Delivering the Nuclear Promise
Top Innovative Practice

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CAP Intelligent Advisor: A Technology Enhanced Corrective Action Program
2023 Top Innovative Practice Winner[1]

Summary

Nuclear power plants are required to ensure that conditions adverse to quality are promptly identified and corrected.[2] For this reason, nuclear plants have corrective action programs (CAPs) to manage the identification, screening, and fixing of adverse conditions. The scope, complexity and amount of information involved in CAPs require the use of software that provides a centralized system for collecting information on issues of all levels of significance. Issues may range from minor concerns (e.g., a sidewalk crack) to critical situations that may present potentially unsafe operating conditions in the plant. Entries into the CAP are routed to relevant administrators and specialists to triage, remedy, and resolve the issues that have been raised in CAP reports. At a typical U.S. nuclear plant, the CAP may receive 10,000 or more new entries annually. These are screened by a multi-disciplinary team of senior plant personnel, requiring many labor hours each week. This review of CAP entries may vary depending on the individuals reviewing the CAP entry, their experience level and familiarity with the issues that are described. To improve the accuracy, consistency and efficiency of this process, Xcel Nuclear developed machine-learning (ML) models to identify, screen and remediate adverse conditions described in CAP entries.

Background

An Introduction to CAP Intelligent Advisor:

The CAP Intelligent Advisor (CAP IA) is a computer technology intended to improve the accuracy, consistency, and efficiency of CAP systems. It leverages unique combinations of trained machine-learning models to identify, screen, and remediate adverse conditions in a nuclear or other regulated generation facility. This system has been in use by the Xcel Energy Nuclear Fleet since early 2022. As discussed above, CAP systems have traditionally relied on people to triage and resolve negative conditions, and to ensure regulatory compliance. For example, CAP entries are manually reviewed by humans to identify the negative conditions and prioritize those conditions to receive appropriate attention. This involves reviewers evaluating the CAP entries based on a variety of factors, including judging the significance of the reported problem. Additionally, the reviewers can assign the CAP entries to groups, teams, or individuals for resolution. Even with standard guidelines used for performing such tasks, outcomes can still vary due to the complexity of the issue and

[1] Winning entries of from NEI's Top Innovative Practices (TIP) awards are republished as DNP Efficiency Opportunities to ensure the broadest possible dissemination of these operating plant innovations.

[2] Per Code of Federal Regulations, Title 10, Part 50, Appendix B, Criterion 16, "Corrective Action", available at https://www.nrc.gov/reading-rm/doc-collections/cfr/part050/part050-appb.html.

subjective nature of human review and assessment. In short, manual review and handling of CAP reports can be labor and resource intensive, inconsistent, and potentially erroneous. In contrast, the CAP IA software improves the accuracy, consistency and efficiency of the CAP resulting in improved overall plant performance on problem remediation. This is accomplished by using specific combinations of machine learning (ML) models and signals derived from CAP reports to provide better categorization, prioritization, and disposition of issues.

The CAP IA system is designed to remedy the subjectivity and variation in conventional CAP systems. The system can handle significant variation in CAP reports (e.g., variation in manually entered unstructured data fields) through combinations of ML models that are designed to individually assess aspects of CAP reports and are then combined to determine appropriate handling and remediation of CAP reports.

The models are used to identify and analyze various signals in a CAP report such as the presence of particular keywords (e.g., stems, phrases, words), word count in a particular text/input field in the report (e.g., when fewer words are used to describe an issue, it can be inferred that the negative condition in the CAP report is less severe or less critical than if more words are used to describe the condition), trend codes, equipment type, and signals related to other CAP reports submitted within a facility. These inputs are used to determine priority, severity, type of corrective action needed, and assignment of such actions to appropriate individuals within the organization. The models provide the top three criteria involved in determining a prediction. This allows the user to see how the CAP wording affects the model output as well as an explanation of that output.

