cause analysis with the aim to identify potential natural gas transmission pipeline failure causes together with the corresponding performance indicators and the respective performance elements. It provides for the basic elements in a comprehensive and effective manner to set up the companies “Pipeline Integrity Management System”.

Acknowledgement
TNO Safety Solutions Consultants, Apeldoorn, Netherlands provided Tripod assistance

REFERENCES

1. EN 1594 - "Gas supply systems - Pipelines for maximum operating pressure over 16 bar - Functional requirements", March 2000, CEN (European Committee for Standardisation).

2. TRIPOD model: www.tripod.nl

Annex 1 - Root Cause Failure diagrams in Tripod format

The Tripod methodology has been developed by two Universities (Leiden and Manchester) on behalf of Shell. The Tripod philosophy concerns the pro-active (Tripod delta) or re-active (Tripod beta) characterisation and identification of 11 General Failure Types (GFT). Tripod delta allows to measure the 'condition' of these GFT's in a company in a validated way. The BRF profile of a company represents the effectiveness of the (Safety) Management System. Because of the Central Database concept of Tripod International BV, the result can be benchmarked against other companies and/or industrial sectors. In addition, the Tripod beta accident analysis method is developed to systematically investigate which weaknesses in which GFT's may have contributed to the accident causation. In this way, also a GFT profile can be built on the basis of accumulated accident investigation results. In working on improvement of the identified GFT's, a whole range of future accidents can be prevented (instead of preventing the type's that did occur and are investigated).

In this report, the Tripod beta investigation structure is used as a framework. This framework will show the Safety Management Measures put in place to work safely (prevent accidents). In Tripod beta this concept is used to investigate which Measures did fail and why (working back to the GFT's). The (failing) Hazard Management Measures are referred to as Controls (Controlling a Hazard) and Defences (Defending a Target). See the figure below:
THE USE OF THE TRIPOD BETA TREE FOR PIPELINE SAFETY
PERFORMANCE INDICATORS

Pipeline Safety need to be managed necessarily by designing and maintaining the required Controls and Defences. As the figure above shows: without failing 'barriers' (both need to fail) the accident cannot occur. It is therefore essential to identify the required Controls and Defences. Once these barriers have been put in place, the 'only' activity necessary is to keep them in good condition (non failing). If you manage to do so: the pipeline system will be safe. To formulate it differently: the condition of the Controls and Defences are an indication of how well safety is managed. In this paper the pipeline Controls and Defences are defined (see figures 4 - 6). For each of them a performance indicator will need to be defined. This will lead to a set of practical indicators. This is the approach of this report.

Another, more indirect way of measuring the Safety performance of a pipeline Company is to use Tripod delta to measure the GFT's. This is at an organisational level.

TRIPOD BACKGROUND INFORMATION

General Failure Type

The General Failure Types distinguished in Tripod are as follows:

- Hardware
- Design
- Maintenance Management
- Procedures
- Error Enforcing Conditions
- Housekeeping
- Incompatible Goals
- Communication
- Organisation
- Training
- Defences