Forced Rank Methodologies to More Efficiently Perform Criticality Analysis (the Solomon Oldach Asset Prioritization Method, or SOAP)

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SUMMARY & CONCLUSIONS

An alternate method for conducting asset criticality ranking for use on industrial assets and public infrastructure can result in staff time savings of up to 70% as compared to traditional methods, which are time consuming and sometimes misleading. The methodology proposed in this paper does follow many of the traditional approaches, including the use of cross-functional teams. Its primary differences are related to the use of preference ballots for system level evaluation and the subsequent use of a function-based scoring system at the asset level. The authors suggest that the uses of a relative asset criticality ranking as it applies to industrial assets and public infrastructure does not require the detailed and time consuming analysis that has been traditionally promoted.

1 BACKGROUND

O'Connor and Kleyner [1] have documented reliability engineering as originating in the United States in the 1950s largely as the result of increasing complexity of military electronic systems. The techniques were adopted in the space industry by NASA in the 1960s and quickly spread to other industries by the 1970s. The British defense industry published its first standard in 1981. Over the course of the 1980s and early 1990s, many of the reliability standards were complemented by the production and quality measures that were championed in Japanese manufacturing, more generally referred to as Total Quality Management. In the 1990s many reliability standards began being incorporated into those published by the International Organization of Standardization (ISO).

1.1 Definitions

Establishing a clear understanding of definitions is a key to building consensus and for effective decision-making. A common understanding of terms such as criticality, function, and failure should be established prior to performing any type of system or asset prioritization activity.

US Military Standard 721C (MIL-STD-721C, 1981) defines criticality as a relative measure of the consequences of a failure mode and its frequency of occurrences. Gulati [2] describes critical assets as those which have been identified and classified as such due to their potential impact on safety, environment, quality, production/operations, and maintenance if failed. MIL-STD-1629A (1980) defines a criticality assessment as a procedure by which each potential failure mode is ranked according to the combined influence of severity and probability of occurrence [3].

Key terms within the definition of criticality include failure and function. Failure is commonly defined as the event, or inoperable state, in which any item or part of an item does not perform as previously specified [4]. Failure can also be further subdivided into forms such as catastrophic failure, critical failure, dependent failure, functional failure, hidden failure, and others.

Function is commonly defined as "what the owner or user of a physical asset wants it to do" [5]. Functions can also exist as primary functions and secondary functions, or as hidden or evident functions. A function statement helps to clarify what is meant by both function and failure. The function statement is the stated and written documentation of the facility, system, or asset function being evaluated. The function statement should start with the word "To…", and usually contains a verb, an object, and at least one performance standard.

The primary function constitutes the main reason(s) why a physical asset or systems exists. Secondary functions are those that the physical asset or system has to fulfill apart from the primary function, such as those needed for attributes such as convenience, comfort, appearance, and energy efficiency.

In the methodology provided in this paper, secondary functions related to safety, environment, or minimizing cost, are assumed and do not need to be defined as part of the primary function, unless the primary function is related to safety, etc. These secondary function considerations will be made at the asset level.

1.2 Traditional Criticality Evaluations

In the context of Failure Modes and Effects Analysis (FMEA), Wasserman [6] states that each failure mode is rated by its criticality – the severity of the failure event multiplied by the likelihood of its occurrence – or by its risk prioritization number (RPN) – severity multiplied by the likelihood of its occurrence and multiplied again by the likelihood of it not being detected. Wasserman and others have recommended prioritization of actions related to failure modes based on: (1) effects that have the highest severity rating; (2) causes that have the highest severity times occurrence ratings, and (3) the highest RPNs.

Moubray [7] has stated that a large number of techniques have been developed which attempt to provide a systematic basis for deciding what asset are likely to benefit most from analytical approaches such as Reliability Centered Maintenance (RCM). Also known as "criticality assessments", most of these techniques use some variation of the concept known as the probability/risk number, or PRN. The PRN is derived by multiplying the probability of failure, or failure rate, by the consequences of the failure.

More sophisticated variations build up composite PRNs by attaching different numerical ratings to categories of failure consequences. Such systematic rankings can be useful to clarify and build consensus about what assets really matter and about where large, complex systems are particularly vulnerable.

2 METHODOLOGY

The methodology provided in this paper is built upon sentiment expressed by Moubray that the underlying benefit of systematic approaches is to "clarify and build consensus about what assets really matter and about where large, complex systems are particularly vulnerable" [8]. It is also built upon the desire to minimize staff time in a workshop setting to achieve the same intended benefit.