Feedback from the model output is also used to continuously train the models to improve the handling of negative conditions and corrective actions to be taken. Any time a model prediction is found to be incorrect by a human reviewer, thus requiring a modification to the screening outcome, that correction is used in the next monthly training cycle to incorporate the situational learning into the model, making it more accurate with each interaction. By implementing this system, the operation and management of negative conditions at nuclear generating facilities can be optimized.

Additionally, CAP IA automates trend analysis over time. With statistics, graphs and charts, the software provides insights into whether a particular condition in the facility is experiencing a long-term negative performance trend or a short-term negative performance spike. These results are flagged to the CAP entry within hours of submittal. Such trending analysis can beneficially be used by relevant stakeholders for short-term and long-term strategic planning in the facility.

<u>An overview of the ML Models used in CAP IA:</u>

- CAQ/NCAQ Model

  This ML model uses issue-level information documented by the author of the CAP entry at the time of submittal combined with any notes provided by senior reactor operators when available, to determine if this issue is a condition adverse to quality (CAQ) or not a condition adverse to quality (NCAQ). CAQs are those that could affect the quality of structures, systems, components, and activities within the scope of the Quality Assurance program required by the nuclear plant license. Every entry into the CAP program requires this determination and it greatly affects the priority and options available to resolve the issue. Model outputs provide: "CAQ" or "NCAQ" for every CAP entry.

- CAQ Priority Model

  Not all CAQ carry the same actual or potential consequences. In cases where an issue is determined to be CAQ, they are also graded as level "A," "B," or "C," with "A" being the most consequential and "C" least consequential. This prioritization helps guide the programmatic elements of the CAP process ensuring that more resources and greater evaluations are assigned to issues that represent greater risk. Model outputs provide: "A", "B" or "C" for every CAP entry.

- Maintenance Model

  Many CAP entries do not require additional evaluation or actions to resolve other than performing the proper maintenance to fix the issue. This model considers the information provided by the author along with specific equipment information to determine if the issue can be resolved appropriately by maintenance alone. In many of those cases the CAP entry can be closed to the work management system that governs maintenance work. Model outputs provide: "Close this CAP to a Maintenance Notification" or "Close this CAP to a Maintenance Work Order."

- Management of Change (MOC) Model

  Outside of the Corrective Action process there are many processes and programs that exist to institute changes. These may include programs that govern and track procedure changes, changes to the preventative maintenance of equipment or the review of significant industry operating experience. Within Xcel Nuclear, 13 such programs exist that are housed inside a software named Management of Change. In cases where an issue entered in CAP was not a CAQ, and the solution to resolve the issue is performed in one of those processes outside of CAP, then the CAP entry can be closed to that external process. This model determines if the CAP can be closed to an external process without additional actions. Model outputs provide: "Close this CAP to an existing process."

- CTAT Model

  In some cases, an issue can be found and fully corrected so quickly that when it is entered into the CAP program the author will document not only the issue but also document how the issue was resolved. This model looks for CAP entries that meet that description and identifies that they can be Closed to Actions Taken (CTAT). Model outputs provide: "Close this CAP to actions already taken."

- Evaluation Model

  For issues that present larger actual or potential consequences or those issues that are repetitive, it is not enough to correct the condition via maintenance or other means. In those cases, the issue requires a greater evaluation (Cause Evaluation or Root Cause Evaluation). This model reviews the CAP entry, the equipment information, and the results of other models to determine if the issue should be assigned an evaluation to drive a greater understanding of the issue and more effective corrective actions. Model outputs provide: "This CAP requires an evaluation" or "This CAP does not require and evaluation."

- Maintenance Rule Evaluation Model

  In nuclear power generation there are many regulatorily required programs. One such program that overlaps with the corrective action program is the Maintenance Rule program. It relies on the CAP for identification of issues which could require further evaluation and action under the Maintenance Rule program. Identification of these issues in the CAP is often left up to a small population of subject matter experts (SMEs). This Maintenance Rule Evaluation model uses the information in the CAP entry along with equipment information and information generated in previous CAP entries to determine if the CAP entry is applicable to the Maintenance Rule Program. This narrows the review needed from SMEs to 4 or 5 out of a hundred cap entries instead of reviewing all CAP entries. Model outputs provide: "This CAP requires a Maintenance Rule Evaluation" or "This CAP does not require a Maintenance Rule Evaluation" (See Attachments 1 and 2).

