Knowledge Model Integrated in SCADA/HMI System for Failure Process Prediction

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Abstract: - This article contributes to a discussion about plant intelligence on the basis of the integration of knowledge model in SCADA/HMI (Supervisory Control and Data Acquisition/Human Machine Interface) systems. It emphasises supporting the process operators and management not only with measured data, chemical analysis results and process visualization, but with knowledge expressed by expert evaluation for process operation and decision making, too. It is demonstrated by an open and scalable application on the requirements coming from real time operation at plants - risk based inspection and failure process prediction in an oil refinery.

Key-Words: risk based inspection, SCADA/HMI system, alarm, operator, knowledge model, process prediction

1 Introduction

An effective integrity management program for a gas or oil facility (see Fig.1) must take into account all potential threats and risks occurred during its operation. This information and data is gathered through industrial experience, which can be expressed in specific project information, such as quality control, operating guidelines, and process flow drawings, which are then used in corrosion manuals for the facility. When the process is then divided into corrosion circuits, the areas of potential failure modes are defined. Within these corrosion circuits the consequences of failure are assessed and used with the probability of failure arriving at a critical rating. The criticality rating is used to determine the frequency of inspections.

Corrosion monitoring and inspection programs are also defined within each corrosion circuit. Inspection information gathered from the on stream inspection program and turnarounds is used in conjunction with corrosion monitoring information to continually improve the corrosion manual and hence, the overall integrity management program.

2 Problem Analysis

RBI (Risk Based Inspection) is a method for using risk as a basis for prioritizing and managing the efforts of an inspection management program. Since a relatively large percentage of risk is associated with a small percentage of equipment, RBI permits allocating inspection and maintenance resources to provide a higher level of coverage on high – risk equipment and an appropriate effort on lower – risk equipment.

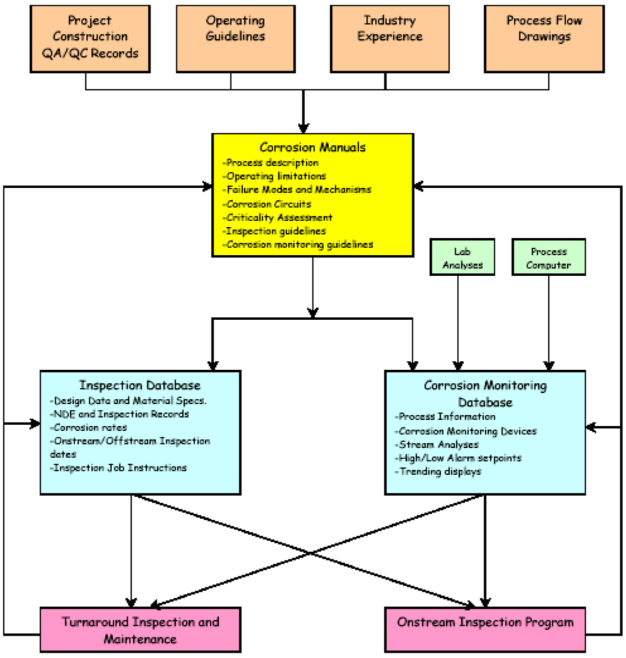


Fig.1 Integrity management plan for an oil and gas facility [courtesy of Ammonite Corrosion Eng. Inc.]

The RBI methodology provides a logical, documented and repeatable system for making informed decisions on inspection frequencies, inspection scopes, etc.

2.1 Determining the total equipment criticality factors

Evaluating criticality of production equipment is a complex decision making process which determines priorities for carrying out inspections and maintenance based on setting up risk factors originated from equipment operation. The method for determining priorities for all operations is based on sophisticated methods [3] for the evaluation of risks.

The risk $\boldsymbol{R}$ is being evaluated as an overall probability factor for a failure multiplied by a summary factor of consequential impacts. The easiest definition can be:

$$\boldsymbol{R = p\ n\ (e)} \qquad (1)$$

where $\boldsymbol{R}$ is risk in agreed units, $\boldsymbol{p}$ is the probability of an event, $\boldsymbol{n}$ is the impact of an event, $\boldsymbol{e}$ is the factor of exposition.

