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Predictive Strategy and Technology for Operation & Maintenance Decision-Making

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In power generation must have robust decision-making, either for operation & maintenance (O&M) decision-making or capital investment decision-making. This aims to increase reliability and efficiency with life cycle cost (LCC) as low as reasonably practicable (ALARP). To achieve these goals, power generation should implement asset health management (AHM) through digital power plant (DPP), where one of the functions is prognostic health management.

In previous research related to prognostic health management, the asset condition criteria were based on the asset health index (AHI) of the asset. The smaller the AHI, then the criterion is danger. Even though every asset that has the same AHI, it doesn't necessarily mean that the remaining uptime is the same. So that the recommendations generated based on the criteria have a low effect on improving asset condition and power generation performance. Therefore, it is not possible to use AHI as the asset condition criteria.

In this research, the prognostic (prediction) in DPP requires strategy and technology, where there are 3 (three) predictive strategies, namely predictions obtained from the input parameters of online performance monitoring (asset performance management / APM), online / offline conditions-based monitoring (APM), and computerized maintenance management systems (enterprise asset management / EAM). APM is used for short-term planning (< 1 year), where criteria developed based on the remaining uptime of power generation (PF-curve) are used for decision-making. Meanwhile, EAM is used for long-term planning (≥ 1 year), where risk cost criteria are used for decision-making.

Keywords: Predictive strategy and technology, operation & maintenance decision-making, capital investment decision-making, prognostic health management, asset health management, asset health index, asset condition criteria.

1. Introduction

In an organization (a state electricity company), business objectives or visions must be based on the wishes of stakeholders, especially the government. These business objectives are contained in the Company's Long-Term Plan (RJPP) which is published every 5 (five) years. To achieve the business objectives for the next 5 (five) years, strategic goals and strategic enablers are needed. Strategic goals consist of 4 (four) goals, namely (i) Green, (ii) Innovative, (iii) Customer Focused, and (iv) Lean. Where one of the strategic objectives of Lean is to increase operational efficiency, one of which is through prognostic health management in DPP as a performance indicator. PT PLN (Persero) (2020). Therefore, in this research was developed a prognostic health management concept which can increase reliability and efficiency of power generation while still considering the financial sustainability factor. Where the analysis result of the prognostic must can be used to make plans (short-term and long-term).

In previous research, prognostic health management was developed using real-time data. Bousdekis et al. (2015) and Sardi et al. (2020). In determining the asset condition criteria based on AHI. However, this method only knows the first asset failure, so it is only suitable if used for short-term planning. In addition, recommendations based on AHI criteria have a low effect on improving asset condition and power generation performance.

Prognostic health management was also developed using condition-based maintenance (CBM). Bousdekis et al. (2015), Acernese et al. (2020), and Nystad and Rasmussen (2010). And using predictive maintenance. Antomarioni et al. (2019), Tinga et al. (2019), Tiddens et al. (2020), Wang et al. (2019), and Thalji and Liyanage (2012). However, these methods also only know the first asset failure, so are used for short-term planning.

Other method used EAM data. Semaan and Yehia (2019). Used big data analytics. Sardis et al. (2019), Antomarioni et al. (2019), and Chongwatpol (2016). Used the cost of quality-to-quality performance. Sturm et al. (2019). And used overall equipment effectiveness (OEE). Singh et al. (2016). However, these methods are not real-time, so are used for long-term planning.

Based on the previous research, then was necessary prognostic health management that can be used for short-term and long-term planning. Where this method combines input parameters from APM and EAM, which is called DPP. APM is used for short-term planning (< 1 year), where criteria developed based on the remaining uptime of power generation (PF-curve) are used as decision-making. By carrying out short-term planning, forced derating or forced outage does not occur which will cause disturbances in the power system and decrease power generation performance. In addition, with the longer remaining uptime, capital investment for purchasing materials / spare parts can be carried out normally without having to act as an emergency, to reduce material costs.

Meanwhile, EAM is used for long-term planning (≥ 1 year), where risk cost criteria are used as decision-making. By carrying out long-term planning, risk costs at the equipment level and at the power generation level are less than or equal to the risk appetite statement (RAS) and key performance indicators (KPI) will also be achieved with LCC ALARP.