- Aging Management Model

  The Aging Management program is another regulatorily required program which relies on the CAP program for identification. Just as in the Maintenance Rule program model above, identification of these issues in the CAP is often left up to a small population of subject matter experts (SMEs). This model uses the information in the CAP entry along with equipment information and information generated in previous CAP entries to

determine if the CAP is applicable to the Aging Management program. This narrows the review needed from SMEs to 4 or 5 out of a hundred CAP entries instead of reviewing all cap entries. Model outputs provide: "This CAP requires an aging management review" or "This CAP does not require an Aging Management Review."

- Disposition Model

  By using the results of the other models in CAP IA, this model can determine how the condition should ultimately be resolved. This is referred to as the CAP disposition. It is the conclusion that is applied to the CAP issue. Model outputs will provide one of the following per issue:

  - CTMOC – Condition is being resolved by a cross referenced MOC.
  - CTPMN – Condition is being resolved by a cross referenced Work Notification.
  - CTPMO – Condition is being resolved by a cross referenced Work Order.
  - CTT – Condition does not require resolution but will be trended.
  - QIM – Condition is being resolved by new activities under this CAP entry.
  - CTAT – Condition was resolved through actions already documented in the CAP entry.
  - CTEQIM – Condition is being closed to an existing CAP entry.

<u>Features of Note</u>

- CAP Entry: Targeted questions designed to feed reviewers and ML Models

  The CAP IA tool has been designed with an entry point for users to write CAP entries that provide the maximum information, while not overwhelming users. By soliciting information such as "what is the worst actual or potential consequence that could come from this issue," the quality of CAP entries has greatly increased leading to less follow up needed with authors. Since implementing CAP IA there has been a 200% increase in the number of top quality (good catch) CAPs entered in the system.

- CAP Search: Search Engine

  The CAP Search feature made available with CAP IA allows users to conduct searches of every text field in a CAP entry. They can search CAP entries as far back as 1980. A word search feature as well as over 40 different filters are provided to find any information in the program quickly. The results of searches can be exported into Excel files for further use or PDF for improved readability. This format has been so successful that it has become the default tool for preparing and conducting the plant's problem identification and inspection (PI&R) inspections by the NRC.

  User feedback shows this is the feature most appreciated in CAP IA for its simplicity and the time savings it represents to users in locating CAP information. Xcel Energy has not received any NRC violations related to CAP or PI&R since CAP IA has been in service.

- My Work and Teamwork Dashboards: Work management for individuals and teams

  The nuclear industry has exacting standards for the management of actions tracked in the CAP. The "My Work" dashboard is designed to present all activities assigned to an individual employee. These include not only CAP activities but also activities from thirteen additional programs creating a single dashboard for employees to manage all work assignments. These activities are sorted by priority and due date to ensure the work tasks are always visible and easily manageable. The "Teamwork" dashboard allows users to designate people from the organization to be part of their team, displaying all actions team members are assigned to by priority and due date.

  Since this feature has been implemented, Xcel Energy has experienced an unprecedented 60% decrease in overdue NCAQ activities and well as zero overdue CAQ actions.

- CAP Screening: Inline editing and management review of model determinations

  Even with the automation of many of the aspects of the corrective action process, there will always be a need for a human to review those results and concur. By designing a screen specifically for management review of CAP entries, with inline editing, the time required to complete a management review of CAPs has been cut by 50%. This has allowed for one meeting fleetwide (involving multiple sites) to review an average of 100 CAP entries in less than 30 minutes. This has come with an added benefit of internal operating experience being shared between participating locations and an increase in cross-disciplinary resolutions to issues. (See Attachment 3)

  Since this feature was put in place and the ML models activated which discourage low value actions from being created, Xcel Nuclear has seen a 20% reduction in its NCAQ low-level CAP actions. This equates to over 900 low-value CAP actions that did not get assigned across the fleet because of these combined features.