The term "forced ranking" refers to an approach that "forces" participants to make a decision on the relative importance of each item as compared to the other items, and thereby avoids an often common response that all of the items in a facility are critical. Forced ranking also avoids the issue of having the participants reach consensus on every consequence and/or likelihood of failure feature of each asset being considered.

The method proposed begins the ranking process at the system level, and then uses a decision flow process to rank assets within the system based on the impact of asset failure on the system function. A ballot forces workshop participants to independently prioritize systems by ranking them in relative order of importance considering the system function as it supports potential impact categories (Environmental, Safety, Operations, etc.) as opposed to giving each item a quantitative score based on failure consequence.

The process involves two distinct steps. The first step involves a system ranking and those results are used in the second step to develop the asset ranking. Both steps use a 5 level criticality system with 5 being the most critical and 1 being the least critical. The resulting scores are merely representations of the importance of the asset as compared to another asset in the population of facility/system assets. The term associated with this method is "relative criticality ranking".

3 FORCED RANK APPROACHES

Forced rank approaches can take a variety of forms. An approach described in this paper is based on preferential voting methods by ballots (a ballot is simply a record of how a voter, in this case a workshop participant, voted). A preference ballot is utilized to provide a complete ranking, from most important to least important, of relative importance of infrastructure systems in fulfilling the primary function of a facility. The preference ballots are then converted into a preference schedule which summarizes the results of all of the individual preferences.

A group of analytical methods are used to analyze and rank the data summarized in the preference schedule. Plurality, Borda Count and Pairwise Comparison are the three consensus methodologies that are used in the approach proposed in this paper.

3.1 *General Background*

Voting consensus methodologies dates to the Roman era. Jean-Charles de Borda officially complied the system that bears his name in the 1770s. Marquis de Condorcet put forth another general theory in 1781 related to what is generically called Pairwise Comparisons; A.H. Copeland described his method of pairwise aggregation consistent with Condorcet in 1945. Both the Borda Count and Condorcet methodologies are referred to as constructive consensus methods. Voting theorists have developed the Fairness Criteria to describe what is meant by a "fair" preferential election [9].

Arrow [10] concluded in his Impossibility Theorem that none of the preferential voting methods will satisfy all of the Fairness Criteria. Judgement is needed to look at any one of the preferential voting methods to determine which are most applicable in a given situation. This, in turn, means that there is no perfect preferential voting procedure and the decision about the procedure to be used is, by necessity, subjective. In applications related to assessing system criticality, the analysis should be considered as a guide, rather than an absolute, and should be fine-tuned by human judgement.

3.2 Plurality

Plurality involves prioritization based on the number of first place rankings. The alternative with the most first place votes wins and the winner does not have to receive a majority of the first place votes. Plurality is perhaps the most intuitive and the most over-simplistic of all of the preferential voting methodologies. However, it is a useful starting point for developing consensus.

3.3 *Borda Count*

The Borda Count Method involves providing points based on where alternatives appear in a ranking. Each alternative gets 1 point for each last place vote received, 2 points for each next-to-last point vote, etc., all the way up to N points for each first place vote (where N is the number of alternatives). The alternative with the largest point total wins the election, or in this case, is considered most critical.

In the Plurality Method, only the information related to first place is used; however, the Borda Count Method uses all of the information from the ballots. The result is that this approach provides greater importance to the voter's lower preferences and favors alternatives with broad consensus. The tradeoff, however, is that the highest ranked alternative may not be any single voter's highest priority alternative.

3.4 Pairwise Comparison

In the Method of Pairwise Comparisons, each alternative is matched one-on-one with each of the other alternative. Each alternative gets 1 point for a one-on-one win and a half a point for a tie. The results of the one-on-one competitions are transferred to a preference table and the alternative with the most total points is the winner.

The Method of Pairwise Comparisons was explicitly designed to satisfy the fairness criterion. Any alternative that wins all possible head-to-head matchups always has a higher point total than any other alternative and thus is declared the winner. The family of methods that meets the Condorcet Criterion is referred to collectively as Condorcet's method.

Copeland's method is utilized for the Method of Pairwise Comparison described in this paper is based on its relative simplicity and the nature of the required outcomes for infrastructure systems. Copeland's method is a Condorcet method in which alternatives are ordered by the number of pairwise victories, minus the number of pairwise defeats. Other Methods of Pairwise Comparison that meets the Condorcet Criterion include Black's, Dodgson's, Kemeny-Young, Minimax, Ranked Pairs and Schulze's.