2. Asset Health Management Design

Asset health management (AHM) is one of the processes in carrying out O&M decision-making and capital investment decision-making at the equipment level and/or the power generation level, either for short-term action or long-term action. In AHM, there are 11 (eleven) processes (AHM can be seen in Fig. 1), namely: (a) identify equipment for AHM, (b) determine appropriate health parameters, (c) determine health parameter importance, (d) data collection method, frequency, quality, etc, (e) perform health calculations, (f) evaluate health vs criteria, (g) trigger appropriate short-term action, (h) combine with additional parameters, (i) perform risk calculations, (j) evaluate risk vs criteria, and (k) revise long-term asset class plans.

3. Identify Equipment for AHM

In the making of AHM modeling, not all equipment is modeled, because they require a lot of time for analysis (time consuming). Therefore, only equipment that has a significant contribution needs to be made into AHM modeling, so that it can represent the real conditions at the power generation but is not too burdensome in terms of time and energy in the process. Equipment that is not modeled, if: (i) run to failure, (ii) does not cause power generation derating, (iii) does not cause power generation outage, and (iv) does not affect efficiency significantly.

4. Determine Appropriate Health Parameters

There are 3 (three) input sources of health parameter (can be seen in Fig. 2), namely:

(i) Online performance monitoring (APM), where AHI of 0% is an asset that has experienced a shutdown (has not been damaged). Health parameters used to calculate AHI are protection parameters that cause the equipment to shutdown;

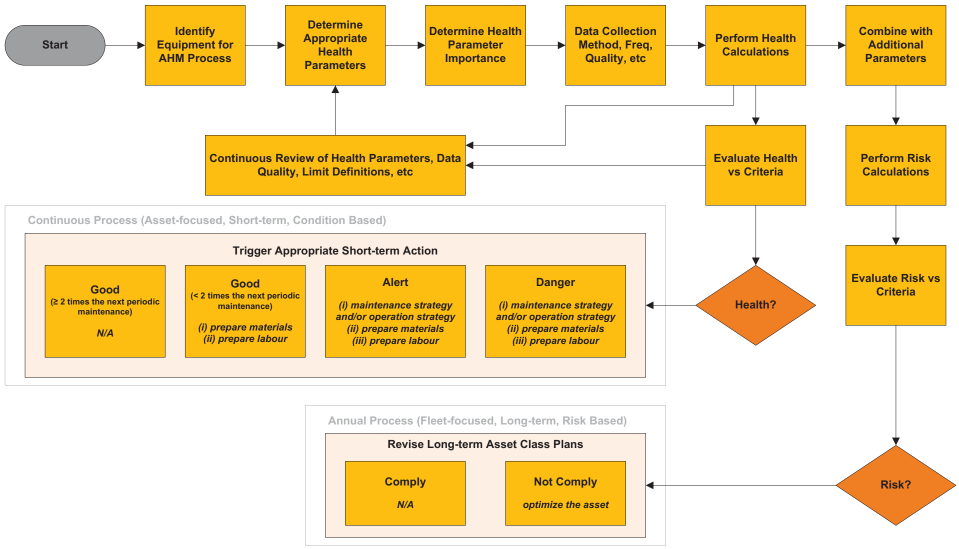


Fig. 1. Asset health management (AHM) design.

(ii) Online/offline condition-based monitoring (APM), where AHI of 0% is an asset that has been damaged. Health parameters used to calculate AHI are parameters that cause the equipment to be damaged;

(iii) CMMS (EAM), where AHI of 0% is an asset that has been damaged. Health parameters used to calculate AHI are failure mode parameters.

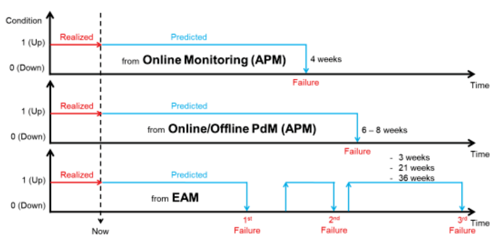


Fig. 2. The prognostic health management strategy and technology.

The input sources of health parameter above are used depending on the purpose. If it is used for O&M decision-making and short-time investment planning decision-making (< 1 year), then it uses input parameters from online performance monitoring (APM), while other input parameters as supporting. Meanwhile, if it is used for O&M decision-making and long-time investment planning decision-making (>= 1 year), then it uses input parameters from CMMS (EAM), while other input parameters as supporting.