- CAP KPIs

  Management of the work residing in the CAP program is not only the responsibility of individuals but must be managed as a fleet. This feature provides a command center view of all key performance indicators in CAP. Automation of key performance indicators for the CAP program allows for oversight of the volume of open actions and timeliness of open actions across multiple categories, priority, and type, without the need to mine data or administer graphs and charts. As a result, Xcel Nuclear currently enjoys the lowest backlog of CAP actions it has experienced in over five years.

- CAP Trending and Monitoring

  CAP IA provides for automating trending and monitoring of negative conditions identified in a particular facility, which includes automatic and efficient flagging of information in CAP reports using trending criteria. It also automatically evaluates whether the negative conditions are part of an ongoing negative trend (over the last 2 years) or a short-term negative spike (one month spike above normal variation) in performance, which can further be used to quickly generate response plans to cure the effects of the negative conditions on the facility before serious consequences are incurred. (See Attachment 3)

  Many additional trends have been identified since this tool has been in place including those that have been used in security and outage performance to correct the course of performance.

Innovation

This technology leverages a novel use of an array of self-training ML models to produce highly accurate solutions to issues identified in the CAP. Unique model training techniques have produced individual models that are between 81% and 97% accurate on their own. When combined in a heuristics array, they predict with greater accuracy than any one model alone and provide the Severity (NCAQ vs CAQ), Priority (A, B, C, N), Disposition (means by which the issue will be corrected) and the type of action that will be needed to correct the issue if one is required (Non-Regulatory Action, Regulatory Corrective Action, Advanced Evaluation). This is the first time that Xcel Energy implemented continuous ML algorithms in production. In addition, this project used cloud resources (Amazon Web Services) for deployment and training of the ML algorithms – technology and in-house expertise that can be used for other projects in the future. (See Attachments 4 and 5)

Safety

CAP IA produces automated trending and monitoring that provides long-term trend and spike detection that has already been used to identify early degradation in areas of security loggable events and predecessors to events as well as outage industrial safety insights that directly impact workers.

Cost-Savings

Due to the programs' ability to deliver on time-saving features and models that reduce low value actions, the combined cost savings of the CAP IA project has been estimated to be 36,000 person hours. This estimate was made before yearly performance results were published that show performance surpassing expectations in several areas including action backlog and low-value activity reductions.

Productivity/Efficiency

The model algorithms have been tuned to identify and discourage low-value activities. Even though the system was trained on human inputs, tuning off the models allows for targets that are in line with the programs' optimal outcomes instead of repeating the performance of the past. Due to this model tuning, the Xcel Energy nuclear fleet has seen a 20% reduction in the number of CAP entries requiring distinct actions to resolve. This amounts to over 900 low-value actions that were not created in CAP in 2022 that otherwise would have negatively impacted resources.

Transferability

Xcel Energy is currently working with all its business units (Gas, Fossil, Distribution, etc.) to adopt CAP IA. While only the nuclear business unit are required to maintain a CAP, the benefits of this automated CAP IA system have made it ideal for adoption across the other energy business units due to its proven impact on efficiency, cost savings and unique statistical insights. This next phase in the CAP IA project is expected to produce a step change in performance across Xcel Energy. This innovation can also be used by other nuclear utilities.

Team Members

- Dylan D. Wojchouski, Fleet Performance Improvement Manager/Business Product Owner
- Robert J Foster, Senior Data Scientist
- Jetrey W. Bond, Senior IT Engineer
- Courtney R. Krieger, IT Product Owner
- Patrick L. Beyers, Nuclear Director/ Business Product Owner
- Jessica M Rieder - Principal Performance Improvement Coordinator
- Samuel M Hinh - Nuclear Data Scientist
- Gerard P Horgan - Data Engineer
- Justin L Fields - Senior Data Scientist
- Gil H Leibovich - Associate Data Scientist
- Denny D Lehman - Associate Data Scientist
- Aubrey S Hughes - Data Engineer
- Faezeh Ebrahimi - Associate Data Scientist
- Blake E Kleinhans - Data Scientist
- Andrew Brown – Senior Engineering Analyst

