CRIM

Identifying the best maintenance strategy for complex process plants

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– Changing from a reactive to a preventive maintenance strategy can yield substantial cost savings in many sectors of industry. However, in the process industries, an installation may have many thousands of maintenance-worthy elements, rendering a solely preventive maintenance strategy impractical or even impossible. How then to determine the optimal maintenance strategy mix for such situations? CRIticality-analysis-based Maintenance (CRIM) optimization introduces a systematic maintenance planning methodology for identifying critical equipment and appropriate preventive maintenance plans, taking into account environmental and process conditions. The method utilizes fast criticality assessment of the plant equipment prior to life-cycle cost analysis.

CRIM can deliver a cost-effective maintenance strategy for the whole plant by systematically utilizing criticality analysis, life-cycle cost analysis and lifetime estimates.

The term "maintenance optimization" touches on a wide range of approaches from simple experience-based, rule-of-thumb methods to complex systematic methods. Examples of simple methods include run-to-failure maintenance, appropriate for redundant equipment and equipment with very low failure rate; time-based maintenance (TBM), most effective when the regular overhaul/replacement of the equipment is cheap compared with the cost of a failure and a single, known failure mode dominates; and condition-based maintenance (CBM), which is most cost efficient for critical equipment.

The more complex approaches include reliability centered maintenance (RCM), the most thorough method to determine the right proactive maintenance approach to use for high system reliability, and total productive maintenance (TPM), which combines total quality management and proactive maintenance policies in order to achieve maximum production efficiency. RCM is a rather weighty approach and TPM focuses on maximizing machine throughput, so neither is appropriate in the context discussed here. However, ABB's CRIM methodology does fit the bill as it can deliver a cost-effective maintenance strategy for the whole plant by systematically utilizing criticality analysis (CA), life-cycle cost analysis (LCCA) and lifetime estimates.

Criticality factors are reached by consensus with the maintenance and process experts.

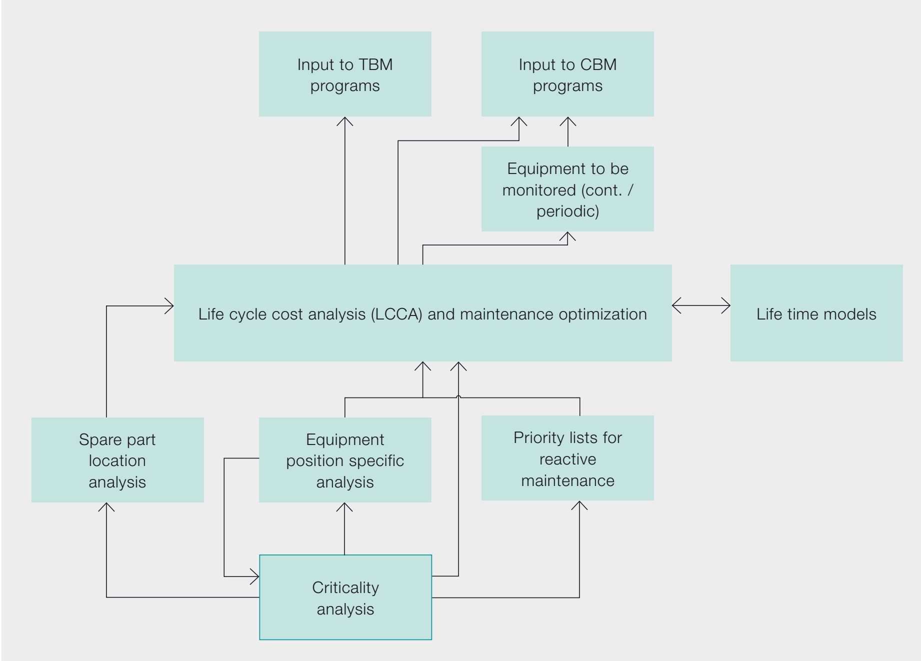
Title picture
Deciding on appropriate maintenance strategies in a plant with many thousands of devices (like this iron ore pelletizing facility) can be tricky. CRIM helps identify appropriate maintenance plans.

CRIM

The CRIM process starts with a criticality analysis – a key process in any main-

Criticality assessment includes the quantitative analysis of events and faults and the process of ranking them in order of the seriousness of the consequences.

1 CRIM process flowchart



tenance and reliability method → 1. CA provides the basis for determining the value of specific equipment and the impact it has on the safety of people, the environment and the production process. CA also determines the level of attention that equipment requires in terms of maintenance strategy and tactics.

In the CA team meeting the facilitator asks a set of carefully selected questions and chooses the criticality levels for each criticality factor.

The second step in the CRIM process is the LCCA, which is performed for critical objects to show the benefits of using certain maintenance programs for that object → 1.

