



Practice Note

Unified Recommendation Alert Management XMPro APM Capabilities and Design Patterns

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Glossary

ADT	Asset Digital Twin
APM	Asset Performance Management
CBC	Composable Business Capabilities
CMMS	Computerized Maintenance Management System
EAM	Enterprise Asset Management
EWMA	Exponentially Weighted Moving Average
LOESS	Locally estimated scatterplot smoothing
LOWESS	Locally weighted scatterplot smoothing
PBC	Packaged Business Capabilities
RPN	Risk Priority Number

Audience

The readers who will find this documentation most useful will have a working knowledge of XMPPro and use XMPPro to address asset performance business problems. It is suggested that new users of XMPPro should workshop their requirements with their XMPPro partners. It is useful to emphasize that XMPPro is an Intelligent Business Operations Solution (iBOS).

Introduction

This document has arisen from the work done with partners and seeks to align some APM capabilities pertaining to Recommendation Alert Management with XMPPro configurations based on standard XMPPro capability. For ease of use we have labelled those configurations 'Design Patterns'.

We call these patterns 'Composable Business Capabilities'. (CBC¹) The customer will need to adapt the design pattern to their own situation. Some of the Design Patterns have been further developed and are available as Apps in our GitHub² – these are enabled 'Packaged Business Capabilities' (PBC)³.

Summary

High Level Summarization	APM Capability	Associated Design Pattern	Application Description
Management of Prioritized Recommendation Alerts	Unified view of Recommendation Alerts, reliability health and risk scores Asset and alert rating <ul style="list-style-type: none">Asset criticalityRecommendation severityRecommendation alert priority Recommendation alert management Priority map of asset criticality	Strategy and Aggregator Pattern	<ul style="list-style-type: none">Recommendation Alert Scoring (including Asset Criticality)WorkbenchAsset Analysis meta tagsRecommendation Analysis meta tagsShutdown
Prioritization of Assets subject to open prioritized Recommendation Alerts	Unified view of Recommendation Alerts by asset Asset and alert rating <ul style="list-style-type: none">Asset criticalityRecommendation severityRecommendation alert priority Priority map of asset criticality	Strategy and Aggregator Pattern	<ul style="list-style-type: none">Recommendation Alert Scoring (including Asset Criticality)Asset Analysis meta tags

¹ Gartner Reference Model for Intelligent Composable Business Applications

² <https://xmpro.github.io/Blueprints-Accelerators-Patterns/>

³ Gartner Reference Model for Intelligent Composable Business Applications

High Level Summarization	APM Capability	Associated Design Pattern	Application Description
Management of Recommendation Alerts during Shutdowns	Capability to suspend alerts during a Shutdown process.	State and Observer Pattern	<ul style="list-style-type: none"> Shutdown
Ability to track Work Orders arising from Recommendation Alerts	Reliability-Centered Maintenance (RCM) and Work Order Management	Aggregator Pattern	<ul style="list-style-type: none"> Work Bench Configured Recommendation Alert page
Categorization of Recommendation Alerts	Recommendation alert management	Decorator Pattern	<ul style="list-style-type: none"> Recommendation Analysis meta tags
Categorization of Assets	Asset hierarchy will cater for user defined categorization. Asset hierarchy capability within the system and not rely on the historian asset hierarchies.	Decorator Pattern	<ul style="list-style-type: none"> Asset Analysis meta tags

Part 1: APM Capability

This document seeks to address an overall APM capability of unified view of scored Recommendation Alerts and Prioritized Assets. We link these APM capabilities with Design Patterns of XMPPro capability. There are other APM requirements that we address in separate documents.

1. Management of Prioritized Recommendation Alerts and Prioritized Assets subject to Recommendation Alerts

APM capabilities

- Unified view of Recommendation Alerts
- Asset and alert rating
 - Asset criticality
 - Recommendation severity
 - Recommendation alert priority
- Recommendation alert management
- Priority map of asset criticality

Design Pattern

- Recommendation alert scoring – Strategy Pattern
- Workbench – Aggregator Pattern
- Asset Analysis Meta Tags – Decorator Pattern
- Recommendation Analysis Meta Tags – Decorator Pattern

APM requirements

- *A number of the requirements are addressed out of the box. Design patterns can be used to further enhance the systems capability.*
- **Unified view**
 - The APM system will provide a unified view of the reliability health and risk scores through integration of asset strategy, condition monitoring, analytics, and APM data systems to measure cost, failure rates and compliance metrics.
- **Priority**
 - The APM system will provide a standard process for defining the criticality of assets.
 - The APM system will provide a standard process for defining the Risk Priority Number (RPN) / severity score of recommendation alerts.
 - The APM system will provide a standard process for prioritising recommendation alerts by the measure of an alert's Risk Priority Number (RPN) and an asset criticality score.
 - The APM system will provide a modifiable risk matrix that can be adjusted to the company's definition of risk.
- **Recommendation management**
 - The APM system will provide the ability to create recommendations within each area of functionality that can be associated to an equipment ID or functional location.

- The APM system will provide means to track and follow up recommendations from several hierarchical levels perspective in the organization (site, areas, units, system, and assets).
- The APM system can provide the ability to schedule an alert email message to be sent to the person responsible for ensuring that the recommendation is addressed.
- The APM system will provide concise reporting and alerting capability to track outstanding and past-due recommendations.
- The APM system will provide the ability to initiate recommendations for further planning and execution.

2. Management of Recommendation Alerts during Shutdowns

The Shutdown Management App uses the State and Observer Patterns to manage preplanned shutdowns effectively. During a shutdown, the app transitions assets to a "Disabled" state using the State Pattern, silencing recommendations and preventing the creation of equipment alerts based on anomalies. The Observer Pattern ensures stakeholders are notified about the shutdown schedule via email, enhancing communication and coordination. This approach maintains system integrity and operational efficiency by ensuring that no unnecessary alerts are generated during maintenance periods.

APM capability

- Capability to suspend alerts during a Shutdown process.

Associated Design Pattern

- Shutdown – Object, Observer patterns

APM requirements

- *A number of the requirements are addressed out of the box. However, the design patterns can be used to enhance the systems capability.*
- The APM system will provide the capability to automatically suspend generate alerts during a planned shutdown / start up.
- The APM system will provide the capability to amend planned shutdown and startup times for a planned shutdown / start up.
- The APM system will optionally categorize, and store alerts generated during the shutdown and start up procedures.

3. Ability to track Work Orders arising from Recommendation Alerts

APM capability

- Paper free integration to CMMS for work order process.

Associated Design Pattern

- Work Bench – Aggregator Pattern
- Custom Recommendation Alert page – Aggregator Pattern

APM requirements

- The APM system will provide linkage from the analysis of recommendation alerts to the resulting work order.
- The APM system will provide integration to a maintenance management / paper free work order process.

1234 - Drive End AX Fill Vibration has exceeded the threshold

Rule: Critical Recommendation: Conduct vibration analysis and inspect conveyor for abnormalities. Assigned To: 10 Score: 10 Alert ID: #12345 Asset ID: #98765 Date Generated: Apr 21, 2024, 2:44 PM

Did this recommendation solve the problem? ☐ Yes ☐ No

Workbench Save Share Assign False Positive Resolve

Recommendation Details

The vibration metric of "Drive End AX Fill Vibration" has exceeded the threshold of 10 with a recorded value of 10.4. Immediate inspection and analysis are recommended.

Open WO/WR Details (for this Asset)

WO Created Date	Scheduled Date	WR #	WO #	Status	Title
01/15/2024	01/28/2024	451289	7801456	Closed	123 Repair belt
01/16/2024	01/27/2024	451289	7801456	Completed	21 Annual Mal...
01/17/2024	01/29/2024	451291	7801459	Completed	123 Repair gat...
01/18/2024	02/22/2024	451291	7801459	SCHED	123 Overheatin...
01/18/2024	02/22/2024	451291	7801459	SCHED	ABC Quarterly I...
01/18/2024	02/24/2024	451294	7801462	SCHED	XYZ Replace w...
01/19/2024	12/23/2024	451294	7801462	SCHED	456 Realign co...
01/20/2024	02/28/2024	451296	7801463	SCHED	DEF Lubricatio...
01/20/2024	02/28/2024	451296	7801463	SCHED	123 Belt tensio...
10/26/2024	12/23/2024	3891342	3646017	SCHED	PM - SEM AN...
10/26/2024	12/23/2024	3891342	3646017	SCHED	PM - SEM AN...
10/26/2024	12/23/2024	3891342	3646017	SCHED	PM - SEM AN...