Attachments (5)

Attachment 1

MRE model

Objective	Predictive model that suggests if a maintenance rule evaluation is required
Impact	More rapid and transparent recommendations for maintenance rule evaluations

Overview and Inputs

Data used: Issue-level data (pre-screening user SRO inputs, user free-text input), equipment data (criticality data, safety rating, system), actions-level data (disposition, user free-text input)

Data filters: None

Model: Yandex CatBoost (gradient boosted random forest)

Target variable: ACT_TEMPLATE with value MRE

Baseline: Target variable is true for ~1.5% of actions
Note: Check weekly for changes in baseline % in data. May need to tweak thresholds

Model Performance *Run on 3/15/2022*

Train data	Test data	Model utility	Thresholds [t1, t2]	ROC AUC[1]	PR AUC[1]
[2019, 2020]	[2021, 2022]	FP	[0.0078,0.0082]	0.894	0.271

Accuracy	PPV[2]	NPV[2]	Recall	Selectivity	Optimized hyperparameters[3] [depth, iterations]
92.0%	10.5%	99.5%	67.8%	91.9%	n [4,834]

For MRE model utility parameters, **we chose a +35.5 reward for true positive values** to increase recall since baseline rate is low

- False Negative penalty: -35.5
- False Positive penalty: -1.013
- Uncertain Positive penalty: 0
- Uncertain Negative penalty: 0
- True Positive reward: +35.5
- True Negative reward: +1.013

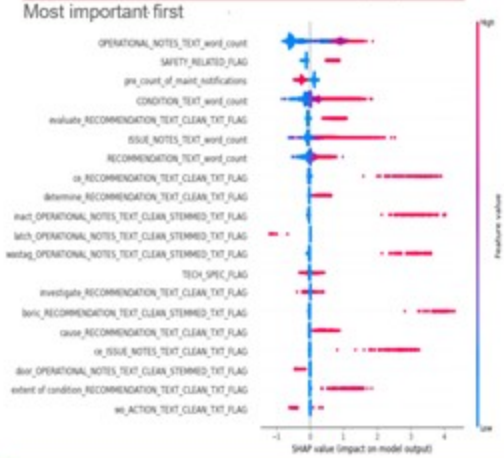
1. Receiver operating characteristics area under the curve, PR-AUC used with imbalanced datasets. 2. Positive predictive value, negative predictive value. 3. Using five fold cross-validation