The first and most practical issue related to Pairwise Comparison is the number of one-on-one comparisons that are required, ½(N)(N-1), where N is the number of alternatives on the ballot. For 20 alternatives, 190 one-on-one comparisons are required. Obviously this is best performed with a spreadsheet tool, and requires some time to check and verify the results when in a workshop setting.

A second, more theoretical issue is that it violates the Independence of Irrelevant Alternative Criterion. The practical ramification of this is that the initial rankings will change if an alternative is subsequently dropped from consideration.

3.5 Aggregation of Rankings at the System Level

The results of the three preferential voting methods are summarized in tabular and graphical form. In tabular form, the relative rank of each can be compared in a single row. Averaging the results of each row is recommended for positioning the results graphically on an x-y plot. Averaging the result of the Borda Count and Pairwise Comparison methods has some theoretical problems; however, from a practical standpoint it has proven effective for ranking results in terms of an initial 3-point scale (high, medium, low) for immediate feedback with workshop participants.

The graphical presentation should include each voter's preference clustered by alternative on the x-axis. The y-axis should reflect the actual voter preference. From this plot an understanding of the variability by voter for each alternative can be determined.

The final ranking (5 is most important and 1 is least important) at the system level is the reverse of the voting ranking (1 is most important and N is least important). The final ranking for each system is scientific, based on the preference methodologies described, and one of end user judgement. Both Borda Count and Pairwise Comparison methods provide good consensus for alternatives (systems) in the "5" and "1" classifications. There is usually a broader set of voter preferences, and perhaps more uncertainty, associated with alternatives in the middle of the ranking. For "4" and "2" classifications, it has been found that both Borda Count and Pairwise have more variability when compared to the more extreme "5" and "1" classifications. The "3" classification becomes almost apparent both by variation in the tabular comparison and graphically by the variation in individual voting preferences.

As is the case with traditional criticality methods, the intended outcome of systematic rankings is to be useful to clarify and build consensus about what assets really matter and about where large, complex systems are particularly vulnerable. The results of the voter preference approach is less about a mathematical, closed-form solution and more about quickly coming to consensus. The initial system classifications for "5" to "1" should be used as an intermittent step in the workshop process to drive discussion of system vulnerability and establish consensus of the final system classification.

3.6 Application at Asset Level

The system classification results, developed from the forced rank approach using voter preference methodology and consensus verification, are transferred as the starting point for evaluation at the asset level with the given system of interest. This process is described subsequently in this paper. In general terms, the system classification will provide the basis for the relative criticality ranking at the asset level. However, classifications will be adjusted upward or downward based on the nature of the asset (in example, higher if a safety feature is associated with the system) or lower depending on the asset's importance relative to meeting the primary function of the system.

4 PROCEDURE

This section outlines the steps in performing the simplified criticality analysis methodology. A primary goal of this simplified procedure is to increase the efficiency and effectiveness of the cross-functional team time that is required to perform a criticality analysis, while yielding similar ranking results. This simplified process can be performed with a quarter of the time dedication that is required for other asset criticality ranking methods.

4.1 Data Collection, Systems Review, and Development of Function(s) Statements

This initial step includes the collection of information related to each facility (or collection of systems) to determine the critical systems and the development of a draft function statement for the facility. The following documents and information should be collected for each facility and used for the succeeding step: (1) current Process and Instrumentation diagrams (P&IDs); (2) geospatial configuration or aerial photograph; (3) most recent preliminary engineering report (PER); (4) regulatory permits; (5) summary of production/quality reports over most recent 3 years; (6) summary of regulatory compliance data for past 3 years; and (7) access to maintenance histories.

It is recommended that the facility information be summarized electronically as well as in a notebook for use during workshop discussions. A scripted presentation that describes the basic process flows and performance issues for the given function statement will also be of benefit in the workshop, as well as large prints of relevant process and facility drawings, summarized tabular data, and other engineering and reliability information.

A draft statement of the facility primary function should be developed. The time duration for this function is important, especially when developing performance criteria related to cases where a facility is permitted in excess of its current production levels. In this case, a reasonable estimate must be made as to what level the facility must be maintained over the specified time interval.

Depending on scope of analysis, a similar process may be used to address secondary functions. However, first generation criticality exercises should focus on the primary function at the system level, and utilize the procedure described to adjust the classification of assets within the system by their secondary functions.

A comprehensive list of systems (or subsystems) that make up the facility should be developed. This list will serve as the draft ballot which will be confirmed in the workshop.