123 - Motor XY Belt

Equipment WO/WR Details Maintenance... Graphs Alerts

Shift Maintenance Log: ☒ WO/WR Details ☐ Spare Parts

WO/WR Details

Alert ID	Score	Title	Created Time	WR #	WO #
<input checked="" type="checkbox"/> 4355	10	System Alert - 1234 - Motor ODE - ...	1/29/2025, 11:33 PM	451297	7801459
<input type="checkbox"/> 4357	8	System Alert - 1235 - Conveyor XD...	1/30/2025, 08:15 AM	451289	7801463
<input checked="" type="checkbox"/> 4358	8	System Alert - 1236 - Pump DE - Cr...	1/30/2025, 09:45 AM	451293	7801456
<input checked="" type="checkbox"/> 4359	10	System Alert - 1237 - Fan IDE - War...	1/30/2025, 02:12 PM	451296	7801460
<input type="checkbox"/> 4360	6	System Alert - 1238 - Motor IDE - C...	1/30/2025, 05:21 PM	451291	7801465
<input type="checkbox"/> 4361	5	System Alert - 1239 - Compressor...	1/31/2025, 10:00 AM	451295	7801458
<input type="checkbox"/> 4362	10	System Alert - 1240 - Pump OBE - ...	1/31/2025, 01:45 PM	451290	7801462
<input type="checkbox"/> 4363	10	System Alert - 1241 - Fan IDE - Cn...	1/31/2025, 03:30 PM	451294	7801457
<input type="checkbox"/> 4364	10	System Alert - 1242 - Conveyor OD...	1/31/2025, 06:25 PM	451298	7801464

Event Data

Date/Reference	0.00123456789
AssetNo	12345
ThresholdHigh	10
ThresholdHigh	10
AssetType	Conveyor
Process	Loading
Asset Subtype	Conveyor
Metric	AX Fill Vibration
Display/Name	Drive End AX Fill Vibration
MetricValue	10.4
Timestamp	2025-01-17T17:15:58.19Z
EntityID	12345_CONVEYOR_AX_FILL_VIB
High	10
HighHigh	10

Notes Triage Instructions Discussion Analytics

And Paragraph Medium **B I U S**

Sample text

Figure 1 - Example Recommendation Alerts detail page

4. Categorization of Recommendation Alerts

A Recommendation Meta Tag App uses the Decorator Pattern to dynamically enhance asset data without altering the original schema. By assigning meta tags such as performance metrics, maintenance recommendations, and operational statuses to assets, the app enriches contextual data, enabling more informed decision-making. This approach allows for flexible and scalable data enhancement, improving predictive maintenance, performance monitoring, and overall asset management within the APM framework.

APM capability

- Ability to contextualize and categorizes alerts by customizable metrics for targeted filtering.

Design Pattern

- Workbench – Aggregator Pattern
- Recommendation Analysis meta tags – Decorator Pattern

APM requirements

- *A number of the requirements are addressed out of the box. However, the design patterns can be used to enhance the systems capability.*
- **Recommendation management**
 - The APM system will provide the capability to filter and categorize alerts, and by fault mechanism.

5. Categorisation of Assets

An Asset Master Hierarchy App utilizes the Decorator Pattern to dynamically enhance the hierarchical representation of assets without altering the original asset structure. This app assigns hierarchical meta tags, such as parent-child relationships, asset dependencies, and location mappings to assets, for more informed decision-making.

APM capability

- Asset hierarchy will cater for user defined categorization.
- Asset hierarchy capability within the system and not rely on the historian asset hierarchies.

Associated Design Pattern

- Asset Analysis meta tags – Decorator Pattern

APM requirements

- *A number of the requirements are addressed out of the box. However, the design patterns can be used to enhance the systems capability.*
- **Recommendation management**
 - The APM system will provide the capability to filter and categorize assets.
 - The APM system will provide the capability to allocate a criticality score to each asset.

Part 2: XMPro configurations as Design Patterns

This section articulates how using XMPro capabilities the APM requirement is addressed. This assembly of configured XMPro capability is the foundation for a low code XMPro App.

The authors have used standard XMPro functionality to create the various Design patterns. This Practice Note is primarily concerned with a unified view of prioritized Recommendation Alerts. The most popular Design Pattern is definitely 'Work Bench', but we recommend that the other Design Patterns should be reviewed and considered.

1. Design Pattern: Work Bench

The objective of the Recommendation Alerts Workbench design pattern is to allow for the prioritization, categorization and filtering of alerts. The workbench addresses the following APM capabilities:

- Unified view of Recommendation Alerts, reliability health and risk scores
- Asset and alert rating
 - Asset criticality
 - Recommendation severity
 - Recommendation alert priority
- Recommendation alert management
- Priority map of asset criticality
- Generic querying, reporting, graphing, and searching capabilities for all asset types, alert histories, and work orders.

Users have a high-level unified view to assist in their workflow process by providing the ability to see XMPro alerts filtered by criticality and status as well as associated WO's.

Priority	Alert ID	Date / Time	Site	Asset	Model	Asset #	Fault Code	Category	SubCategory	Occurrence
362	1591301476	4/04/2024	MT-Arthur	Truck	795F	MT-ARTHUR-795F-RD70	Low Steering Accumulator Pressure	Powertrain	Transmission	82
2975	1591304896	5/04/2024	MT-Arthur	Truck	795F	MT-ARTHUR-795F-RD71	Dipper	Hydraulics	Brake System	16
1012	1591303109	6/04/2024	MT-Arthur	Truck	795F	MT-ARTHUR-795F-RD72	Parking Brake Switch Off At Inappropriate Time	Powertrain	Transmission	2
872	1591303109	7/04/2024	MT-Arthur	Truck	795F	MT-ARTHUR-795F-RD73	Low Steering Accumulator Pressure	Hydraulics	Brake System	1
543	1591303109	7/04/2024	MT-Arthur	Truck	795F	MT-ARTHUR-795F-RD73	Low Steering Accumulator Pressure	Hydraulics	Brake System	1
452	1591303109	7/04/2024	MT-Arthur	Truck	795F	MT-ARTHUR-795F-RD73	Low Steering Accumulator Pressure	Hydraulics	Brake System	1
123	1591303109	7/04/2024	MT-Arthur	Truck	795F	MT-ARTHUR-795F-RD73	Low Steering Accumulator Pressure	Hydraulics	Brake System	1
128	1591303109	7/04/2024	MT-Arthur	Truck	795F	MT-ARTHUR-795F-RD73	Low Steering Accumulator Pressure	Hydraulics	Brake System	1
356	1591303109	7/04/2024	MT-Arthur	Truck	795F	MT-ARTHUR-795F-RD73	Low Steering Accumulator Pressure	Hydraulics	Brake System	1
786	1591303109	7/04/2024	MT-Arthur	Truck	795F	MT-ARTHUR-795F-RD73	Low Steering Accumulator Pressure	Hydraulics	Brake System	1
842	1591303109	7/04/2024	MT-Arthur	Truck	795F	MT-ARTHUR-795F-RD73	Low Steering Accumulator Pressure	Hydraulics	Brake System	1
421	1591303109	7/04/2024	MT-Arthur	Truck	795F	MT-ARTHUR-795F-RD73	Low Steering Accumulator Pressure	Hydraulics	Brake System	1
213	1591303109	7/04/2024	MT-Arthur	Truck	795F	MT-ARTHUR-795F-RD73	Low Steering Accumulator Pressure	Hydraulics	Brake System	1
864	1591303109	7/04/2024	MT-Arthur	Truck	795F	MT-ARTHUR-795F-RD73	Low Steering Accumulator Pressure	Hydraulics	Brake System	1
795	1591303109	7/04/2024	MT-Arthur	Truck	795F	MT-ARTHUR-795F-RD73	Low Steering Accumulator Pressure	Hydraulics	Brake System	1
234	1591303109	7/04/2024	MT-Arthur	Truck	795F	MT-ARTHUR-795F-RD73	Low Steering Accumulator Pressure	Hydraulics	Brake System	1

Figure 2 - Workbench Landing Page – Unassigned Alerts

In the above example the first three tabs focus on the status of Recommendation Alerts – Open, Assigned without WO and Assigned with WO. The landing page alert tabs will include all unassigned

alerts. The last three tabs focus on linked WO and the appropriate status; Open, Complete WO and Closed WO. The filtering, tabs, actions, and various status would be set for your circumstance.

