Development of a Software Application for Implementation of Risk-Based Reliability Asset Management System for Industrial Instrumentation, Control Systems and Control Valves

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Abstract
This paper describes the developmental process and features of a software application developed at Engro Fertilizers Ltd. for increasing the accessibility of equipment data and implementation of risk-based maintenance regime. The developed application has been specifically designed for instrument and control related equipment which includes field instrumentation, control valves and control systems of the site. This paper describes the potential for cost saving and maintenance optimization when a structured and tailor-made system is implemented in order to address the key pain points of the maintenance function.

Introduction
Engro Fertilizers Pakistan operates and maintains two Ammonia-Urea manufacturing complexes. The first one is the base plant which was relocated in 1991 and the other one is the expansion plant (Enven 1.3) which was commissioned in 2010 and is one of the largest single train ammonia-urea complexes in the world having capacity of 3835 MT of urea per day.

Since commissioning of the expansion plant in 2010, the instrument and controls (I&C) team faced numerous maintenance challenges due to the increased number and complexity of I&C related equipment installed on the new plant. A large number of new equipment was added in the maintenance scope of the team. A summary of additional scope is given below:

- Addition of more than 6,000 field instruments
- Addition of more than 50 control systems
- Addition of more than 800 control valves

Addition of a large number of equipment, presented multiple challenges for the team with respect to maintenance and reliability. As a first step, the team had to define a risk-based maintenance philosophy in order to ensure that maintenance efforts make maximum contribution towards the overall reliability of the plant. Secondly, the application of this philosophy on a large number of equipment was itself a challenge due to limitations in existing software. Traditional tools had limited capability, were difficult to use and were not specific to the trade. The team then adapted a software based approach to address these concerns. The team developed an in-house software platform which evolved over time addressing multiple issues which were being faced by the maintenance function. This paper will define the development process for the
software application, its features and how it enabled the team in optimizing their maintenance strategy.

**Post Expansion Maintenance Challenges**
Initially, I&C team adapted a very aggressive preventive maintenance regime for the newly commissioned facility. The regime predominantly catered for the safety related equipment at site. The introduced regime resulted into generation of excessive preventive maintenance work orders every month. These work orders consumed most of the available man-hours and also resulted into excessive overtime.

An analysis of the PM/CM history and past failures revealed that more effort was being done on maintaining equipment which had lesser probability of failure and loss of safety function whereas multiple equipment with single points of failures were being ignored. For example, most of the safety related instruments which were installed for safe shutdown of the plant were installed and configured in 2 out of 3 trip logic arrangement. This implied that the spurious actuation of any one of the instruments would not result into a trip or loss of safety function until at least two instruments report the same status. In case an instrument fails, the fault can be rectified after the failure has occurred without impacting safety or reliability. Aggressive maintenance was being performed on these instruments even when by design it had tolerance for one failure at a given time.

On the flip side, there was equipment which was not safety related, did not have inherent fault tolerance and could directly result in downtime which was not being catered in the PM plan. This disparity resulted in downtime and inefficiencies in the maintenance function.

Control valves maintenance presented another mammoth challenge for the team as 800+ control valves were installed at site during the expansion. Most of their spares were common for multiple valves due to same model, manufacturer and size. However, identification of spares for each valve was a lengthy process due to large quantity of spares, complicated interchangeability matrix and incomplete data in the CMMS. During annual turnaround planning and execution, identification of spares was an intensive and non-value added task. Additionally, accessibility of datasheets and drawings was a challenge during the turnaround window.

Most control valves could not be handed over online for maintenance due to field limitations and had to be planned in shutdown opportunities. Limited shutdown window and challenges faced in spares identification limited the number of valves which could be attended in the opportunity which directly impacted plant reliability.
To summarize, the team was presented with the following key challenges:

- Excessive number of PM work orders every month
- Disparity in PM regime with more focus on equipment will lesser probability of failure
- Spares identification for new equipment due to large numbers and limited CMMS data

**Proposed Solutions & Limitations**

The team developed two basic improvement strategies in order to address these challenges:

1. Adapt a risk-based maintenance approach for streamlining the effort and reduce overall quantum of work
2. Develop a dynamic database for improving accessibility of equipment and spares data

In order to implement the proposed solution, conventional office tools (like MS Excel) and the existing CMMS were found to be limiting.