The probability of an event is sometimes difficult to define. Usually, it is less difficult to predict an event, since one has some idea about how and when the event will occur. A similar concept can be defined as criticality $\boldsymbol{C}$:

$$\boldsymbol{C = p'\ n\ (e)} \qquad (2)$$

where $\boldsymbol{C}$ is criticality in agreed units, $\boldsymbol{p'}$ is the predictability of an event, $\boldsymbol{n}$ is the impact an event, $\boldsymbol{e}$ is the factor of exposition.

In situations like refinery operations, expert judgement is used and the concept of criticality might be easier especially at the initial state of risk evaluations [2]. Matrices of predictability and consequences of events determine the criticality. For the purpose of RBI, it is possible to use the scale of coefficients as well. The value of coefficients grows with predictability and consequences as Table 1 shows:

Table 1 Predictability coefficients

		Consequences		
		Low	Mid	High
Predictability	Unsatisfactory	3	4	5
	Satisfactory	2	3	4
	Very satisfactory	1	2	3

2.2 Evaluating the predictability of a failure occurrence

Evaluating the predictability of a failure occurrence is based on data describing corrosive loops and historical inspection data. Corrosive loops can be described by the probable course of corrosive, mechanical and temperature mechanisms for failures occurrence, with setting their priorities.

Evaluated mechanisms for failure occurrence are:

- Internal corrosion
- External corrosion including corrosion under insulation
- Erosion
- Cavitation
- Creep
- Mechanical and thermal treatment
- Corrosive cracking under pressure
- Cracking in humid hydrogen sulphite
- Hydrogen corrosion
- Low temperature embrittlement
- High temperature embrittlement

Predictability of the course of each mechanism is divided into four groups and ranges from no failure to the hardly predictable, with coefficients as shown in Table 2:

Table 2 Evaluating the predictability of a failure occurrence

No failure	1
Can be predicted well	3
Can be predicted	10
Hardly predictable	25

It is up to the operator to evaluate these predictability coefficients caused by given mechanisms according to his/her personal experience, knowledge and real time situation with these values.

2.3 Evaluating the reliability of inspection data

Reliability of inspection data can significantly influence the predictability of a failure. Therefore, the predictability coefficient is being calculated as the average value of the coefficient for predictability of a failure multiplied by a coefficient representing the reliability of inspection data. This is the second time, when the operator needs to evaluate reliability according to his/her personal experience, knowledge and real time situation with these values:

Table 3 Evaluating the reliability of data

Highly reliable	1
Representative	3
Good	10
Just for orientation	25

2.4 Evaluating consequences of a failure

Consequences of a failure are evaluated from these three points of view:

- The safety consideration based on the volume, see Table 4, flammability of the medium (oil, gas etc.), see Table 5, and the security factor 1.5, which expresses the high concentration of equipment in the area (by multiplying the safety coefficient calculated as an average of the two evaluated values);
- Environmental impact (see Table 6),
- Financial consequences evaluated as a loss of the production (see Table 7).

The resulting consequence is calculated as the sum of these three factors.

Table 4 The safety consideration based on the volume of the medium

Volume	Factor
> 5 t	25
3 - 5 t	10
1 - 3 t	3
< 1 t	*1*

Table 5 The safety consideration based on the flammability of the medium

Medium	Factor
LPG	25
Gas with >1.5 MPa and 0.5% of H_2S, liquid hydrocarbons with ignition below the operational temperature	10
Gas with <1.5 MPa and 0.5% of H_2S, liquid hydrocarbons with ignition above the operational temperature	3
other	1

Table 6 Determining factors for the environmental impact

The environmental impact		Factor
Negligible	Localised within the place	1
Minimum	Small damages (small contamination) with no permanent effect	3
Local consequences	Effect localised within surrounding area	10
Heavy	Damaged environment; costly renovation	30
Very extensive	Permanent ecological impact to a large area	110

Table 7 Determining factors for the financial consequences

Production loss (mil. CzK)	Factor
< 0,7	1
0,7 – 7	3
7 – 70	10
70 – 700	30
> 700	110

2.5 Planning the inspection schedule

Inspections are planned based on the remaining life cycle for the equipment operation and the risk factors regarding the setting of the date in the inspections schedule.

