

Guidance

G0213

Asset Condition Monitoring, Alarm and Alert Management

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1 Purpose

- 1.1 The purpose of this guidance is to outline a consistent and integrated approach for the introduction of Asset Condition Monitoring (CM) and Alarm and Alert Management also called Notification Management (NM) systems within London Underground (LU).
- 1.2 The document provides guidance for the introduction and implementation of new, or the expansion of, existing Asset CM and or NM systems. It covers information relating to:
 - a) The selection of CM and or NM systems.
 - b) The design, installation, maintenance, management and audit of Alarm, Alert and Supplementary information systems.
 - c) Embedding the CM and or NM systems into business-as-usual use
 - d) Explanation of the reasoning for the technical content of the Category 1 Standard (S1213).

2 Scope

- 2.1 This guidance is provided for those who specify, design, install, maintain and operate Asset CM and or NM Systems on London Underground (LU) premises.
- 2.2 This Guidance applies to all works required to implement new Asset Condition Monitoring and or Notification Management systems and the development or expansion of existing Asset Condition Monitoring and or Notification Management systems.
- 2.3 This guidance document explains the reasoning behind the requirements mandated by the Category 1 Asset Condition Monitoring, Alarm and Alert Management Standard (S1213) and offers best practice approach guidance for achieving compliance with this Standard.
- 2.4 The guidance document also, where relevant, refers to the current approach to Asset Condition Monitoring and or Notification Management within London Underground (as at the date of issue of this document).

Note: in recognition of the rapid pace of development of CM, NM and associated technologies as well as an accelerating adoption of CM and or NM in the railway industry, it is recommended that this document is planned for review on a two yearly basis.

- 2.5 The process outlined within this guidance is applicable at varying levels of detail. It can be applied to perform a high level analysis of CM prioritisation across asset areas, through to development and delivery of discrete CM and or NM solutions.
- 2.6 This guide is intended to be followed within the current LU best practice project delivery process.

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- 3.7.2 All data, raw and processed, shall be the property of TfL.**

3.2.2 *An existing NM system shall be expanded to accommodate additional CM outputs, unless there is strong justification otherwise.*

Each NM system has considerable on-going associated core costs, including the costs of engineering, IM and maintenance support, support contracts, maintaining knowledge of the system, upgrading the system to newer/supported versions and other whole life cost considerations. There are benefits delivered by the critical mass of expanding an NM system to incorporate additional CM assets/applications where possible.

If the quantity of new assets requiring NM capability is small then the cost of maintaining a separate CM and or NM system over the life of the asset may be far greater than the cost of providing the new CM and or NM capability using an existing CM and or NM systems.

Thus, principally on the grounds of whole life cost, it is desirable to expand existing CM and or NM systems rather than implement new ones.

3.2.3 *An evaluation shall be performed of any relevant existing LU CM and or NM system to understand if it could be re-used in whole, or in part, in order to meet the requirement.*

The CM engineering experts are best placed to provide information on the functionality of existing CM systems.

3.3 CM System Design

3.3.1 *The CM solution shall be designed and optimised using the methodology in section 4 of BS ISO 13379:2012 to:*

- a) Decide if CM is the right solution*
- b) Measure the correct variables*
- c) Define the timeliness of access to data for both 'immediate' and 'historic' analysis*
- d) Optimise the CM system*

The process defined in Figure 1 below is based on BS ISO 17359:2011 Condition Monitoring Diagnostic of machines – General guidelines and outlines a best practice process to address the requirements defined in clause 3.3.1 above.