4.2 Cross-Functional Team

The SAE JA1012 Reliability Centered Maintenance standard [11] states that the very diversity of factors involved makes it often impossible for any one person to decide what is "tolerable" on behalf of all the people exposed to a particular risk. It recommends two general characteristics of a group of people representing: (1) people who are likely to have an understanding of failure mechanisms, failure effects, and the likelihood of the failure mode occurring; and (2) the likely victims and the people who have to deal with the consequences of a failure.

Similar to traditional approaches to evaluate criticality and risk, this method also requires the use of a cross-functional team. This team should include individuals who are familiar with the overall operations, and should include the following disciplines: Reliability Engineer; Engineering Staff; Plant Manager; Operations Manager; Lead Operator; Maintenance Manager; and Health & Safety, and Compliance

4.3 Criticality Workshop

A criticality workshop should be conducted for each facility (or collection of systems) that is to be evaluated. The planned duration for first-time participants should be 2 hours. The pre-selected cross-functional team should be invited well in advance of the workshop and participate in person.

The workshop needs to include the following activities: (1) an overview of purpose and outcomes of the general task and specifics related to the workshop; (2) an overview of common attributes associated with criticality, risk, and reliability functions; (3) review of potential uses and applications of criticality scores; (4) validation of the pre-developed draft function statement; (5) a sub-group breakout session to discuss technical aspects related to systems design and performance issues; (6) validation of the pre-developed list of systems (the ballot) through a group review and adjustment of the list as necessary; and (7) executing the forced rank exercise.

To perform the forced ranking exercise, the cross functional team determines the relative criticality of the pre-developed list of alternatives based on their consequence of failure on the pre-developed function statement. Participants are encouraged to use their perceptions of the likelihood of failure or the presence of fault tolerance, typically redundancy, as tiebreakers for those systems that are closely ranked. Systems are ranked from 1 (most critical) to N number of systems (least critical). Each system must be force ranked on the ballot with a unique rank (no duplicates).

The rankings are based on the participants' perspective of the severity (or consequences) of failure.

4.4 Post-Processing of the Workshop Results

Depending on the availability of a spreadsheet tool, it is usually feasible to analyze the ballots with a spreadsheet tool and to produce preliminary data over a 15- to 30-minute period. Where feasible, it will be possible to extend the workshop in order for participants to validate the preliminary results.

If not possible to input the data at the time of the workshop, then a separate de-briefing with the team is required. In all cases, input data from the ballot should have formal quality control review before using it at the asset level.

4.5 Relative Criticality Ranking at the Asset Level

The system ranking of 5 (high criticality) through 1 (low criticality) will then be applied to the assets within each system. This is most effectively performed by a two-person team that includes an engineering/reliability person and an operations and maintenance (O&M) specialists who is familiar with the facility as a whole.

In this phase of the procedure, considerations for the specific impact of each asset to the primary function statement will be used to determine whether assets within the system have a higher or lower priority than the system as a whole. It is also where an understanding and confirmation related fault tolerance (including redundancy) is evaluated into the scoring of each asset.

The majority of assets within a given system will normally assume the criticality ranking of the overall system. However, assets with high consequences related to health & safety or high replacement value may receive a higher ranking than the system as a whole. Other assets that may either support secondary functions instead of the primary function, or whose failure has minimal impact on primary function, may receive lower rankings than the system as a whole. A flow chart is provided to describe the procedure.