Criticality analysis

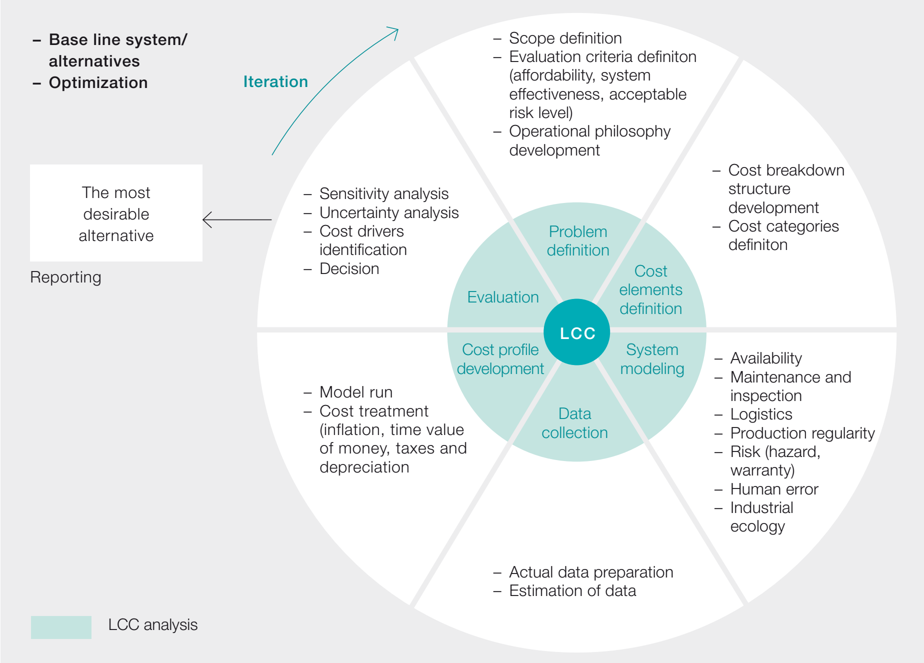
Criticality is a relative measure of the consequences of a failure. Correspondingly, a criticality assessment includes the quantitative analysis of events and faults and the ranking of these in order of the seriousness of the fault consequences. In other words, only the consequences of failures are assessed in this approach; probabilities of failure are considered later in the LCCA.

With a well-defined process and proper tools, it is possible to cost-effectively assess thousands of pieces of equipment.

Prior to starting the criticality analysis, ABB's facilitator asks the customer to load a list of all the equipment positions to be analyzed into the CA tool. In the CA team meeting, the facilitator asks a set of carefully selected questions for each position and, from the answers, chooses the properly calibrated criticality levels for each of the tabulated criticality factors. These factors will have been previously identified in discussions with the maintenance and process experts. The final criticality level that is automatically generated for each asset takes downtime, production response time, capacity, quality, environment, safety and energy losses caused by equipment failure and eventual secondary effects all into account. From all this, a CA report is generated.

Life-cycle cost analysis

LCCA is a collective activity comprising many kinds of analysis aimed at calculating the costs and profitability of a system or piece of equipment over its life span, including research and development, 2 An LCC concept map [1]



The difference between production losses due to equipment failure and those due to preventive maintenance action is the key element in the analysis.

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construction, operation, maintenance and disposal → 2. LCCA starts with the problem definition process as shown in the figure and proceeds clockwise in an iterative fashion until all the criteria defined in the first process are satisfied.

In the CRIM case, the problem is to determine the minimum long-term average maintenance costs per unit time calculated for reactive, time-based and condition-based maintenance strategies.

The LCCA concept applied here only considers those costs that depend on the selected maintenance strategy for that piece of equipment. Thus, the only capital cost considered is the specific equipment cost required for CBM. Accordingly, there is no capital cost related to the reactive maintenance strategy. Operational cost is divided between fixed annual cost and costs due to reactive or preventive maintenance actions. The fixed annual cost includes only costs due to condition monitoring.

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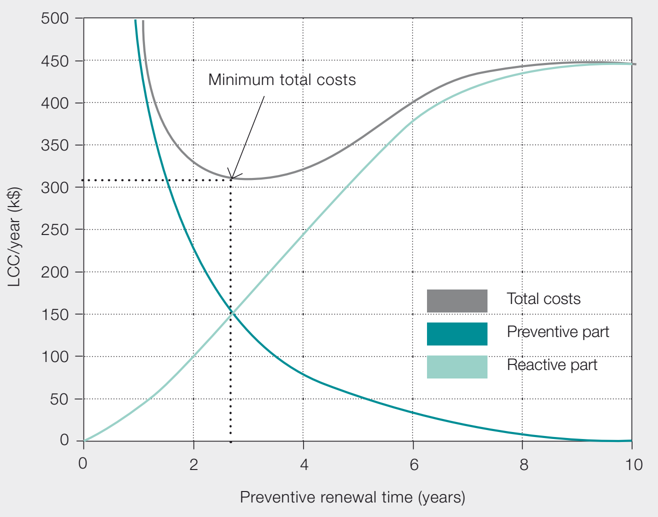
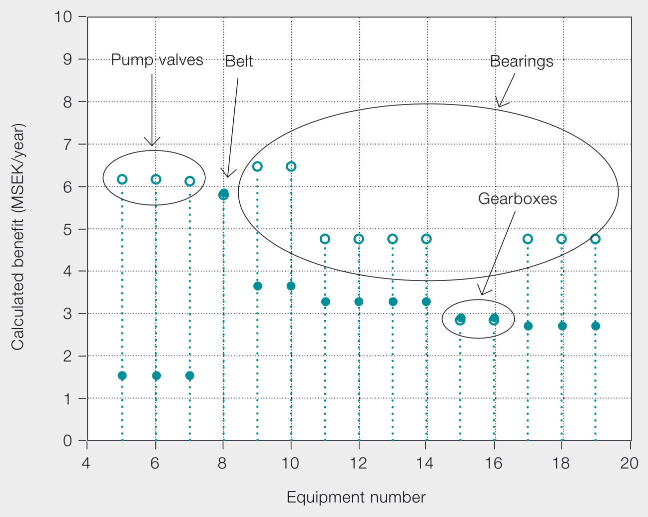
Proactive or preventive maintenance is initiated based on predictions of maintenance need and its definition does not include the diagnostics stage. If the process is well-designed and preplanned, the production downtime should be much shorter than in the reactive process. Also, any necessary materials can be ordered before the failure occurs so that they are ready for use when needed.