5. Determine Health Parameter Importance

AHI of equipment is an equipment health value that indicates condition of the equipment constructed of health parameter values (can be connected in series or parallel depending on the parameters affecting the equipment, usually connected in series). AHI of equipment is calculated using Markov analysis. Likewise for the AHI of power generation constructed from AHI of equipment and calculated using Markov analysis.

6. Data Collection Method, Frequency, and Quality

Health parameter values used for AHI calculations must have quality. There are 6 (six) qualities, namely:

(i) Accuracy, the data must be a true and accurate reflection of the physical asset;

(ii) Validity, the data must be consistent and in accordance with the relevant standards;

(iii) Timeliness, the data must be current, or correct within the designated time period for use;

(iv) Uniqueness, the data must represent a single view of the asset, and not replicated elsewhere;

(v) Completeness, the data set must be complete, with all asset attributes accurate and valid; and

(vi) Consistency, the data that are is represented in more than one data store can easily be matched.

In case data quality is not met, then can use data source combination from site specific data, industry data, and/or generic data, where the confidence level will also changes depending on the data source. Smith (2001). Meanwhile, data collection method and frequency depend on input sources of health parameter.

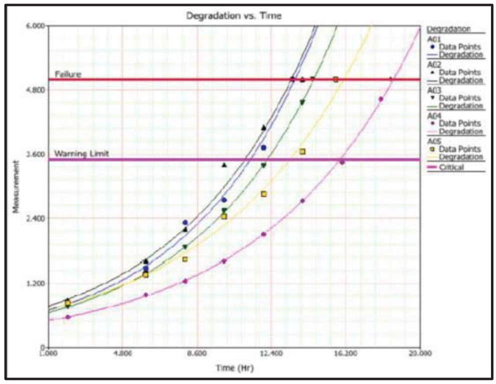
(i) Online performance monitoring, health parameter values are obtained in real-time using sensors that are permanently installed;

(ii) Online/offline condition-based monitoring, health parameter values are obtained in real-time and/or periodically using sensors that are permanently and/or temporarily installed respectively;

(iii) CMMS, health parameter values are obtained every time there is an event.

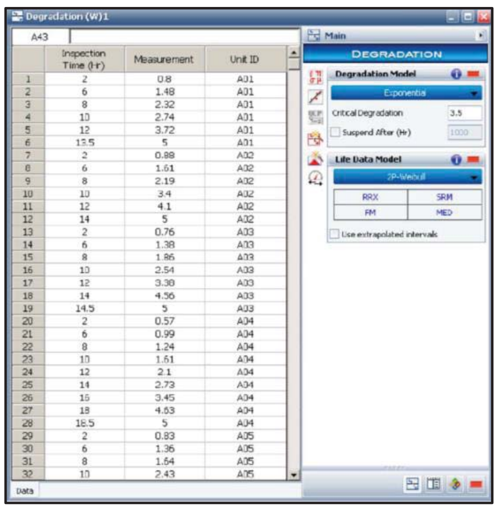
7. Perform Health Calculations

AHI calculation of equipment is carried out by making PF-curve. In the PF-curve, the most important information is not the AHI value, but time interval from potential (P) to failure (F) or how many time the equipment will fail. This aims to prepare actions that must be taken so that the equipment does not experience failure and does not decrease power generation performance (reducing risk costs at the power generation level and at the power system level). Meanwhile, the AHI value of equipment is only used to calculate and determine the AHI value of power generation, not for O&M decision-making and capital investment decision-making.



Unit ID	Warning (P)	Failure Time (F)	P-F Interval
A01	11.33	13.5	2.17
A02	11.05	14	2.95
A03	12.19	14.5	2.31
A04	15.90	18.5	2.60
A05	13.34	15.7	2.36

Fig. 3. Failure to time curve of health parameter.



	Inspection Time (Hr)	Measurement	Unit ID
1	2	0.8	A01
2	6	1.48	A01
3	8	2.32	A01
4	10	2.74	A01
5	12	3.72	A01
6	13.5	5	A01
7	2	0.88	A02
8	6	1.61	A02
9	8	2.19	A02
10	10	3.4	A02
11	12	4.1	A02
12	14	5	A02
13	2	0.76	A03
14	6	1.38	A03
15	8	1.86	A03
16	10	2.54	A03
17	12	3.38	A03
18	14	4.56	A03
19	14.5	5	A03
20	2	0.57	A04
21	6	0.99	A04
22	8	1.24	A04
23	10	1.61	A04
24	12	2.1	A04
25	14	2.73	A04
26	16	3.45	A04
27	18	4.63	A04
28	18.5	5	A04
29	2	0.83	A05
30	6	1.36	A05
31	8	1.64	A05
32	10	2.43	A05

Fig. 4. Inspection data of health parameter.