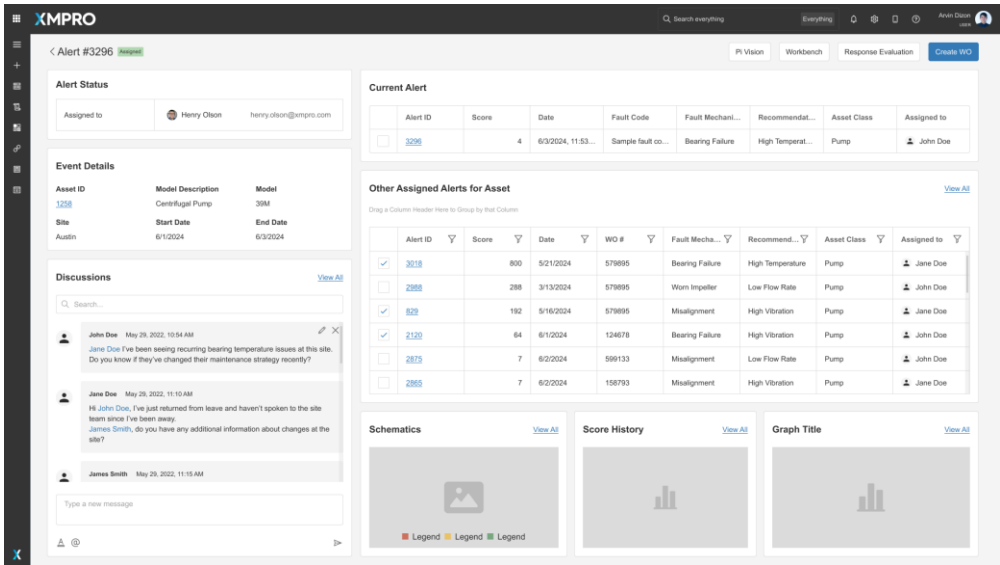


Figure 3 - Workbench – Create WO Page

The aim is to give the user situational awareness to all the elements of the Recommendation Alert. The above example page provides the relevant information on an alert to allow users to:

- See a holistic view of a piece of equipment (ability to see all alerts related to that asset)
- Any associated discussion which may provide insights into investigation and actions take
- Data at time of alert triggering
- Relevant metrics (schematics, score history)

In the Figure 3 this shows an example of assigning many Alerts to one WO.

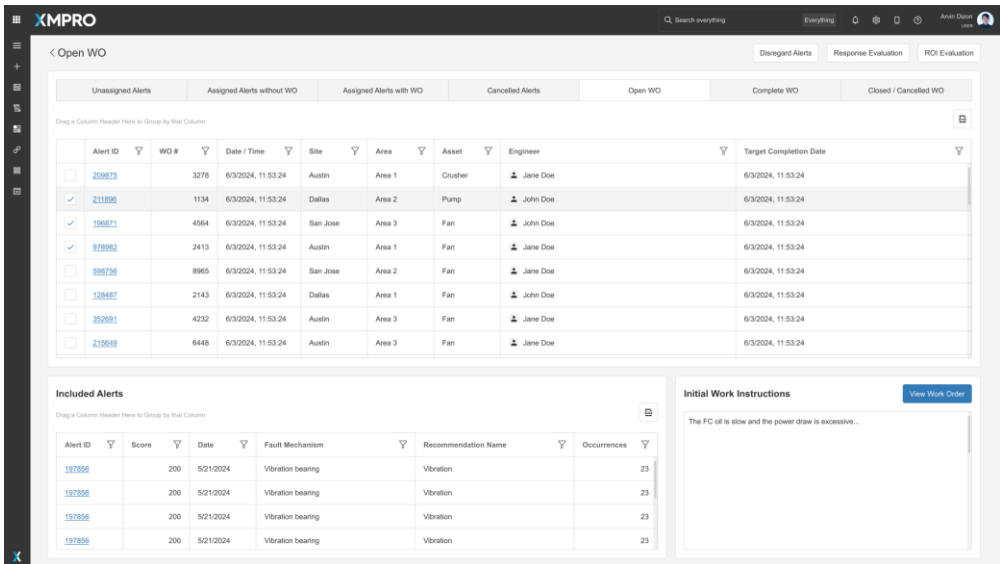


Figure 4 - Workbench – Open Work Orders

This page shows all open work orders and associated Recommendation Alerts.

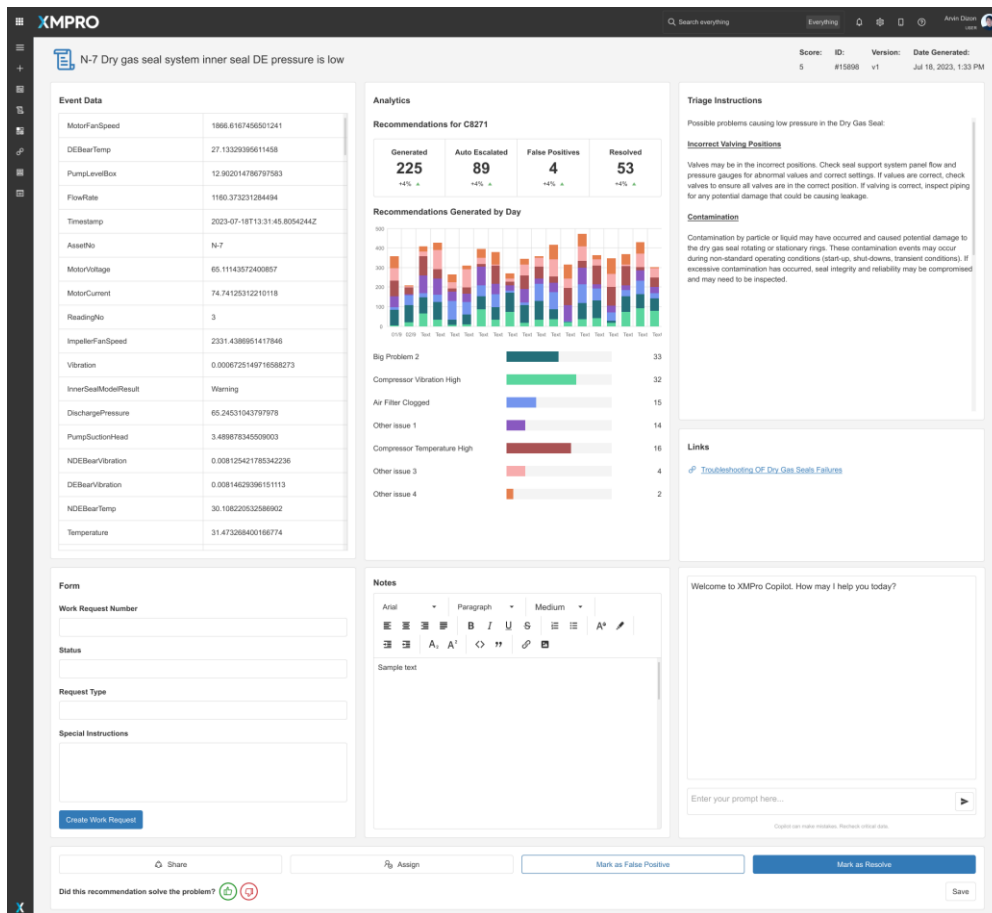


Figure 5– Workbench – Custom Alert Page

Additionally, users can create custom recommendation pages which display relevant data to the alert including:

- Other alerts associated with the Asset ID
- Metadata associated with the alert
- Ability to tie a WO/WR to the alert
- All WO/WR available

2. Design Pattern: Asset Prioritization

Asset Prioritization= (**Severity (Recommendation Alert Setting)** X **Occurrence X Detectability**) X **Asset Criticality** settings (assigned at Asset level).

Severity set at Recommendation level with Recommendation Category factor, Recommendation Factor and Recommendation Rule Factor.

Occurrence is measured in the Data Stream and updated with the 'Run Recommendation' agent.

*Note: For calculating Occurrences with tags, log on all occurrences should be enabled for your recommendations

Occurrence can be calculated with two methods which is based on the data.