The remaining life cycle for the equipment can be calculated according to this formula [1]:

$$Z=(S_z-S_{min})/K=K(S_z-S_{min})/(U_z/t), \qquad (3)$$

where: Z is the remaining life cycle of the equipment [years], S_z measured parameter for the thickness of the piping wall [mm], S_{min} the minimum allowed thickness of the piping [mm], K speed of the corrosion progress [mm/year], U_z corrosion decline [mm] = $S_p - S_z$, S_p the initial thickness of the piping wall [mm], t period of the operation [years]. The important thing about this calculation is that the measured parameters (for example wall thickness S_p) are monitored online.

2.6. Main function of SCADA/HMI system

SCADA/HMI systems are defined mainly as the following subsystems and their functions [5]:

- **HMI - Human Machine Interface (MMI –Man Machine Interface)**
  - enables access into a system with different access levels of rights,
  - makes easy user orientation in control process with visualization (animation, display) according to a real structure and state of the process,
  - intermediates mutual interaction with a control system with the aim to supervise control by graphical control panels,
  - intermediates mutual interaction with other associated systems,
  - visualizes different types of information about control process and control system, for example alarms, trends, statistical diagrams, system events, help texts,
  - enables the allocation of sound signals,
- **SC - Supervisory (Operator, Manager) Control**
  - remote control, for example for input of a new required state of technological elements, for actions into the control process in the case of usual operation and emergency unpredictable events, set points for emergency limits, control of controllers, setting up parameters of controlled circuits, control of sequential processes,
  - working out messages coming from process and processing control stations, it means signals for originated alarms (critical values), their acknowledgment, filtering by priorities,

  - various possibilities of working out real time and historical process data,
  - computing statistical information for monitoring and control of process quality,
  - diagnostics of equipment according to a periodic plan or special requirements,
  - other modules supporting control and decision making,
- **DA - Data Acquisition**
  - data acquisition from process and processing control systems and storing information and knowledge into database of various types (technological real time and historical values, alarms, critical values, reports about user activities and system events),
  - their interchange with associated systems.

2.7 Designing of knowledge model – predicting corrosion

Anytime the equipment is processing a more aggressive medium, the operator should be able to check what effect it has on the overall state of the equipment. It is well known from the practical experience of the operators that the progress of corrosion can change quite significantly, and these parameters must be monitored. The date for the inspections would be planned according to the updated calculated value of the total criticality factor in an application and sent back to the operator with a message.

For that reason predicting corrosion in the process equipment was used as the focus for the case work. Corrosion is the main reason for degradation of the oil-refining production processes, influencing the breakdown of equipment and the economics and quality of the ultimate product.