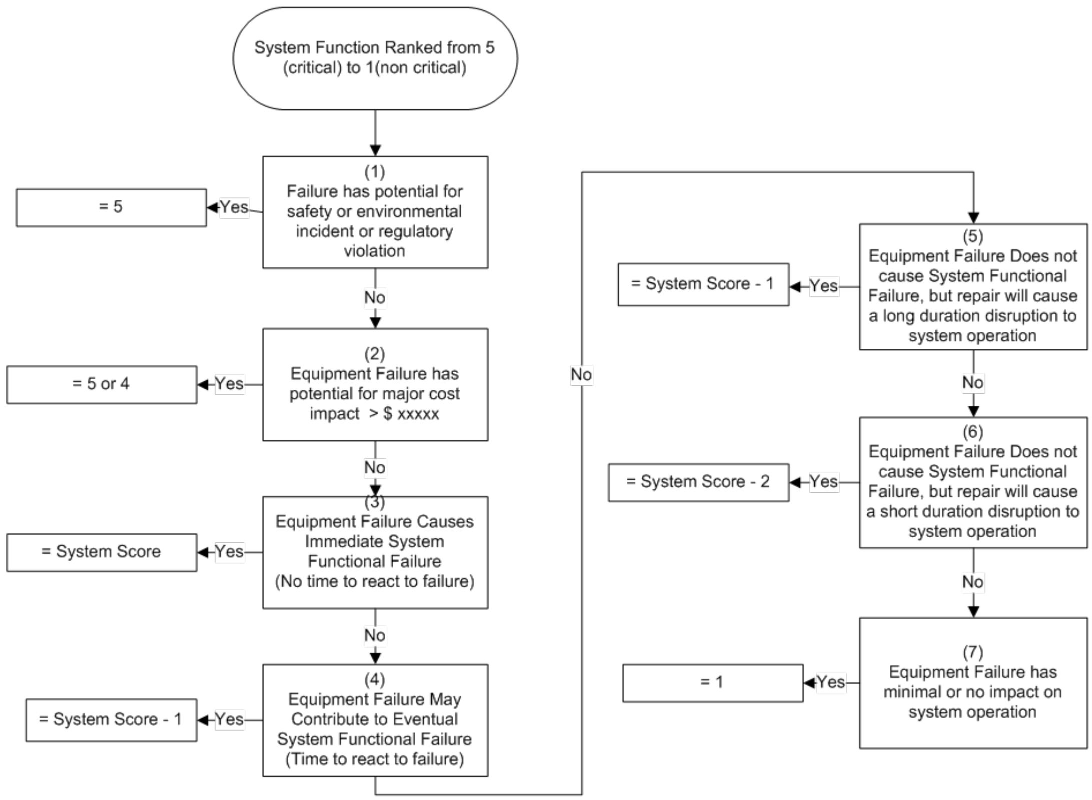

Figure 1: Application of System Criticality to Assets

4.6 *Final Review with Cross-Functional Team*

A final review should be conducted with the cross-functional team. This should include the previously validated summary of the ranking at the system level and the final relative criticality rankings at the asset level. This will be the first time the full team has seen the final rankings at the asset level. However, the experience to date has been that the results are typically intuitive to the team and minimal review and discussion time is needed. Obviously the time required to review may vary with system complexity and personalities of the team members.

In final review, it is important to review the purpose for performing the relative criticality ranking. In the applications to date, the described methodology has been used as an efficient and effective tool related to preventative maintenance (PM) development or optimization and for performing baseline condition assessments. Therefore, it provides a solid indicator of where to start. Like most traditional methods, it is based on individual opinion and some fine adjustment based on preference should be both expected and incorporated.

5 *DISCUSSION*

5.1 *Similarities to Traditional Approaches*

The methodology proposed in this paper closely follows many of the traditional approaches to criticality analysis. Similar activities include: detailed review of existing systems and asset information (including process and instrumentation diagrams (P&IDs), geospatial configurations, maintenance histories, and production/quality reports); establishment of function statements; defining system failure; utilizing cross-functional teams in workshop settings; and review and validation of results with the cross-functional team.

The primary departures in the described criticality assessment methodology relates to the use of preference ballots and the related significant reduction of staff hours to obtain similar results when compared with traditional approaches.

5.2 *Limitations of Methodology*

The method is clearly more efficient and effective in terms of total staff time. However, arguably the method requires a similar amount of preparation time by the primary person in charge of the process and the facilitator.

Another key limitation is that it assumes that something is going to be done – a cut off line is not present. This is also true when making comparisons across different parts of an operation - like comparing two different plants– because of lack of unified basis of comparison. In both cases, the preference ballots apply to only the systems that were compared against one other.

The method, at least in a formal sense, short-cuts the detailed problem decomposition, which is an advantageous decision-making technique in most cases [12]. The methodology relies on the experience of the key staff members and the power of the different ways to analyze the preference ballots in lieu of formal problem decomposition.

5.3 Advantages over Traditional Approaches

The primary advantage of the methodology is that it is quicker and easier than traditional approaches, while also providing similar end results. This advantage is mainly realized in terms of minimizing key staff time in workshops rather than being at their posts.

Most participants believe that their perspective is heard and accounted for in the process. They greatly appreciate the assessment not being overdone in terms of its required duration.

The methodology also has a sound technical basis in human choice (preference) theory and in reliability theory in terms of focusing first at system function. The results are also team-based and transparent, which often meets an important criteria for senior management and other stakeholders.

Lastly and perhaps most importantly, it works.

6 MOVING FORWARD

The methodology described in this paper has shown its merit in terms of practical efficiency and effectiveness when compared with traditional methods. More academic study of the methodology is needed as well as a broader study across many different industries.

The methodology has also show solid results for PM program development and optimization as well as for baseline condition assessments. While the authors have full confidence in its universal applicability, more evaluation is needed related to its applicability for other purposes where criticality is a driving consideration.

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