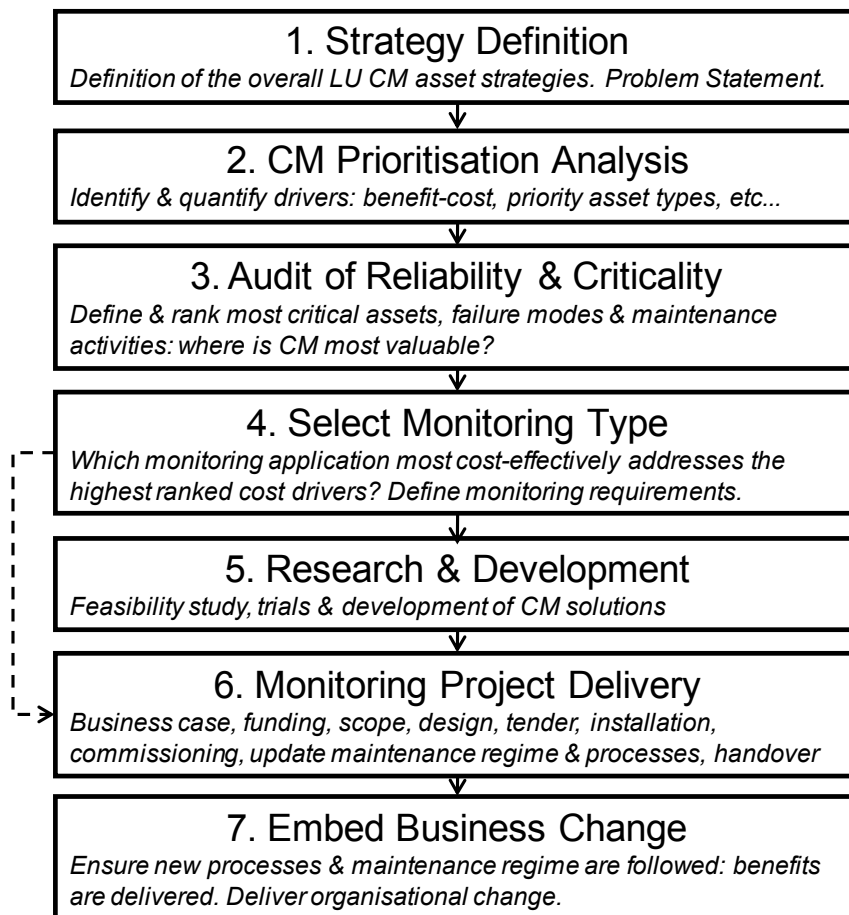


Figure 1 - Best Practice Process for delivery of Condition Monitoring

Applying this process ensures consistency to the way in which CM systems are developed and delivered in cost effective manner.

The subsections below offer explanation and guidance for each process step.

3.3.1 Strategy Definition

The Strategy for CM should be defined at several levels:

- The High-Level Condition Monitoring Strategy
- Its alignment with relevant Asset Group Strategies (AGSs) and Line Asset Management Plan's (LAMP)
- Project specific CM Strategy defining the aims and objectives of a specific CM project or existing monitoring solution

As relevant to the work being carried out, the relevant parent documents should be reviewed to ensure the CM Solution delivered is consistent with these strategies and plans.

3.3.2 CM Benefit-Cost Prioritisation Analysis

Prioritisation analysis establishes the key business drivers for applying CM to a particular asset type, application or problem, thereby setting out what the success criteria for effective solutions.

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Factors worth considering when performing the analysis are:

- a) Cost of failures: Lost Customer Hours, replacement & repair cost, consequential damage, equipment life degradation, reputational cost.
- b) Life cycle cost: Life extension, replacement & refurbishment timings optimisation,
- c) Asset population & variability: more assets → sharing of core costs, more variable assets → cost of customisation, benefit of full asset base CM coverage
- d) Cost of maintenance: potential gain through maintenance based upon condition (note: at this stage a possible monitoring solution may not yet have been identified).

3.3.3 Audit of Reliability & Criticality

A reliability and criticality audit is to determine where to implement CM. It should be noted that there may only be value in performing condition monitoring on a subset of assets of a particular type.

Some asset types maybe considered equally critical (e.g. a given fleet of identical trains) whereas for other asset types some are more critical than others (e.g. criticality of point sets will vary by location). Thus, criticality analysis can be quite simple, or when the asset base is highly variable more factors may need to be taken in to consideration. In many instances certain subsystems of assets may be more critical than others.

Whilst reliability is invariably a key factor to derive criticality due to the potential for customer-affecting disruption, it is not necessarily the sole driver.