In making PF-curve of equipment, it is constructed of health parameter value depending on input sources of health parameter. Where, each health parameter has a PF-curve, can be seen in Fig. 3. Meanwhile, the parameter values used to make the PF-curve, using inspection data (at least 3 (three) data for each the parameter) plotted using reliability software, can be seen in Fig. 4.

Action priority is carried out based on the smallest time interval from the current condition until failure (F) occurs of the parameters used to calculate AHI. In Fig. 3, if the current conditions of all parameters used to calculate AHI are at their warning limit, then the action prioritized is caused by A01, because it is predicted A01 will cause the equipment to fail for the first time, which is equal to 2.17 hours. After that, the actions caused by A03, A05, A04, and A02 are 2.31, 2.36, 2.60, and 2.95 hours respectively.

8. Evaluate Health vs Criteria

There are 3 (three) criteria based on the remaining uptime of power generation (PF-curve), namely:

(i) Good, if the AHI prediction reaches 0% when it is more than or equal to the period of periodic maintenance (can be repaired during periodic maintenance) and does not incur emergency costs for procuring materials / spare parts;

(ii) Alert, if the AHI prediction reaches 0% when it is more than or equal to 1 week (can plan Maintenance Outage / MO), less than the period of periodic maintenance (can't be repaired during periodic maintenance), and does not incur emergency costs for procuring materials / spare parts;

(iii) Danger, if the AHI prediction reaches 0% when it is less than 1 week (can't plan MO) or incurs emergency costs for procuring materials / spare parts.

9. Trigger Appropriate Short-Term Action

There are 3 (three) trigger appropriate short-term actions based on the remaining uptime of power generation (PF-curve), namely:

(i) Good, if the AHI prediction reaches 0% when it is more than or equal to 2 (two) times the next periodic maintenance, then N/A. Meanwhile, if the AHI prediction reaches 0% when it is less than 2 (two) times the next periodic maintenance, then: (i) prepare materials / spare parts and (ii) prepare labour.

(ii) Alert, then: (i) carry out maintenance strategy and/or operation strategy, so that the AHI prediction reaches 0% when it is more than or equal to the period of periodic maintenance (can be repaired during periodic maintenance), (ii) prepare materials / spare parts, (iii)) prepare labour, (iv) if the maintenance strategy and/or operation strategy is predicted to be unable to change the prediction of AHI reaching 0% when it is more than or equal to the period of periodic maintenance, then carry out MO planning.

(iii) Danger, then: (i) carry out maintenance strategy and/or operation strategy, so that the AHI prediction reaches 0% when it is more than or equal to the period of periodic maintenance (can be repaired during periodic maintenance) or more than or equal to 1 week (can plan MO) and does not incur emergency costs for procuring materials / spare parts, (ii) prepare materials / spare parts, and (iii) prepare labour.

10. Combine with Additional Parameters

In long-term planning, not only the remaining uptime of power generation (PF-curve) is used. However, it is also necessary to use the equipment risk cost which is used as the equipment priority index and LCC at the power generation level.

11. Perform Risk Calculations

This section contains the predictions of risk cost at the equipment level or the power generation level. The risk calculation is necessary at least 3 (three) data for each equipment. The risk cost is calculated using Eq. (1).