Four major limitations have been given below:

- Unable to handle complex spare parts interchangeability matrix
- Limited data handing capability
- Limitation in performing extensive risk-based assessments (FMEA)
- Limitation of data input and enrichment method

**1. Complex Spare Parts Interchangeability**

More than 7,000 new equipment had approx. 3,000 unique spare parts which could be used interchangeably. For example, a unique gasket could be used with more than 10 different control valves and each valve could have more than 10 different spares. In terms of data management, it forms a many-to-many relationship between the parts and equipment. It was difficult to manage this relationship on a spreadsheet program and required a structured database driven approach. An elaboration of this relationship is given in the figure below:
2. Data Handling Capability
There was limitation in attaching documents like photos, datasheets and drawings with the equipment. Accessibility of this data is extremely important during maintenance activities. This is especially important for control valves. CMMS restricted data upload due to access, storage and format limitations. An elaboration of the expected data for control valve maintenance is given in the figure below:

3. Extensive Risk-Based Assessments (FMEA)
For developing a risk-based maintenance regime, failure mode and impact analysis for every equipment was necessary. This required identification of multiple failure modes for each equipment including identification of the probability of failure, identification of the impact of failure and checking the availability of safe guards in the form of spares, training and maintenance regime against each failure mode. It was not possible to manage these assessments for a large number of equipment on a spreadsheet or available CMMS.

4. Data Enrichment Method:
Another limitation was the enrichment of huge volumes of data in the system before it could be used effectively for identification of spares, documentation and failure modes. This manual process had to be automated in an effective way where multiple technicians and engineers could conveniently upload the data into the system. This required a network implemented application easily accessible by multiple users giving them restricted access to upload and make changes in the system.
Development of Software Application

In order to implement the proposed solution and to address these limitations, an in-house software application was developed using the open-source PHP & MySQL platform. Although the development process was continuous and the software platform evolved over time, we can still divide the process into three major steps:

- Database Development
- Frontend Development
- Analytics

Database Development

This was the first and most important step. Database development started off with the definition of the overall data structure to be followed for the application. Data structures were defined uniquely for the following equipment:

- Control Valves
- Field Instruments
- Analyzers
- Vibration Sensing Probes
- Control Systems

Database for each equipment type was defined with its specific characteristic fields. For example, for control valves characteristic fields like Equipment Tag, Serial Number, Type, Model, Size, Connection Type, Connection Class, Leakage Class, PID No, Line No, Bypass Availability, Hand jack Availability, Valve Description, Service, Fail Safe Configuration and Online Handover were created in the system.

Further database tables were developed for managing the following data related with each equipment.

- Assets Table
- Spare Parts Table
- Photos
- Datasheets
- Drawings
- P&IDs
- Failure Modes
The overall relationship of these tables with one and other is represented in the figure below:

In the relationship shown above, an asset is defined as the larger equipment to which the equipment belongs to. To give an example, a control valve with tag 11-PV-2031 is actually a furnace flue gas damper to control the furnace draft. This belongs to bigger equipment which is the induced draft blower tagged as 11-U-201. In this example, 11-U-201 (the blower), will be the asset and the control valve 11-PV-2031 will be the assigned equipment to that asset. Assets can be further assigned to parent assets. Parent assets represent the area or unit to which the asset belongs to like reforming post etc.

The tables for parts, photos, datasheets, drawings, P&IDs and FMEA are independent tables and are common for different types of equipment. They can be linked with any type of equipment using link tables. Link tables only keep reference of the equipment ID and the part ID in order to establish a connection among the two. The scheme has been shown in the figure below as an example:
Frontend Development
The frontend of the application is designed for convenient and quick access to the available data. It is also designed for easy data entry and enrichment. There are multiple display and input pages of the application. Major displays of the application are discussed below:

a. Listing of Assets
This page presents a complete list of assets defined in the system along with its parent asset.

b. Listing of Equipment
Equipment like control valves, instruments, analyzers, probes and control systems are assigned to their specific assets and can be accessed through the assets page. However, dedicated listing of each type of equipment regardless of asset assignment is also available as shown below:
c. **Equipment Page**

This page displays all the details of the equipment available in the database. It also shows attached spare parts, photos and documents related to the equipment. You can add or edit data on this page based on your access level. An equipment risk score is displayed on the left side based on the FMEA of this equipment. Calculation of this score is discussed later in this paper under FMEA module.
d. Asset Summary Page
This page displays the overall asset summary. It displays the tags and risk scores for all the different types of equipment installed on that particular asset. It also shows photos of the asset along with “asset health” chart. This chart is populated based on the number of equipment in High Risk, Medium Risk and Low Risk categories. Risk calculation is discussed later in this paper under FMEA module.
e. **New Parts Introduction and Attachment**

This page is used for enrichment of spare parts data. Basic details of the new part along with manufacturer, part number and photos are added using this form.

Once the part has been added, it can be dynamically attached to multiple equipment as shown in the example below. As you enter the tag name of the equipment, a pop-up window appears for selecting the relevant equipment.

A dedicated page is also available to list all the parts available in database for easier search.
f. **FMEA Module for Risk-Assessment**

The system has been developed with an integrated FMEA module which allows you to perform FMEA on any selected equipment and calculate the reliability and risk score. This can be any control valve, instrument or control system. It identifies parts, skill and procedural requirements including availability of maintenance plans in order to reduce the risk of operation. Risk is calculated in terms of Potential and Current risk as defined below:

- **Potential Risk**: It is the risk of failure when no safe guard like PM regime or spare part is available.
- **Current Risk**: It is the prevailing risk after the safe guards have been added.