A) Event Frames

B) Tags

Refer to Appendix A

An occurrence may not necessarily correspond to a new Recommendation Alert. For example, when polling OSI PI tags, the current occurrence might be part of an existing fault that previously triggered an open Recommendation Alert, or it could trigger a new alert if none is currently open. In such cases, an occurrence count is used to indicate the number of polling intervals during which the alert logic is met. Conversely, if the Data Stream is ingesting OSI Event Frames (EF), then each new EF is treated as a separate occurrence. This distinction is vital for accurately defining the measure for occurrence count.

Detectability is omitted as we assume that the Failure Mode is detectable if a recommendation rule exists. Default score = 1

Asset Criticality is assigned at an Asset level in the Asset Master, Asset Hierarchy or Asset meta tags. Ideally, this is pulled from a source system to match the existing criticalities you are utilizing for other reliability activities. If this is unavailable, this can be stored in XMPro.

XMPro capability on Recommendation scoring ⁴.

We suggest the initial default values be 1. We would expect that there will be several cycles as the various score settings are fine tuned.

⁴ <https://documentation.xmpro.com/concepts/recommendation/recommendation-scoring#how-is-the-scoring-calculated>

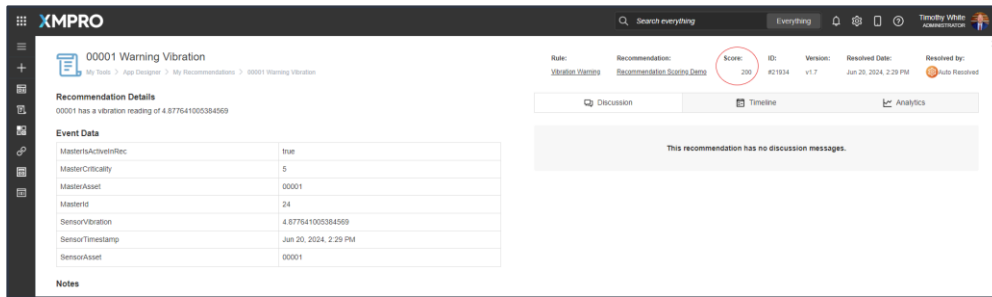


Figure 6 - Assigned score is visible for each Recommendation Alert.

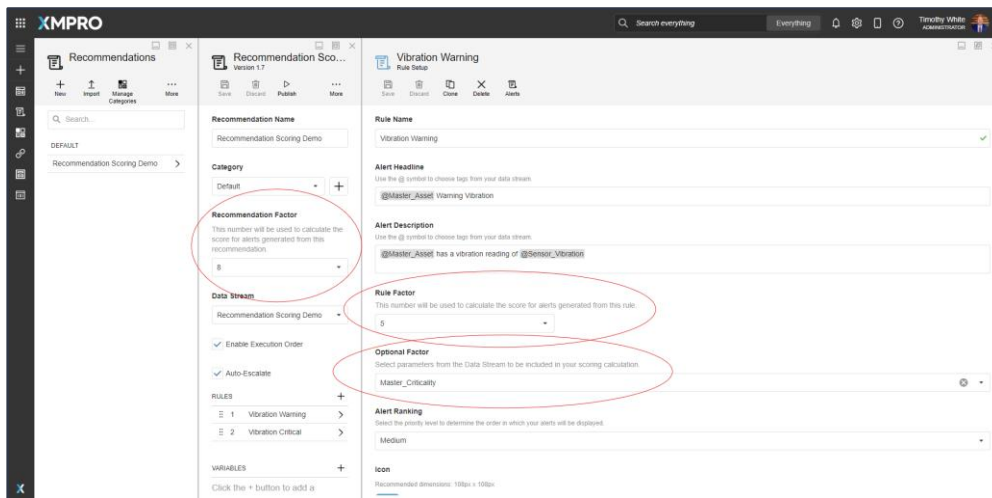


Figure 7 - Each Recommendation contains the Recommendation Factor, Rule factor and Optional Factor.

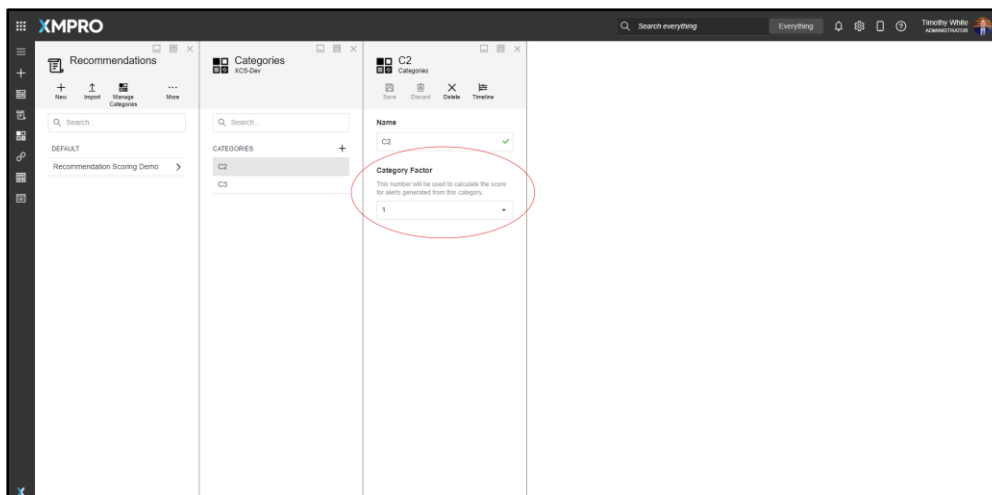


Figure 8 - Recommendation Category Factor

3. Design Pattern: Asset Shutdown

The purpose of the app is to allow users to silence alert generation for specific assets in recommendations while still maintaining the published state of the recommendation. This activation/deactivation will take place automatically based on predefined start/stop dates. The application will also notify users when the shutdown will start and end to determine if a modification is necessary and as a verification step.

In the examples below we have explained the concept detailing a shutdown by asset. However, we strongly suggest that the first iteration allows for shutdown by a level in the asset hierarchy or some other mechanism the sites may have. Example you may wish to shut assets within a certain location.

If your organization analyses Recommendation Alerts across the organization, the analysis is not clouded by the need to omit alerts triggered during a shutdown and the subsequent start up.

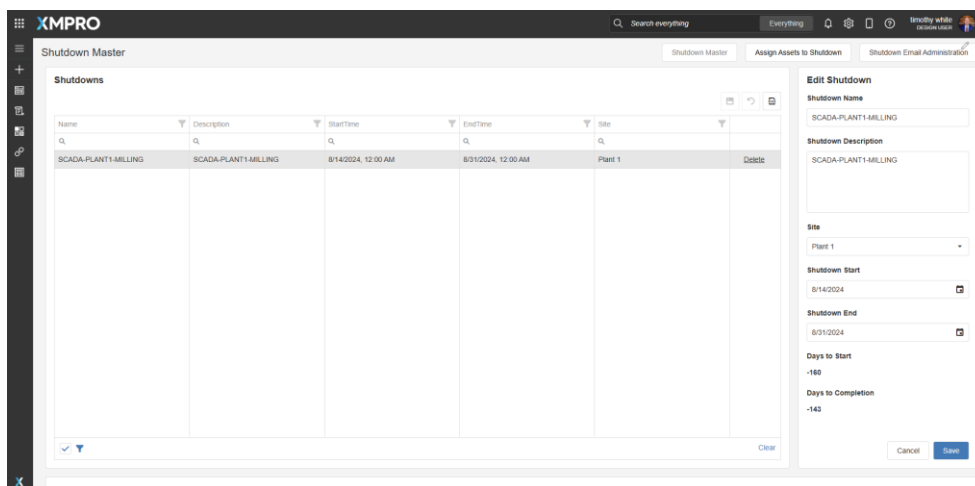


Figure 9 - Shutdown Master – Shutdown Creation Page

This page will be used to create new shutdowns and edit existing shutdowns. For existing shutdowns, assigned assets will appear below the shutdown grid.