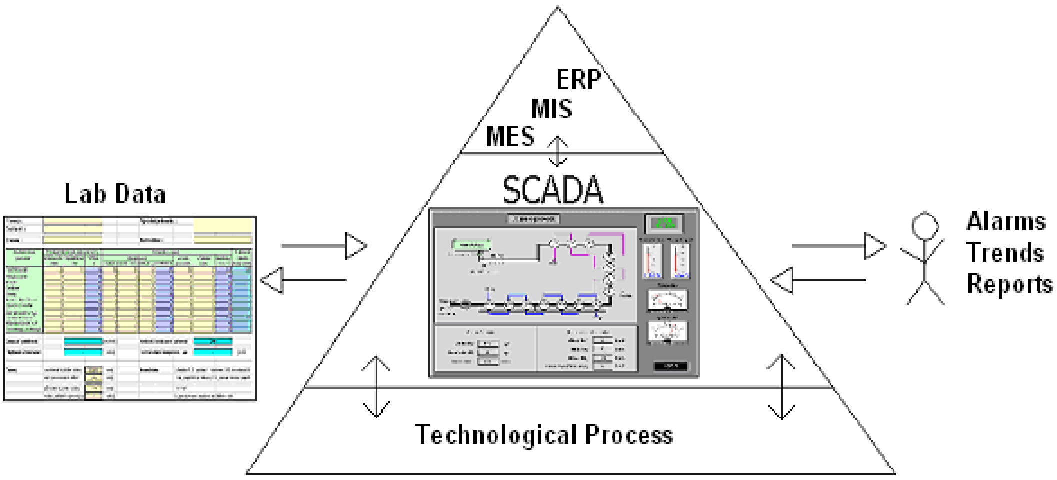


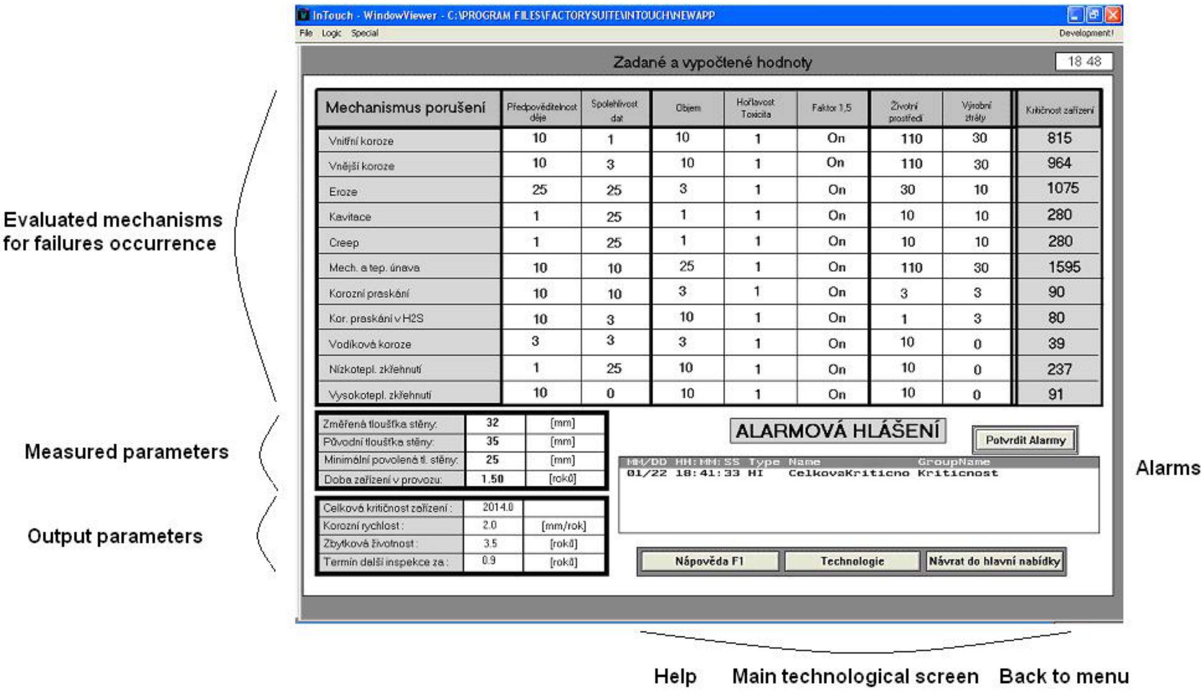
Fig.2 Data/knowledge source and exchange

It was necessary to find a model of supporting the process operators and management not only with measured data and chemical analysis results, but with knowledge expressed by expert evaluation for the process operation and decision-making (see Fig.2). The main tasks are:

- determining the corrosion mechanisms of individual equipment components and their risk,
- determining failures, where corrosion can play a role,
- suggesting methods, especially non-destructive for determining the state of corrosion,
- analysing technological, operational, construction factors for determining critical places,
- cooperating with inspections on the evaluation of data, inspection dates and the life-cycle of equipment, etc.