An example of FMEA performed on control valve 11-PV-2031 using is module is given below:

To perform an FMEA on an equipment, first of all the failure modes are added one by one. Then for each failure mode, selections are made against the following parameters based on available data and site experience:

- Frequency of failure – How often can the failure occur?
- Ease of detection – How easy is it to detect if a failure is imminent before its occurrence?
- Consequence of Failure – What impact will the failure have on the overall operation
Options available for selection in the form are given in the legend tables below:

Potential risk is then calculated based on the consequence of failure and ease of detection according to the following criteria:

<table>
<thead>
<tr>
<th>CF</th>
<th>EOD</th>
<th>Net Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>X</td>
<td>Low</td>
</tr>
<tr>
<td>Medium</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Medium</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td>Medium</td>
<td>High</td>
<td>Medium</td>
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<tr>
<td>High</td>
<td>Low</td>
<td>Medium</td>
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<tr>
<td>High</td>
<td>Medium</td>
<td>High</td>
</tr>
<tr>
<td>High</td>
<td>High</td>
<td>High</td>
</tr>
</tbody>
</table>

High risk is given a score of 3 while Medium and Low risk is given a score of 2 and 1 respectively. To calculate the overall Potential Risk of the equipment, an average of the risk scores of the individual failure modes is taken for all the defined failure modes.
The next step is to define the safeguards available against each of the failure modes. Following safeguards are to be defined in the system:

- Define the preventive action to be performed to avoid subject failure
- Is there any spare part required for performing PM and preventing this failure?
- If spare part is required, is it listed in the spare parts inventory?
- Is a maintenance plan defined in the CMMS to address this failure mode?
- Is a specific job plan available for performing the related preventive maintenance?
- Is there a replacement plan in place for parts which could result in this failure?
- Is required skill available to perform specific PM against this failure mode?

The answer to these questions could be a YES, NO or NOT APPLICABLE. In case the answer is NO to any of the above questions, the Potential Risk score will be forwarded as the Current Risk score for that particular failure mode. All of the above safeguards need to have either a YES or N/A as an answer in order to mitigate the risk. The NOT APPLICABLE option is available for special cases in case that particular safeguard does not apply to the relevant failure mode.

This feature helps you identify if you have the correct maintenance regime in place and correct parts available in your inventory in order to ensure the reliable operation of the equipment. Similarly, only the failure modes with higher consequence or higher risk are required to have safeguards, steering maintenance efforts in the right direction.

The last column of the FMEA table, displays the recommended maintenance strategy. Based on the legend tables shared above, if the consequence of failure has no impact, the failure mode is addressed only on corrective bases after the failure has occurred. For all other consequences, preventive maintenance strategy is adopted. Frequency of the preventive maintenance is suggested based on the frequency of failure selected for that particular failure mode. It is important to note that consequence of failure is defined according to the impact of this failure on the entire plant or operation and not specifically on this equipment. For example, if we are considering the failure of a control valve positioner installed on a control valve which can shut down a specific pump but failure of that pump has no impact on the overall operation or process then the consequence of failure for that positioner will be “no effect”.

Another feature of the module allows you to attach a spare part of the equipment in the safeguards column. This allows you to rank your spares based on the consequence of failure if that part is not available. This allows the system to generate an automated list of critical parts to be kept in inventory. Critical parts list generated from the system is given below:
Analytics
The adapted data structure, FMEA methodology and UI design enables the system to present valuable and key insights regarding current operational risks. Leveraging these capabilities, asset-wise risk can be calculated to present a holistic view of maintenance regime efficiency and available margins for optimization and improvement.

Other analytics can also be presented by the system which can be used to:

- Identify equipment with missing parts
- Identify equipment with missing information
- Identify all the different manufacturers and suppliers
- Identify critical spares
- Identify high risk equipment and assets

List of analytics which can be performed utilizing this platform is non-exhaustive.
Conclusion
By structuring available data, automating the FMEA process, improving data accessibility and utilizing the capabilities of open-source software platform, Engro Fertilizers has created a new platform which will serve the organization in continuously improving its maintenance practices and reducing unnecessary downtime.

Biography
Asad Naeem is an electrical engineering graduate with 6 years of experience in the field of industrial instrumentation and control system. He is currently working with Engro Fertilizers Limited, Pakistan as a Senior Instrument and Control Systems Engineer. In his current role, he is responsible for the maintenance and reliable operation of field instrumentation and control system installed on the manufacturing complex. He is also responsible for the development of reliability centered maintenance regimes and execution of capital expenditure projects related with control system upgrades, retrofits and expansions.

Asad is also an avid software developer and has developed multiple applications for digitizing and improving workflows within the organization. He is also an ASQ certified six sigma green belt and has keen interest in using modern and open-source software platforms for improving the overall efficiency of business processes.