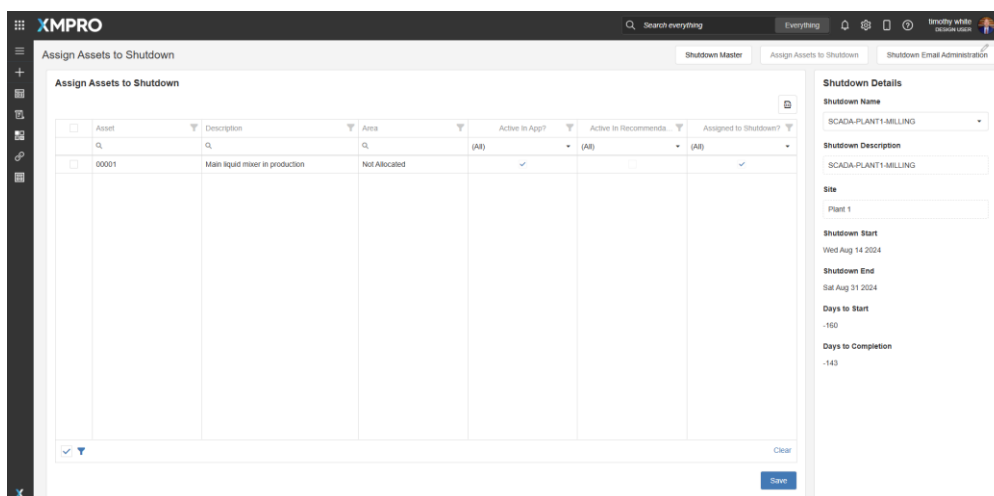


Figure 10 - Shutdown Master – Asset Assignment Page

This page will be used to assign Assets to an existing shutdown. The “Previously Selected” column tells shutdown planners what Assets are already assigned to a shutdown.

4. Design Pattern: Recommendation Meta Tags Administration

The Recommendation Meta Tag Application enriches asset data by dynamically adding meta tags with maintenance recommendations, operational statuses, and performance metrics. This contextual information aids in making informed maintenance decisions and optimizing asset performance. By enhancing data without altering the original asset schema, the application supports predictive maintenance and improves overall asset management, leading to increased operational efficiency and reliability.

Category	Recommendation	R01	R02	R03	R04	R05	R06	R07	R08	R09	R10
Compressor	Bearing Alerts	Not Allocated	Not Allocated	Not Allocated	Not Allocated	Not Allocated	Not Allocated	Not Allocated	Not Allocated	Not Allocated	Not Allocated
Compressor	Discharge Side Temperature										
Compressor	Dry Gas Seal System										
Compressor	Flash Gas Compressor Anomaly Detection										
Compressor	Motor Winding Temperature										
Compressor	Motor Winding Temperature - TimeSFM										
Compressor	Scrubber										
Compressor	Separator Pressure										
Compressor	Suction Side Pressure										
Conveyor	Amp Trip										
Conveyor	Image Defect										
Conveyor	Lagging										
Crossing	Rail Alarms Live										
Crossing	Rail Alarms Battery Level										
Energy	PowerGrid										
Energy	PowerGrid Bus										
Gearbox	Bearing Vibration Monitoring										

Figure 11 - Recommendation Meta Tag Administration – Reference Grid

In this page we have opted to distinguish between 'Not Allocated', or 'Not Reviewed'. 'Not Allocated' means that the Meta Tag is not relevant to the Recommendation (In the above this is the preferred allocation as not blank) and 'Not Reviewed' means that no selection has been decided for this asset.

Category	Recommendation	Assigned?	Active?
Compressor	Bearing Alerts	✓	✓
Compressor	Discharge Side Temperature	✓	✓
Compressor	Dry Gas Seal System	✓	✓
Compressor	Flash Gas Compressor Anomaly Detection	✓	✓
Compressor	Motor Winding Temperature	✓	✓
Compressor	Motor Winding Temperature - TimeSFM	✓	✓
Compressor	Scrubber	✓	✓
Compressor	Separator Pressure	✓	✓
Compressor	Suction Side Pressure	✓	✓
Conveyor	Amp Trip	✓	✓
Conveyor	Image Defect	✓	✓
Conveyor	Lagging	✓	✓
Crossing	Rail Alarms Live	✓	✓
Crossing	Rail Alarms Battery Level	✓	✓
Energy	PowerGrid	✓	✓
Energy	PowerGrid Bus	✓	✓

Figure 12 - Recommendation Meta Tag Administration – Recommendation Assignment Page

In the page above we have assigned Meta Tag Values to a Recommendation.

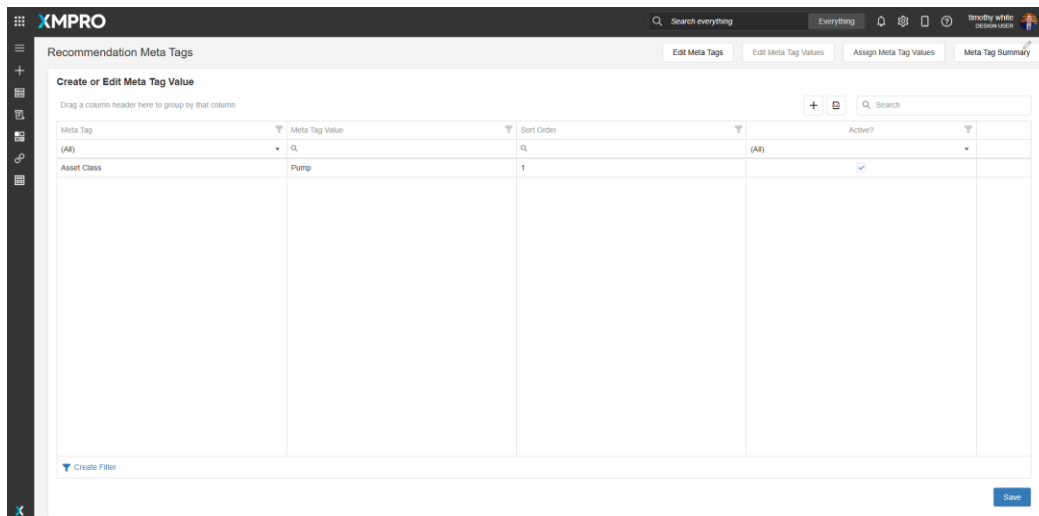


Figure 13 - Recommendation Meta Tag Administration – Meta Tag Value

This page creates or edits the Meta Tag Values. The Meta Tag column will populate a dropdown of existing options from the list of available options Created on the Meta Tags page.

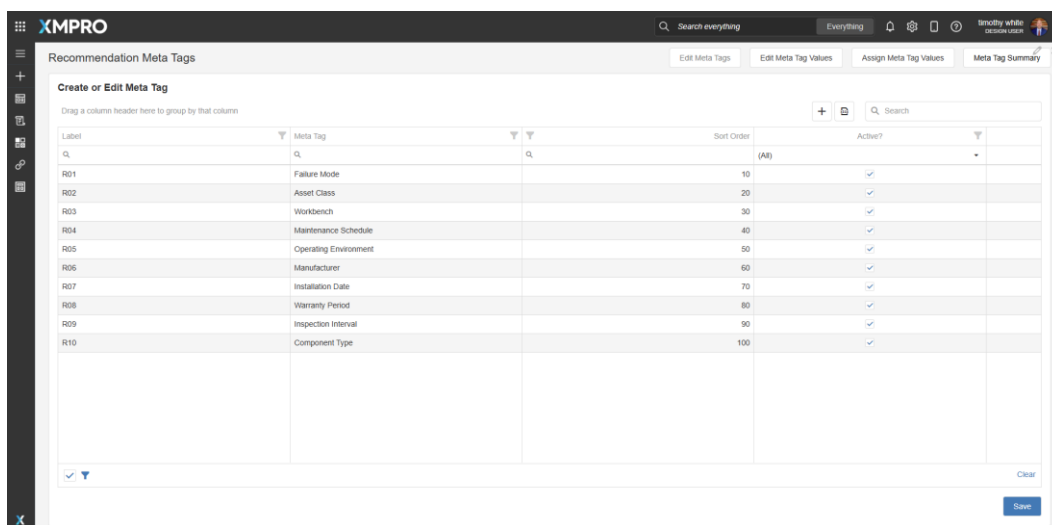


Figure 14 - Recommendation Meta Tag Administration – Meta Tag

This page contains a grid where the user can create or edit the Meta Tags.