Factors which can be considered when defining a particular individual asset's criticality & reliability are:

- a) Cost of failure in terms of Lost Customer Hours, Service Points, Materials and Labour costs (This was covered in 3.1.2 at a macro/strategic level, but here the consideration is for individual assets and ideally individual subsystems of assets).
- b) Cost of maintenance (including inspection) in terms of:
 - Time taken to carry out maintenance tasks
 - Level of skill required to carry out maintenance tasks
 - Cost of consumable items
 - Accessibility of the asset – is it difficult or impossible to access the asset to maintain it without significant cost
- c) Failures by location
- d) Historical failure rates (MTBF/MDBF)
- e) Mean time to repair (MTTR)
- f) Time to site (TTS) and time to fix (TTF)

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- g) System and Asset Redundancy (e.g. multiple escalators running in the same direction versus just a single escalator)
- h) Whole life costs (cost of installation, maintenance, inspection, refurbishment/overhaul, replacement and disposal).
- i) Safety and environmental impact
- j) Items whose failure would have significant impact on the operation of the railway

The factors above, and others as considered relevant, can be weighted, scored and a formula applied to produce a ranked criticality list of assets or sub-assets.

3.3.4 Select Monitoring Type

Performing a Failure Modes Effects and Criticality Analysis (FMECA) is a useful structured approach to follow when selecting the type of CM to use and indeed to also evaluate if CM is the correct solution or if another is best (e.g. redesign or process improvement). An assessment should be performed of the appropriate level of granularity at which to perform a FMECA:

- a) If performed at too high a level (e.g. at a per-asset level) the output in most cases would be quite meaningless as the underlying cause of failure will most likely not be revealed and it will not be possible to see clearly what the best CM or non-CM mitigation is
- b) If performed at a level which is too detailed (e.g. component/sub-component) the process might take too long and cost too much to complete. In some instances it may well be relevant to go to a deep level of detail. For certain assets, a good approach is to perform the FMECA at a higher level to identify those subsystems for which it is worthwhile drilling-down to focus on a more detailed FMECA.

Where historical failure information is available which is accurately attributed to the correct subsystem of an asset then this is useful data to support production of the FMECA. Where this information isn't available the FMECA may either need to be performed at a higher level of the equipment subsystem hierarchy or best-estimate figures derived if possible.

Note: there are many useful resources and guides for carrying out a FMECA so the approach will not be covered here in detail. The approach to FMECA which the CM ISO Standard 17359 recommends is that covered in BS EN 60812. It may also be useful to refer to 'Reliability-Centred Maintenance II 2.1' by John Moubray (ISBN 13-9780-7506-3358-1).

The output from section 3 above should be used to as the basis of information for calculating the criticality variables in the FMECA. The output from the FMECA will be a prioritised list of Failure Modes according to their Risk Priority Number (RPN). It should generally be clear from the distribution of RPN values which ones are of highest significance, and therefore worth putting most effort into devising solutions into to reduce the RPN.

3.3.4.1 CM Selection Considerations

The factors to take into account when deciding which approach to take to reduce the highest RPN scores:

a. Strategy and Key Business Drivers

These will have been defined in the first two steps of this process. It is critical to ensure that the proposed solution is consistent with the Strategy and meets the established business drivers.

b. Symptoms of failure & measurement techniques

The failure modes identified to mitigate a high priority, in accordance with their RPN score, the symptoms of failure which could be caused by the system failing should be established by reviewing them with relevant asset and CM technical experts (e.g. temperature rise, vibration, noise, etc). This defines the parameters which may be worthwhile measuring and therefore the measurement techniques which may be used.

c. Accuracy of monitored parameters

Whilst it may be technically desirable to provide measurement of CM parameters to the highest possible accuracy doing this would tend to come at increased cost. In many instances, the level of accuracy required to provide a useful CM Alert is quite low, and this in turn reduces cost as these components would tend to be cheaper. For example, if detection of a temperature rise of 5°C is necessary the sensor does not need to be accurate to within 0.01°C, rather within 2°C would be acceptable in principle (the sensor would not also need re-calibrating so often to remain accurate, which also incurs cost).

d. Method of CM

The diagram of figure 2 below shows some typical examples of CM techniques which may be used on a particular asset. As the equipment condition (y-axis) falls over time (x-axis) different techniques will be capable of detecting signs of the failure developing at different stages of asset degradation.