3 Problem Solution

The SCADA/HMI application was designed with InTouch (FactorySuite 2000) from Wonderware Co. The application contains, in this case, several operator screens and uses more than 100 variables, which are mostly input/output type variables enabling communication with the processing carried out in MS Excel. The application uses AND/OR logic operators and several scripts written in the scripting language of InTouch. The model of criticality and risk factors previously created and programmed into MS Excel application was connected to the InTouch application using the DDE (Dynamic Data Exchange) communication protocol. Both applications cooperated in order to deliver data, analytical results and knowledge to the operator screen and thus support the operator during decision-making regarding the predictability of sources of failure and their consequences.



Zadané a vypočtené hodnoty

18 48

Mechanismus porušení	Předpověditelnost děje	Spolehlivost dat	Objem	Hořlavost Toxicita	Faktor 1,5	Životní prostředí	Výrobní ztráty	Kritičnost zařízení
Vnitřní koroze	10	1	10	1	On	110	30	815
Vnější koroze	10	3	10	1	On	110	30	964
Eroze	25	25	3	1	On	30	10	1075
Kavitace	1	25	1	1	On	10	10	280
Creep	1	25	1	1	On	10	10	280
Mech. a tep. únava	10	10	25	1	On	110	30	1595
Korozní praskání	10	10	3	1	On	3	3	90
Kor. praskání v H2S	10	3	10	1	On	1	3	80
Vodíková koroze	3	3	3	1	On	10	0	39
Nízkotepl. zkřehnutí	1	25	10	1	On	10	0	237
Vysokotepl. zkřehnutí	10	0	10	1	On	10	0	91

Změřená tloušťka stěny:	32	[mm]
Původní tloušťka stěny:	35	[mm]
Minimální povolená tl. stěny:	25	[mm]
Doba zařízení v provozu:	1.50	[roků]

Celková kritičnost zařízení :	2014.0	
Korozní rychlost :	2.0	[mm/rok]
Zbytková životnost :	3.5	[roků]
Termín další inspekce za :	0.9	[roků]

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MM/DD HH:MM:SS Type Name           GroupName
01/22 18:41:33 HI   CelkovaKriticno Kriticnost
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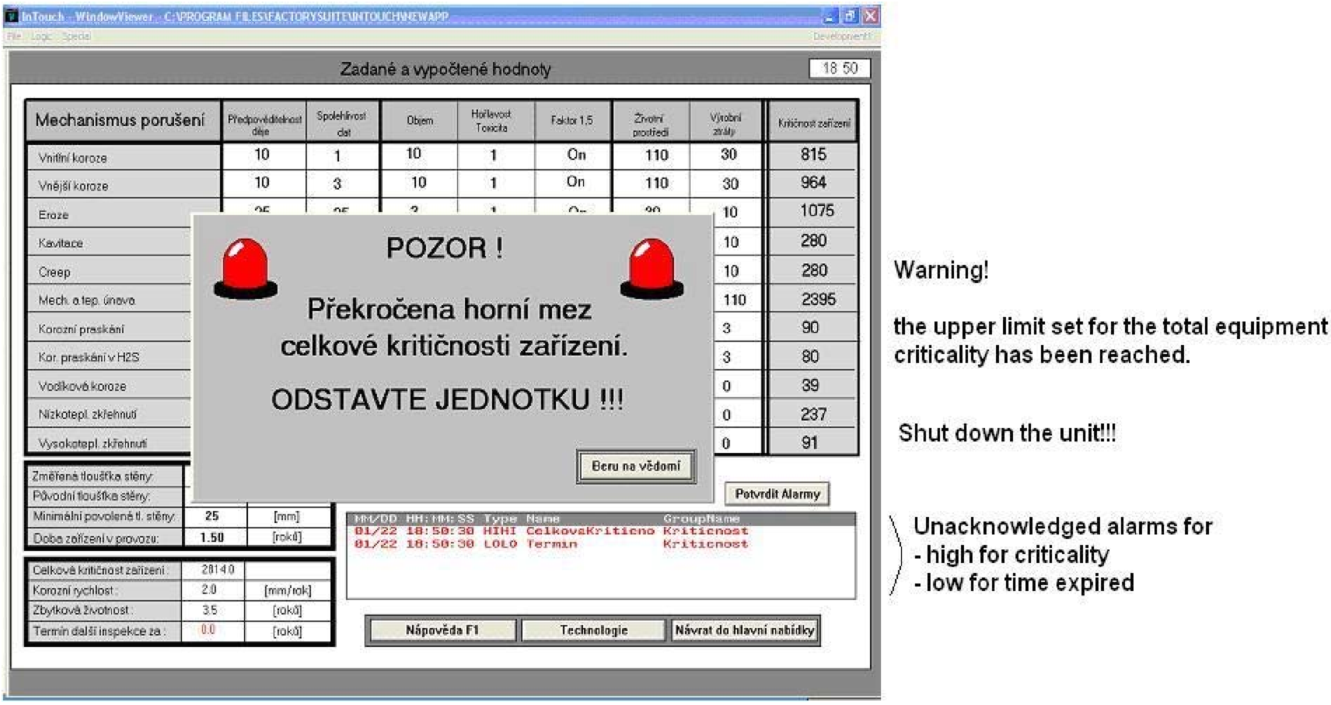
Fig.3 Determining criticality within SCADA/HMI application