5. Design Pattern: Asset Meta Tags Administration

The Asset Meta Tag Application enhances asset management by dynamically adding meta tags to asset data. These tags include performance metrics, maintenance recommendations, and operational statuses, providing enriched contextual information. This additional data helps in predictive maintenance, performance monitoring, and informed decision-making without altering the original asset schema. The application enables better tracking and management of assets, leading to improved operational efficiency and reliability.

Asset ID	Description	Criticality	Active	Active	A01	A02	A03	A04	A05	A06	A07	A08	A09	A10
00001	Main liquid mixer in production	7	✓	✓	Plant 1	Not Allocated	Not Allocated	Not Allocated	Not Allocated	Not Allocated	Not Allocated	Not Allocated	Not Allocated	Not Allocated
00002	Backup liquid mixer in production	6	✓	✓										
00003	Main powder mixer in production	8	✓	✓	Plant 3	Singleton	Not Allocated	Not Allocated	Not Allocated	Not Allocated	Not Allocated	Not Allocated	Not Allocated	Not Allocated
00004	Primary bottling machine	7	✓	✓										
00005	Secondary bottling machine	5	✓	✓										
00006	Primary labeling machine	6	✓	✓										
00007	Secondary labeling machine	8	✓	✓										
00008	Main backup generator	3	✓	✓										
00009	Primary air conditioner in maintenance area	4	✓	✓										
00010	Secondary air conditioner in maintenance area	7	✓	✓										
00011	Main water pump	5	✓	✓										
00012	Secondary water pump	9	✓	✓										
00013	Main air compressor	4	✓	✓										
00014	Backup air compressor	10	✓	✓										
00015	Main steam boiler	10	✓	✓										
00016	Secondary steam boiler	3	✓	✓										
00017	Main cooling tower	5	✓	✓										

Figure 15 - Asset Meta Tag Administration – Reference Grid

In this page we have opted to distinguish between 'Not Allocated', or 'Not Reviewed'. 'Not Allocated' means that the Meta Tag is not relevant to the Asset (A preferred allocation rather than blank) and 'Not Reviewed' means that no selection has been made for this asset.

Asset ID	Description	Assigned?
00001	Main liquid mixer in production	✓
00002	Backup liquid mixer in production	✓
00003	Main powder mixer in production	✓
00004	Primary bottling machine	✓
00005	Secondary bottling machine	✓
00006	Primary labeling machine	✓
00007	Secondary labeling machine	✓
00008	Main backup generator	✓
00009	Primary air conditioner in maintenance area	✓
00010	Secondary air conditioner in maintenance area	✓
00011	Main water pump	✓
00012	Secondary water pump	✓
00013	Main air compressor	✓
00014	Backup air compressor	✓
00015	Main steam boiler	✓
00016	Secondary steam boiler	✓
00017	Main cooling tower	✓

Figure 16 - Asset Meta Tag Administration – Asset Assignment Page

This page will be used to assign Meta Tag Values to an Asset. Each Meta Tag will populate a row with the corresponding Meta Tag Values for selection from the dropdown.

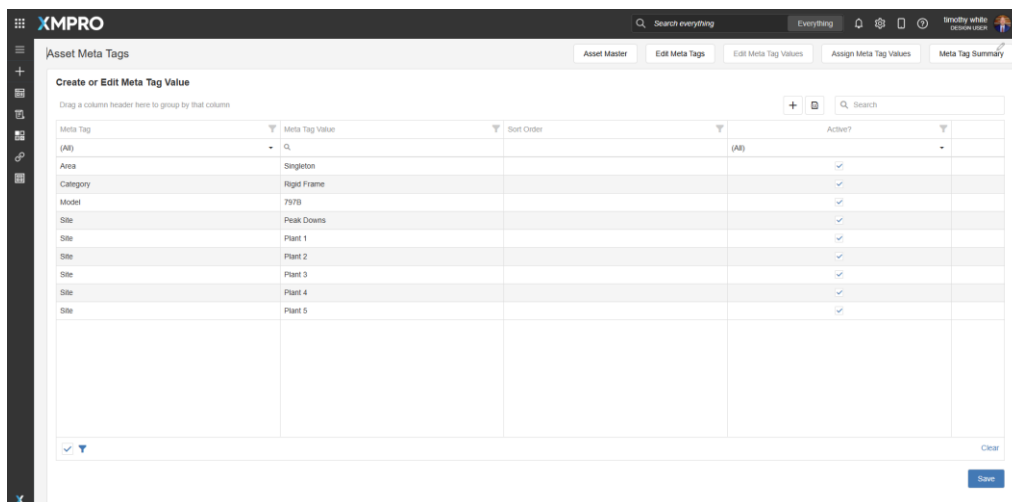


Figure 17 - Asset Meta Tag Administration – Meta Tag Value

This page contains a grid where the user can create or edit the Meta Tag Values. The Meta Tag column will populate a dropdown of existing options from the list of available options Created on the Meta Tags page.

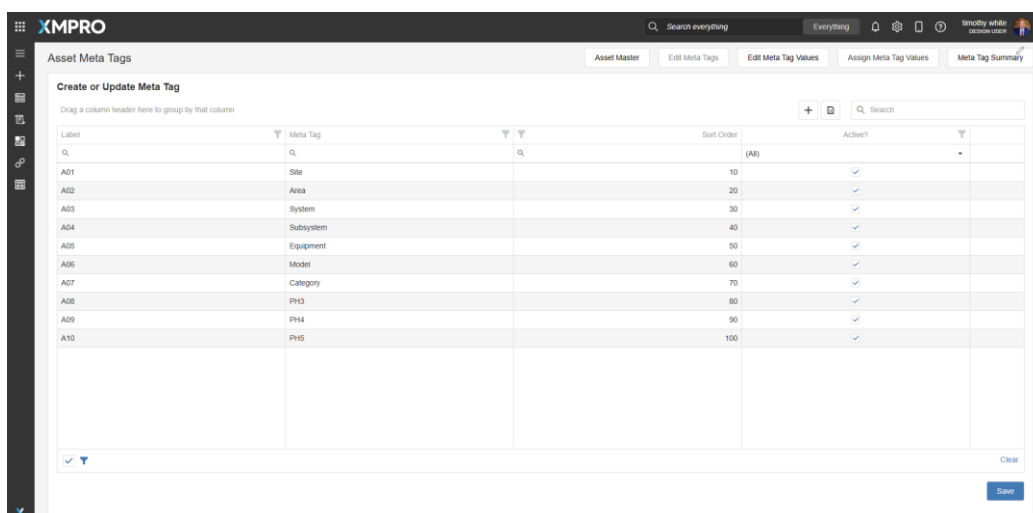


Figure 18 - Asset Meta Tag Administration – Meta Tags

This page contains a grid where the user can create or edit the Meta Tags.

Appendix 1 – Calculation of Recommendation Alert and Asset Priority Scores

Definitions

Overall	
Asset Criticality Score	Asset Criticality is a value (1-10) you set for your site assets based on how critical those site assets are to you. A value of 1 indicates the lowest level of importance, while a value of 10 is absolutely critical to your company. Asset Criticality is assigned at an Asset level in the Asset Master, Asset Hierarchy, or Asset meta tags.
Asset Priority Score	Asset Criticality * Weighted Risk Priority Number for all applicable Recommendation Alerts
Recommendation Alert Priority Score	Risk Priority Number * Asset Criticality
Risk Priority Number (RPN)	Severity * Detectability * Occurrence
Severity	<p>The severity of the failure mode is rated on a scale from 1 (low) to 1000 (high). A high severity rating indicates severe risk.</p> <p>Recommendation Category Factor * Recommendation Factor * Recommendation Rule Factor.</p>
Detectability	Set at 1 as all asset conditions measured are detectable
Occurrence	The logarithmic function $\text{Frequency} = 1/a * \log_b(mx) + c$ to measure operational alarms in a system.

1. Approach to Scoring Occurrence for an individual Recommendation Alert

1.1 Event Frames (Logarithmic Formula)

Event Frames monitor all occurrences unlike the Recommendation Alerts where the occurrence is measured at the polling. Consequently, a Recommendation Alert does not equal all occurrences.

Outcome – Recommendation Alert Priority Score

Formula:

$$\text{Recommendation Alert Priority Score} = (\text{Severity} * \text{Occurrence} * X \text{ Detectability}) * \text{Asset Criticality settings (assigned at Asset level)}.$$

Severity & Detectability as stated in 'Definitions' above.