Attachment 2

MRE Model SHAP values

Top 20 Feature SHAP values ranked by importance

Most important first



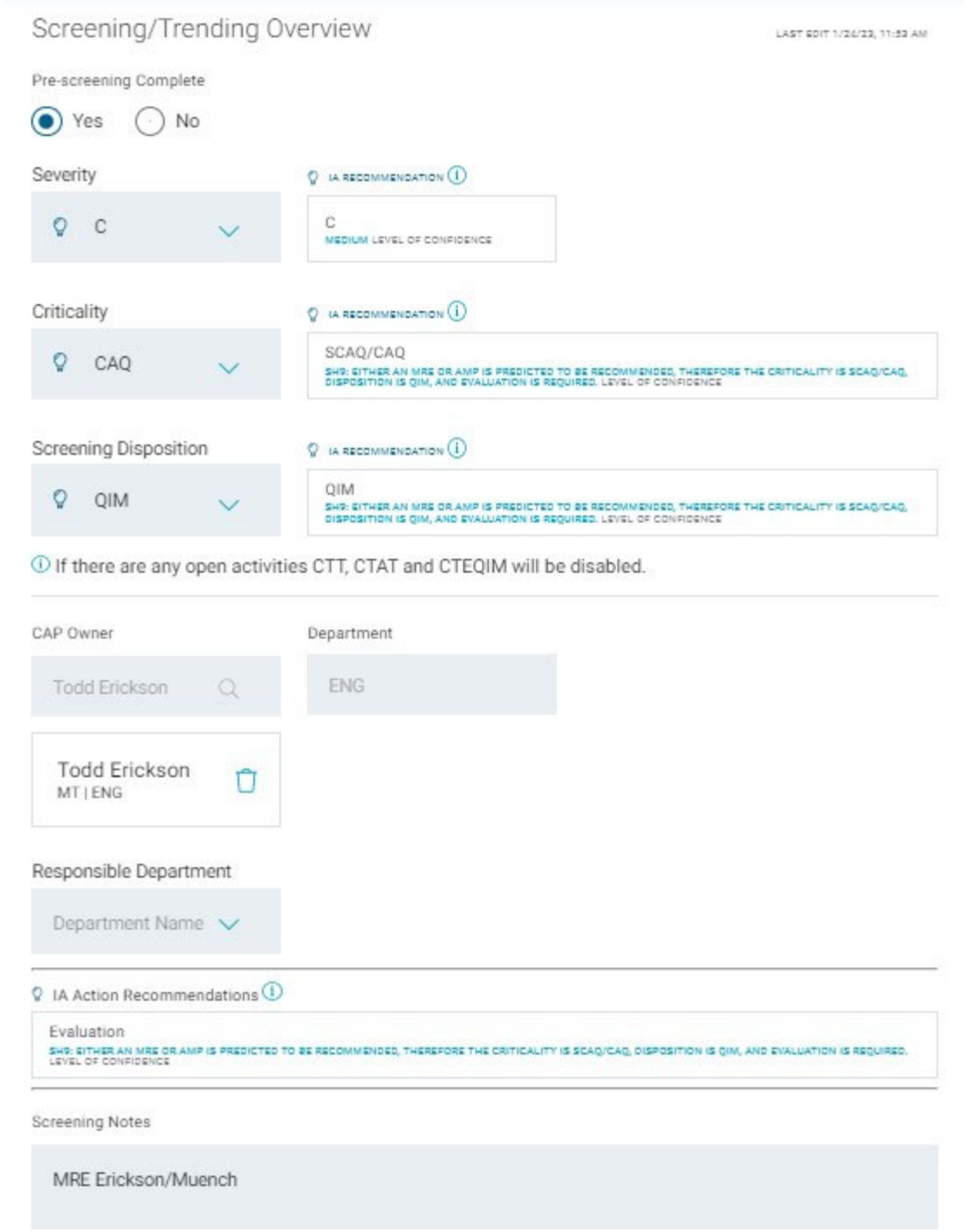
Interpretation of SHAP values

- Issues containing a large number of words in operational notes are more likely to require MRE
- Issues occuring on safety related equipment are more likely to require MRE
- CAP's containing a high number of maintenance notifications are less likely to require MRE
- Issues containing a large number of words in condition text are more likely to require MRE
- Issues containing the word "evaluate" in the recommendation text are more likely to require MRE
- Issues containing a large number of words in issue notes are more likely to require MRE
- Issues containing a large number of words in recommendation text are more likely to require MRE
- Issues containing the word "ce" in the recommendation text are more likely to require MRE
- Issues containing the word "determine" in the recommendation text are more likely to require MRE
- Issues containing the word "inact" in the operational notes text are more likely to require MRE
- Issues containing the word "latch" in the operational notes text are less likely to require MRE
- Issues containing the word "wastage" in the operational notes text are more likely to require MRE
- Issues occuring on tech spec equipment have mixed effects on evaluation
- Issues containing the word "investigate" in the recommendation text have mixed effects to require MRE
- Issues containing the word "boric" in the recommendation text are more likely to require MRE
- Issues containing the word "cause" in the recommendation text are more likely to require MRE
- Issues containing the word "ce" in the issue notes text are more likely to require MRE
- Issues containing the word "door" in the operational notes text are less likely to require MRE
- Issues containing "extent of condition" in the recommendation text are more likely to require MRE
- Issues containing the word "wo" in the action text are have mixed effects on evaluation

- Number of words contained in the operational notes is the most predictive feature of requiring an evaluation

Attachment 3 – Trending Display

Attachment 4 – Example Display



Attachment 5 – Example Display