$$\text{Risk Cost} = \text{Corrective Cost} + \big((\text{EFDH} + \text{FOH}) \times \text{Asset Criticality}\big) + (\text{AC} - \text{Claim}) + \text{F}_\text{t} \tag{1}$$

$$\text{Corrective Cost} = (N_{cm} \times C_{cm}) + \left((\text{EFDH} + \text{FOH}) \times \text{LC} \times n\right) \quad (2)$$

$$\text{Asset Criticality} = \left(\frac{\text{ENS}}{1\ \text{hour}} \times (7\% \times \text{BPP}_{\text{SYST}})\right) + \left(\left(\text{DMN} - \frac{\text{ENS}}{1\ \text{hour}}\right) \times \text{Extra Fuel Cost}\right) \quad (3)$$

$$\text{Extra Fuel Cost} = \text{Marginal Cost} - \text{BPP}_{\text{KIT}} \quad (4)$$

$$F_t = \frac{C_f \times \text{NPHR} \times (\text{GGO} - \text{Aux}) \times T \times \text{EAF}}{\text{HHV}} \quad \text{if EAF} < \text{CF} \quad (5)$$

$$F_t = \frac{C_f \times \text{NPHR} \times (\text{GGO} - \text{Aux}) \times T \times \text{CF}}{\text{HHV}} \quad \text{if EAF} \geq \text{CF} \quad (6)$$

with:

N_{cm} : Failure rate (1/year)
C_{cm} : Average material cost per failure rate (USD.year)
LC : Labour cost per hour per person (USD/hour/person)
n : Number of labours per failure rate (person)
EFDH : Equivalent forced derated hours (hours)
FOH : Forced outage hours (hours)
ENS : Energy not served (kWh)
DMN : Net capacity (kW)
CF : Capacity factor (%)
F_t : Fuel cost (USD)
C_f : Fuel unit price (USD/kg or USD/liter or USD/MBTU)
EAF : Equivalent availability factor (%)
NPHR : Net plant heat rate (kcal/kWh)
HHV : Higher heating value of fuel (kcal/kg or kcal/liter or kcal/MBTU)
GGO : Gross generator output (kW)
Aux : Auxiliary power (kW)
Marginal Cost : Peaker power generation cost due to failure (USD/kWh)
BPP_{KIT} : Production cost of power generation (USD/kWh)
BPP_{SYST} : Production cost of power system (USD/kWh)
AC : Assurance cost (USD)
Claim : Income from assurance claim (USD)
T : Time period in 1 (one) year (8760 hours)

12. Evaluate Risk vs Criteria

There are 2 (two) criteria based on risk cost, namely:

(i) Comply, (i) if the equipment risk cost and the power generation risk cost are less than or equal to RAS and (ii) KPI is achieved;

(ii) Not comply, namely: (i) if the equipment risk cost and the power generation risk cost are more than RAS or (ii) the KPI is not achieved.

13. Revise Long-Term Asset Class Plans

There are 2 (two) revised long-term asset class plans based on risk cost, namely:

(i) Comply, then N/A;

(ii) Not comply, then optimize the asset (at the power generation level) by planning fuel strategy, maintenance strategy, and/or operation strategy. The optimization based on (a) the economic lifetime of power generation (the maximum profit point of the power generation until its end of life), (b) KPIs of power generation, (c) the equipment priority index based on the equipment risk cost, an example can be seen in Table 1 (improvement is carried out on the highest profit combination), (d) predictions of net present value (NPV) and internal rate of return (IRR) of power generation, and (e) predictions of the power generation risk cost based on RAS. The asset class plans can be seen in Fig. 5.

In planning uses qualitative analysis and quantitative analysis to determine: (i) equipment to be improved, (ii) improvement strategy, and (iii) the prediction of KPIs so that KPI targets are achieved. After that, financial analysis is carried out by using LCC. If it is not feasible, then the improvement strategy must be changed. If it is still not feasible, then the KPI targets must be changed otherwise the power generation will suffer financial losses.

Table 1. An example of profit combination of 3 (three) equipment.

Equipment	Risk Cost (USD)	Improvement Cost (USD)
Combination I		
Seal Air Outlet Damper	87,250.57	58,983.19
Mill Seal Air Header	25,188.95	10,255.22
Mill Seal Air Outlet Duct	42,342.08	38,051.87
Profit		47,491.32
Improvement Cost		107,290.28
Combination II		
Seal Air Outlet Damper	87,250.57	58,983.19
Mill Seal Air Header	25,188.95	10,255.22
Mill Seal Air Outlet Duct	*42,342.08*	–
Profit		859.03
Improvement Cost		69,238.41
Combination III		
Seal Air Outlet Damper	87,250.57	58,983.19
Mill Seal Air Header	*25,188.95*	–
Mill Seal Air Outlet Duct	42,342.08	38,051.87
Profit		7,368.64
Improvement Cost		97,035.06
Combination IV …		

Red colour: Improvement is not carried out, then the risk cost will become an impact and will not become an avoided cost (benefit).