Occurrence is a measure of the count that the recommendation logic is met.

We use the logarithmic function to calculate 'Occurrence'. The logarithmic function to measuring operational alarms in a system.

$$\text{Occurance} = \frac{1}{a} * \log_b(mx) + c$$

Where:

- x is the number of alerts for that specific alert type
- a is a scaling factor
- m is the multiplier for x
- c is a vertical shift

Examples for each constant:

x: Number of alerts in the last x hours [x is a global parameter]

Let's say $x = 100$ alerts were recorded in the past 24 hours.

a: Scaling factor for the overall frequency

Example: $a = 0.5$

A smaller value of ' a ' will increase the overall frequency, making the system more sensitive to changes in the number of alerts.

b: Base of the logarithm

Example: $b = 10$

Using base 10 is common and makes the scale easy to interpret. Each order of magnitude increase in alerts will correspond to a unit increase in the log value.

m: Multiplier for x (alert count)

Example: $m = 0.1$

This scales down the number of alerts. If $m < 1$, it reduces the impact of large numbers of alerts, preventing the frequency from growing too quickly.

c: Vertical shift

Example: $c = 3$

This adds a constant to the result, effectively setting a minimum frequency even when there are very few alerts.

The logarithmic function helps to compress the range of occurrence values, preventing the RPN from growing too quickly for assets with very frequent alerts. Adjusting the parameters a , b , m , and c allows you to fine-tune the sensitivity of the occurrence calculation to best fit your risk assessment needs.

The formula can be enhanced to incorporate multiple variables. Example for a pump $1/a * \log_b(mx * V * T * F * E) + c$

Where:
 x = number of alerts in the last 24 hours
 V = vibration level factor
 T = temperature factor
 F = flow rate factor
 E = efficiency metric factor

1.2 Tags (Using time decay)

In the situation where Recommendation Alerts are created from polling asset tags, we normalize the occurrence count with a time decay function.

Recommendation Alert Priority Score =

(Severity * Occurrence * X Detectability)

*

Asset Criticality settings (assigned at Asset level)

Severity & Detectability as stated in 'Definitions' above.

Occurrence is a measure of the count that the recommendation logic is met.

This approach accounts for two factors:

- The gradual decrease in an alert's significance over time
- The varying sampling frequencies across different data sources.

The resulting score reflects both the event's severity and its temporal relevance. The following equation can be used:

$$Occurrence = n * e^{-\lambda t}$$

Where:

- λ is the decay rate
- t is the duration from the current time
- n is percentage of time an alert was open normalized

To calculate n , use the following ratio

$$n = \frac{\text{Actual number of Occurrence for a duration}}{\text{Total Potential Occurance in that duration}}$$

For example, we have two alerts open.

Alert 1:

- λ is .01
- t is every 24 hours
- n is percentage of time an alert was open normalized

Polling Rate = 12 hours

Polling Duration = 24 hours

Total Polling Time Frame = 3 Days

Alert 2:

- λ is .01
- t is every 24 hours
- n is percentage of time an alert was open normalized

Polling Rate = 24 hours

Polling Duration = 24 hours

Total Polling Time Frame = 3 Days

The duration in this scenario is set largest duration between polls (in this case 24 hours).

If we had the following data for the alerts:

Days	1	1	2	2	3	3
Alert 1 Poll	x	x	x	x	0	x
Alert 2 Poll	-	x	-	x	-	x

In the grid above, "x" is an occurrence, "0" is no occurrence, and "-" indicates no poll.

To normalize so we would get the same number of time frames to calculate occurrence for, we would divide the number of total occurrences in each time frame by the number of potential occurrences

Days	Alert 1	Alert 2	Time (hrs)	Alert 1 Occ. Score by Day	Alert 2 Occ. Score by Day
1	2/2	1/1	48	.618	.618
2	2/2	1/1	24	.786	.786
3	½	1/1	0	.5	1
Total				1.90	2.40

Alert 2, which occurs at every interval, has an occurrence score of 2.4 with an aggressive decay factor. While the most recent occurrence receives the maximum score of 1.0, the high decay factor significantly reduces the weight of occurrences from three days ago.

For comparison, we applied the same decay factor to Alert 1. However, Alert 1's latest value was normalized to 0.5 since the condition was true for only half of the potential instances. This normalization reduced Alert 1's occurrence score to 1.90, compared to Alert 2's score of 2.4. The difference in scores demonstrates how recent occurrences have a stronger influence than older ones.

The combination of normalization and decay rates effectively handles both varying polling frequencies and the diminishing relevance of historical occurrences

Scores can also be adjusted based on other factors.

Below shows an example based on the type of alert and how different decay rates affect the scores if decay rates are based on recommendations.

Hours Elapsed	Critical (rate: 0.05)	Vibration (rate: 0.1)	Temperature (rate: 0.3)	Pressure (rate: 0.5)	Transient (rate: 0.8)
0	1.000	1.000	1.000	1.000	1.000
1	0.951	0.905	0.741	0.607	0.449
2	0.905	0.819	0.549	0.368	0.202
4	0.819	0.670	0.301	0.135	0.041
8	0.670	0.449	0.091	0.018	0.002
12	0.549	0.301	0.027	0.002	0.000
24	0.301	0.091	0.001	0.000	0.000

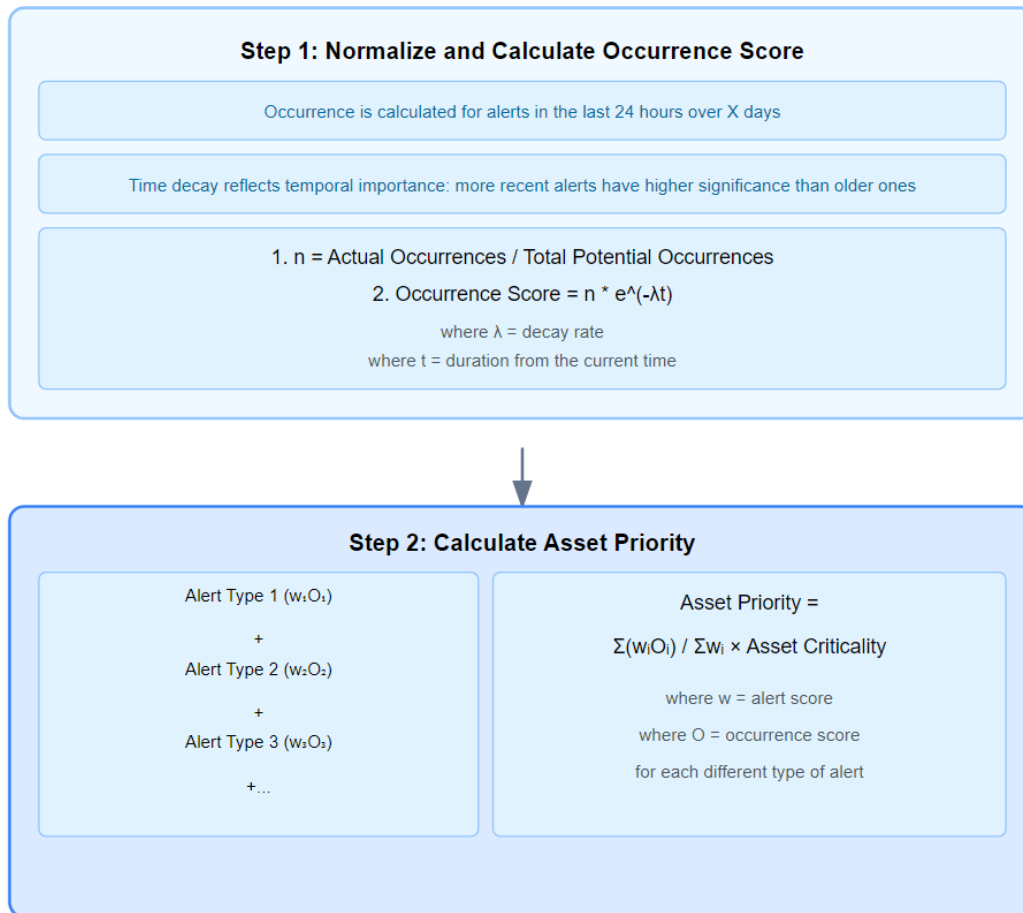
Decay rates can also be adjusted based on an asset's criticality. For example:

- Critical assets: Use lower decay rates (0.05 - 0.1)
- Non-critical assets: Use higher decay rates (0.3 - 0.5)
- Maintenance-dependent alerts: Use very low decay rates (0.01 - 0.05)

2. Priority by Asset for Multiple Recommendation Alert Types

Outcome – Priority score by Asset

For the various recommendation alert types for an asset, we need to calculate individual occurrence scores for each Recommendation Alert type and then aggregate them into a single **asset-level** occurrence score. This approach ensures that we consider all alert types while maintaining a single score for use in the RPN (Risk Priority Number) calculation.