Thus, the average maintenance cost during a period is a sum of different maintenance costs, each weighted by the frequency of the particular maintenance type. The frequencies and the total number of maintenance actions depend on the selected maintenance strategy. These frequencies are estimated by lifetime models that incorporate the operational conditions of the maintenance objects. These conditions – temperature, dirtiness, loading, etc. – are assessed

3 LCC of a maintenance object renewed after a certain number of years or at failure



4 Benefit of using TBM (full circles) or condition monitoring (empty circles) calculated for the equipment with process criticality 4 or 5



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during the position -specific analysis of the critical equipment described above.

The next step in the analysis is to use the lifetime and cost models to formulate the life-cycle cost (LCC) model for each of the maintenance strategies. In one real-life TBM example, where the component is replaced after it reaches its planned preventive replacement age or at failure time, whichever comes first, the optimum replacement time is found to be 2.8 years, which gives an LCC of $310,000 per year ➔ 3.

LCCA can also be applied to optimize spare part location by calculating different LCCs for a selection of these locations.

The impact of changes in input parameters on the result can be examined by sensitivity and uncertainty analysis. Varying the input parameters over a certain range can show the impact of the major factors and tradeoffs on cost.

CRIM figures

A two-day CA at a pilot customer site took in 698 pieces of equipment from two process lines. The calibration and introduction took about half a day. Assessment of the first 100 units took the remaining half of the first day. Afterward, the speed of assessment varied between 50 and 100 units per hour. The CA feeds the LCCA and the tool lists final costs calculated by the LCCA for identified critical components ➔ 4.

All the LCC results calculated for one object, eg, a gearbox, can be summarized ➔ 5. The dashed lines in the figure show the uncertainties of different LCCA estimates. In this case, there is an optimum time interval for the TBM strategy to compete with corresponding CBM strategies. On the other hand, it is shown that a TBM that does not occur during the scheduled maintenance breaks does not have any minimum and is more expensive than reactive maintenance. Sensitivity analysis is usually performed to calculate the effect on the LCC result of a small positive or negative change in every parameter value.

The spare part list generated by the CA tool is used for further optimization of spare part locations using LCCA.

5 LCCs of the “gear box 1” example as a function of replacement age. Ten percent uncertainty (dashed lines) is assumed in the lifetime model parameters.

6 The consequence of decreased criticality value on the LCC due to change of spare part location

Group name	Criticality change	LCC change (k$/year)	Spare part cost (k$)
Switches	5 ➔ 2	350	31
Pump valves	5 ➔ 3	512	15
Cooling fans	3 ➔ 1	113	3
Sensors	3 ➔ 1	77	3

A comparison of the calculated LCC for the listed objects with two different assumptions about the spare part locations – namely, logistic delays of more than one day versus one hour – shows that, in some cases, the LCC can be decreased drastically just by moving the spare part closer to the equipment, or by increasing the availability of the spare part.

Furthermore, changing the location of the spare part may directly affect the criticality value calculated in the CA tool – a decrease from the highest value of five to the noncritical value two was observed in the example ➔ 6.

The consequences of such a decrease of criticality value can be seen in the change of LCC ➔ 6. The corresponding spare part cost used in the calculation is only a fraction of the LCC cost.

CRIM solution

CRIM goes a long way to solve the plant owner´s conundrum of finding an optimum mixture of predictive, preventive and run-to-failure maintenance strategies for the thousands of pieces of equipment in his plant. In the pilot site, by choosing an appropriate CBM strategy and by applying good condition monitoring methods for critical pump valves and bearings, LCC savings of $620,000 per year were identified.

One main finding of the pilot study is that CRIM analysis would be appropriate during the plant design phase or as part of the factory acceptance test. Moreover, it is of vital importance that the process involves expertise from all fields.

Perhaps the strongest endorsement of the CRIM approach was the customer’s comment, “Can we afford not to do CRIM analysis for the whole plant?”

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