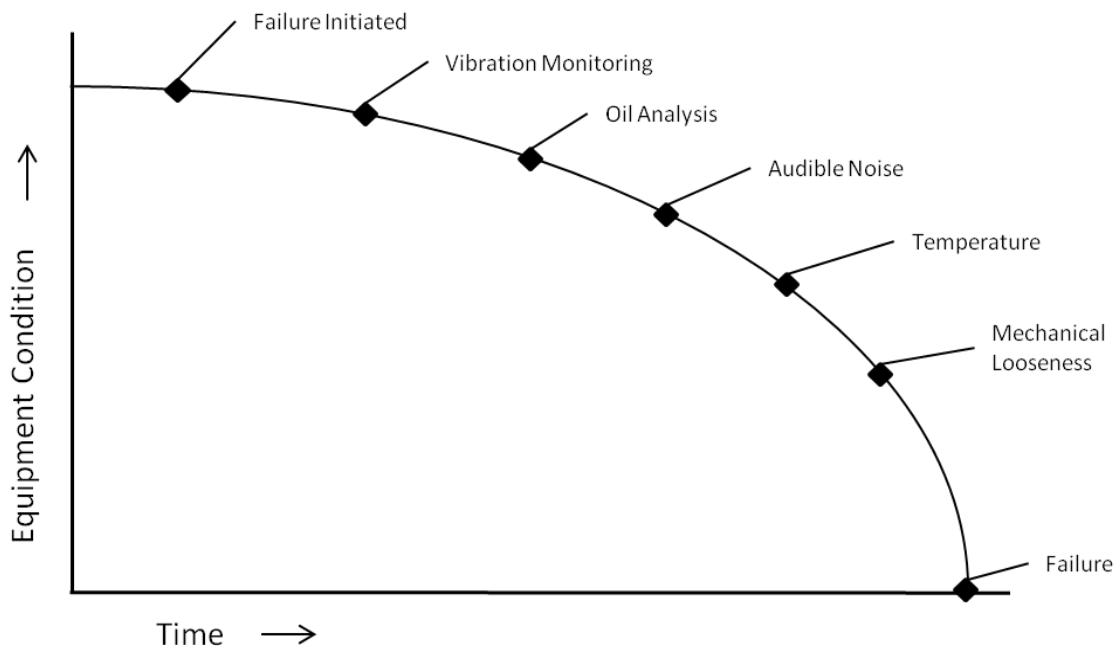


Figure 2 -A typical CM technique identifying failure signs at different stages of asset degradation.

So for the example above, nearest to the initiation of the failure vibration monitoring systems would provide the earliest notification of asset degradation followed by results of oil analysis, audible noise, temperature change and measurable mechanical looseness. These symptoms all relate to a particular failure mode at different stages of degradation, but in the example above the techniques which provide warning furthest in advance (vibration monitoring & oil analysis) are generally more expensive than those which provide less advanced warning (temperature). So, if temperature change provided sufficient advanced warning to be able to respond and prevent failure then, all other things being equal, it is the best technique to choose as it is the least costly. A cost-benefit statement options analysis should be performed as this is a complex balance with many variables to weigh.

e. Method of CM Data Collection

These are the broad options for collection of CM data:

- Connecting the system to a data network (Online CM).
- Log continuously, store data locally and collect it on a regular basis (used less often due to increased availability of cost effective communication networks)
- Take measurements at discrete intervals using portable tools (Offline CM). The benefits of Offline CM is generally less than those of Online systems, but can be more cost effective if combined with an existing site visit so this should be factored into the comparison between the two options.

When considering collecting CM measurements by visiting the asset the appropriate frequency of visits needs to be established. If vibration monitoring was established

as being the necessary technique for CM and the relative merits of Online vs. Offline data collection were being considered then the cost of visiting the site to take measurements on a sufficiently regular basis that asset degradation will be detected before failure happens should be compared to the cost of installing and running an Online system. It should also be appreciated that continuous CM would be more likely to detect symptoms which are intermittent in nature so may not be present when taking measurements with portable tools.

A benefit of Online CM which is worth being aware of is that knowing the precise point that a sudden change in condition happened is helpful in being able to establish the cause (e.g. if degradation happens following a maintenance activity).