Step 1: Calculate Individual Occurrence Scores

Calculated as per Section 1 or Section 2

Step 2: Aggregate Occurrence Scores

After calculating individual occurrence scores, aggregate them into a single asset-level score. Here are three methods to consider:

1. Maximum Method:
 Asset Occurrence = $\max(O_1, O_2, \dots, O_n)$
 Where O_1, O_2 , etc. are occurrence scores for each alert type.
2. Weighted Average: (*Recommended*)
 Asset Occurrence = $(w_1 * O_1 + w_2 * O_2 + \dots + w_n * O_n) / (w_1 + w_2 + \dots + w_n)$
 Where w_1, w_2 , etc. are weights assigned to each alert type based on their importance.
3. Logarithmic Sum:
 Asset Occurrence = $\exp(\log(O_1) + \log(O_2) + \dots + \log(O_n))$

Weighted Average is recommended as the preferred method. the method that best fits your system's requirements and risk assessment strategy.

Step 3: Normalize the Score

Ensure the final asset occurrence score falls within your desired range (e.g., 1-10) by applying appropriate scaling or normalization.

Step 4: Integrate with RPN Calculation for each asset

Use this aggregated asset occurrence score in your RPN formula:

$$\text{RPN} = \text{Severity} * \text{Asset Occurrence} * \text{Detectability}$$

Example Calculation using Event Frames.

Refer Section 1.2 for the calculation of occurrence for tags.

Let's consider an asset with two alert types:

Alert Type 1:

1. $x_1 = 100$ alerts
2. $a = 0.5, m = 0.1, c = 3$
 $\text{Occurrence}_1 = 1/0.5 * \log_2(0.1 * 100) + 3 = 9.64$

Alert Type 2:

- $x_2 = 50$ alerts
- $a = 0.5, m = 0.2, c = 3$
 $\text{Occurrence}_2 = 1/0.5 * \log_2(0.2 * 50) + 3 = 9.32$

Using the weighted average method with $w_1 = 1.2$ and $w_2 = 1$:

$$\text{Asset Occurrence} = (1.2 * 9.64 + 1 * 9.32) / (1.2 + 1) = 9.50$$

Step 5: Calculate the Asset Priority

$$\text{Asset Priority} = \text{Asset Criticality} * \text{RPN}$$

Considerations

1. Address assets with no alerts of a particular type by setting a minimum occurrence value (e.g., 1) or using zero, depending on your risk assessment strategy.
2. The 'Run Recommendation' agent should update the 'x' values (number of alerts) for each alert type.
3. The logarithmic function moderates the growth of the occurrence score for assets with frequent alerts while still capturing the significance of alert frequency. Regularly review and adjust the parameters (a, m, c, and weights) to ensure the system accurately reflects your organization's risk priorities.

Appendix 2 - Analysis of Risk Priority Number (RPN) Implementation in Asset Performance Management: Limitations and Opportunities

Abstract

We examine the theoretical foundations and practical limitations of Risk Priority Number (RPN) implementation in Asset Performance Management (APM) systems. While RPN serves as a cornerstone metric in failure mode and effects analysis (FMEA), significant challenges emerge in its practical application. Through critical analysis of current literature and industry practices, this study identifies key limitations in RPN methodology and proposes potential enhancements for more effective risk assessment in industrial settings.

Introduction

Risk Priority Number (RPN) has long served as a fundamental tool in risk assessment and failure mode analysis. However, as industrial systems grow in complexity and the demands for precise risk quantification increase, the traditional RPN methodology faces several challenges that warrant careful examination. This paper aims to critically analyse these limitations and explore potential solutions for modern industrial applications.

1. Theoretical Framework

1.1 Traditional RPN Calculation

The traditional RPN calculation follows the formula:

$$\text{RPN} = \text{Severity} \times \text{Occurrence} \times \text{Detection}$$

Where:

- Severity (S) represents the seriousness of failure
- Occurrence (O) represents the likelihood of failure
- Detection (D) represents the probability of detecting failure before impact

1.2 Mathematical Limitations

1.2.1 Scale Constraints

Despite the theoretical range of 1-1000, the multiplicative nature of RPN produces only 120 unique values, creating significant gaps in the risk assessment spectrum. This limitation impacts the granularity of risk differentiation and can lead to clustering of risk scores.

1.2.2 Equal Weighting Problem

The multiplicative relationship between factors assumes equal importance of S, O, and D, which often contradicts operational reality where severity might warrant greater consideration in critical systems.

1.2.3 Different Polling Intervals

Traditional Risk Priority Number (RPN) calculations face significant challenges when applied to modern asset monitoring systems. In XMPro, data collection happens at widely varying intervals - from every 5 minutes to every 90 days - rather than continuously. This creates a fundamental measurement problem: alerts from different sampling frequencies cannot be directly compared. For example, equipment monitored every 5 minutes has 288 daily opportunities to trigger an alert, while quarterly oil sampling provides only 4 chances per year. Additionally, we cannot accurately measure how long a condition persists between samples. These limitations require a new approach that accounts for both sampling frequency differences and condition duration.

2. Practical Implementation Challenges

2.1 Subjectivity in Scoring

A significant challenge in RPN implementation lies in the subjective nature of score assignment. Different assessors may assign varying scores to identical situations based on:

- Personal experience and expertise
- Local operational context
- Individual risk perception
- Organizational culture

2.2 Contextual Limitations

2.2.1 Industry-Specific Concerns

The generic nature of RPN calculation fails to account for industry-specific risk factors and regulatory requirements. Different industries may require different emphasis on various risk components.

2.2.2 Asset-Specific Considerations

The standardized approach may not adequately address:

- Unique failure modes of specific asset types
- Complex interdependencies between systems
- Varying operational contexts

2.2.3 Risk Masking

Critical risks may be obscured when:

- High-severity risks receive low overall RPN due to low occurrence
- Critical failure modes are underweighted due to high detection capability
- Multiple moderate risks accumulate without triggering threshold alerts

3. Proposed Enhancements

3.1 Modified RPN Calculations

To address the limitations of traditional RPN, several modified approaches warrant consideration:

3.1.1 Weighted RPN

We propose an enhanced calculation methodology incorporating weighted components:

Modified RPN = $(w_1S \times w_2O \times w_3D)$

Where w_1 , w_2 , and w_3 represent relative importance weights determined through systematic analysis of operational requirements and risk profiles.

3.1.2 Cost-Based RPN

Financial impact consideration enhances risk assessment accuracy through:

Cost-Based RPN = Modified RPN \times Financial Impact Factor

This approach provides more nuanced risk prioritization aligned with business objectives.

3.2 Advanced Risk Assessment Framework

A more comprehensive framework should include:

- Multiple risk assessment methodologies
- Industry-specific risk factors
- Dynamic threshold adjustment capabilities
- Integration with asset criticality metrics

4. Implementation Recommendations

4.1 Systematic Approach

Organizations implementing RPN should:

- Establish clear scoring guidelines
- Provide comprehensive assessor training
- Implement regular calibration exercises
- Document scoring rationale
- Regularly review and update risk assessment criteria

4.2 Technology Integration

Modern APM systems should incorporate:

- Machine learning for pattern recognition
- Real-time data analytics
- Automated threshold adjustment
- Historical trend analysis
- Integration with broader asset management systems

5. Future Research Directions

Several areas warrant further investigation:

- Development of industry-specific RPN modifications
- Integration of artificial intelligence in risk assessment
- Validation of modified RPN methodologies
- Quantification of subjective assessment impacts
- Cost-benefit analysis of enhanced risk assessment methods

6. Conclusion

While RPN remains a valuable tool in risk assessment, its limitations necessitate careful consideration and potential modification for modern industrial applications. The proposed enhancements and implementation recommendations provide a framework for improving risk assessment accuracy while maintaining practical applicability in industrial settings.