13. Conclusion

The AHM process aims to identify potential issues or areas for improvement in the assets, prioritize the assets that require the most attention, and take proactive measures to address them before they lead to asset failure or downtime. There should be a continuous review and improvement of asset health and risk information.

The process has two distinct cycles: (i) the first cycle in this process is a short-term, asset-focused, which uses input parameters from APM and criteria developed based on the remaining uptime of generator (PF-curve) to forced derating or forced outage and emergency costs for procuring materials / spare parts do not occur, (2) the second cycle in this process is a long-term, fleet-focused, which uses input parameters from EAM and criteria developed based on risk cost to comply RAS and achieve KPI with LCC ALARP.

In future work, the concept of determining the equipment priority index will be deepened. Especially in determining the priorities for the next five years (aligned to RJPP) with the delivery plans. In addition, will also deep dive into the confidence level in using data, if the availability of data does not have quality for decision-making or combine site specific data, industry data, and/or generic data.

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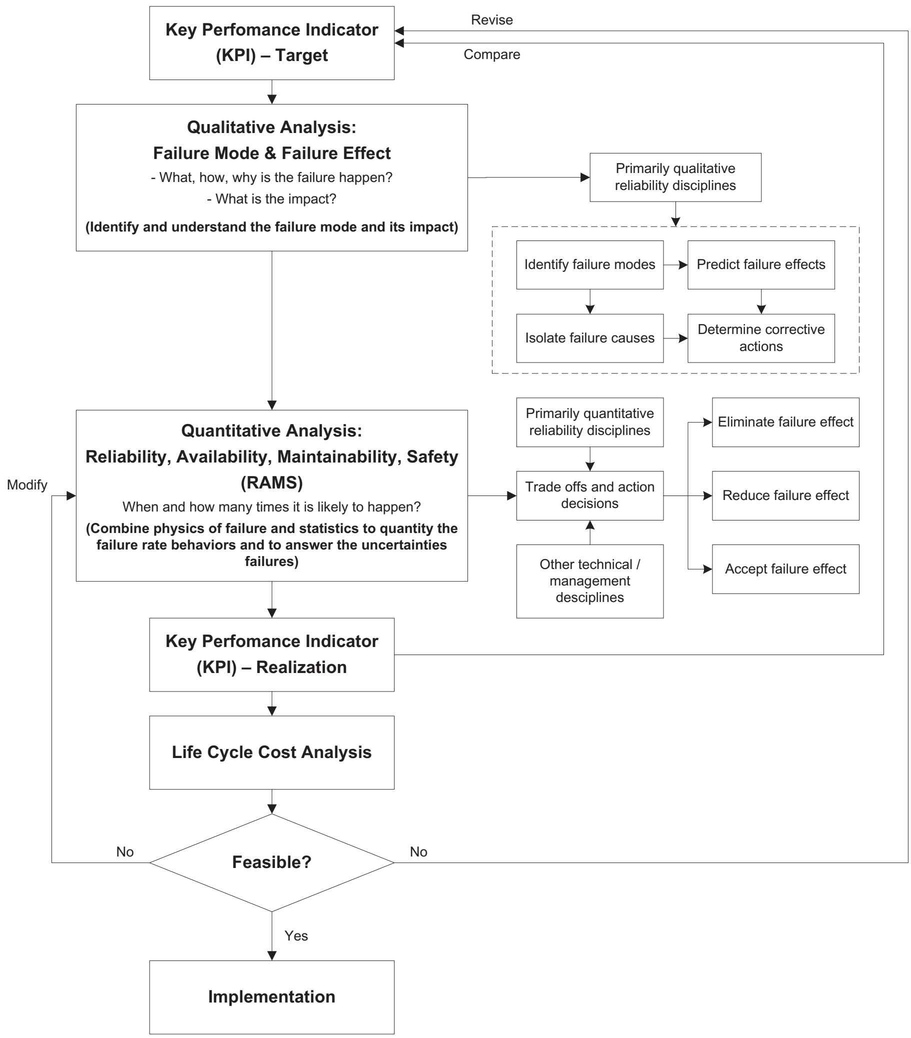

Fig. 5. Reliability, availability, and maintainability (RAM) cycle model in operation & maintenance.