A click of the user opens a dialogue in an individual screen of the InTouch application, where the user consults a particular situation in order to make decisions regarding mechanisms of corrosion (see Fig.3). Values of critical variables are computed in a MS Excel spreadsheet this is based on coefficients and parameters entered by users or read from the technological processes. These values are transferred and interpreted into recommendations to the user; including alarm messages (see Fig.4). In this way, the user is able to evaluate and acknowledge operation equipment, its status, and recommended date for the next inspection.



Zadané a vypočtené hodnoty

18 50

POZOR !

Překročena horní mez celkové kritičnosti zařízení.

ODSTAVTE JEDNOTKU !!!

Mechanismus porušení	Předpověditelnost děje	Spolehlivost dat	Objem	Hořlavost Toxicita	Faktor 1,5	Životní prostředí	Výrobní ztráty	Kritičnost zařízení
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Vodíková koroze							0	39
Nízkotepl. zkřehnutí							0	237
Vysokotepl. zkřehnutí							0	91

Změřená tloušťka stěny:		
Původní tloušťka stěny:		
Minimální povolená tl. stěny:	25	[mm]
Doba zařízení v provozu:	1.50	[roků]

Celková kritičnost zařízení :	2814.0	
Korozní rychlost :	2.0	[mm/rok]
Zbytková životnost :	3.5	[roků]
Termín další inspekce za :	0.0	[roků]

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MM/DD HH:MM:SS Type Name            GroupName
01/22 18:50:30 HIHI CelkovaKriticno Kriticnost
01/22 18:50:30 LOLO Termin          Kriticnost
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Fig.4 Alarms awaiting the operator’s acknowledgement

The most important information is the total equipment criticality value, according to which the remaining life cycle and date for the next inspection is being determined. The advantage of online monitoring is that it brings updated values of the critical factors. When the upper limits of technological parameters are reached, they can considerably change the equipment status and therefore should be included into the total evaluation and decision making.

4 Conclusion

Achieving true overall equipment effectiveness in a production environment can often be much like solving a simultaneous equation. There are large numbers of variables involved, which are changing continuously, that plant staff cannot make realistic business decisions about production operations without the added value of tools such as those supporting their decision-making. SCADA/HMI systems are able to provide them with:

- software platform for industrial automation, e.g. with a secured system by the configuration access levels for end users,
- openness to cooperating applications, influence on the business model of a company,
- support mechanism for process knowledge-intelligence generation.

The HMI – Human Machine Interface between the production process and the human operators may be created by specially designed applications, which project the data/knowledge to user-friendly environments. Decision-making can be then supported by messages sent to the screen, asking operators to acknowledge one of the optional system's statuses and providing more knowledge on related problems in graphical as well as text formats.

The evaluation of the approach was positive, in as much as the system would report on demand, and the corrosion state prediction which correlated well with corrosion inspections and expertise. In this manner product quality is supported in that process noise can be suppressed through process control and process management. The approach projects process knowledge across product life-cycle activities.

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