There can be a cost associated with providing data on a real-time or live basis so it may be most appropriate to provide data at an agreed frequency. Where this is being done it is important to consider how the data is being used. If, for example, it is expected that a maintainer will have access to CM output data on a handheld to be able to review if a preventative maintenance action they've just carried out has been effective then a 15 minute wait for the updated data to be imported from the source CM system may not be considered acceptable.

f. Monitoring Feasibility

When considering using an Offline system the feasibility of accessing the point where measurements need to be taken should be taken into account. If it is unduly difficult, impossible or carries a high safety risk to access the required part of an asset to take measurements then use of an Online system may be justified or alternatively permanent installation of a sensor with a flying lead (or wireless communication) back to a point where it is possible to connect a portable device and take a reading may be an appropriate compromise

If doing something to the asset which could introduce the possibility of future failure is necessary to gain access to take an Offline CM measurement then the impact on the asset reliability should be accounted for. This may result in Online CM, or a permanently connected sensor being determined to be the better option.

g. If CM is the most appropriate solution

Once the options for CM have been considered it can be possible at this stage to make a decision if CM or a non-CM solution is the best mitigation for each failure mode. If a non-CM solution is selected to take forward then this process ends and normal engineering processes should be followed. If CM is believed to be the right option, or if it is not yet clear if CM is better than non-CM alternatives then the process should continue to the Research and Development step below.

3.3.5 Research & Development

This stage may not be necessary if an existing CM system has been identified which is installed for the same purpose on the same asset type which can be expanded to meet the monitoring requirement. If the existing system is to be applied to a new asset type or variant then some amount of Research & Development (R&D) is generally necessary to optimise it for the new application.

If a 3rd party supplier is undertaking CM R&D for LU then the supplier should provide evidence that they have selected the correct CM types and measurement points. It is best practice for the supplier to do this by following the process as described in this Guidance Document.

The first step to take is to perform a feasibility study. The aim is to establish via research and desktop analysis if the proposed solution(s) for CM produce useful indications of degradation, are practicable, cost effective and have an acceptable chance of ultimately providing benefit. The output of the feasibility study is an evaluation of which one or more CM solutions are worth progressing to the trial stage.

The next stage is to run a trial. Trials should aim to evaluate and/or optimise CM solution(s) for the particular application. Before a trial commences, the aims of the trial must be agreed and documented. During the trial these aims should be regularly reviewed and updated as appropriate. Sufficient time should be planned for the purposes of tuning thresholds / limits of the CM system and for confidence building in analytic algorithms. This process can be accelerated by deploying Proof of Concept or trial / shadow installations prior to detailed design. On completion of the trial, the system will be removed or formally handed over to the maintainer and loaded into the asset management system as a maintainable asset. The output from CM trial(s) should be:

- a) Technical results and a forecast benefit of the CM. This includes an assessment of which measurement points and which CM techniques to use. It is worth considering that there may only be a business case for applying CM to a subset of the assets according to their Criticality. It is however also important to establish if there sufficient benefit in applying the same CM solution to 100% of a particular asset type so that the maintenance approach is consistent across the whole population.
- b) A recommendation of next steps which could include
- c) Further trials, in which case the trial step is repeated, or
- d) A recommendation to develop the system into a deployable form
- e) Discontinuation of further work on certain CM system types

Upon completion of the Research and Development it is important to share what has been learned with CM Engineers in the maintenance organisation so that this knowledge can be captured for future use.

3.3.6 Condition Monitoring Project Delivery Steps

When delivering new CM systems as a project it is important to follow Pathway which is TfL's single, consistent approach to managing projects, programmes and delivery portfolios.

3.3.7 Embed Business Change / Benefits Realisation

When a Condition Monitoring system is delivered by a project it is important to ensure that the initial benefits case on which the investment case is built is delivered

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by embedding the system into Business As Usual. If this step is not carried out the system is likely to only provide a small amount of its full potential benefit.

The time resource and costs required to successfully complete this final step is an important part of the overall of the project and must not be underestimated. Important to have engaged with maintenance representatives and the maintenance CM engineering experts early in the process to be able plan effective delivery of this step, which should in turn reduce the cost and financial risk associated.

Steps which should be taken to ensure the improvement promised by implementation of the CM system(s) provided by the project include:

- a) Revise the maintenance regime for the asset being monitored
- b) Deliver a defined maintenance regime for the CM system itself
- c) Ensure there is a spares and service agreement, if necessary, for the CM
- d) CM should be considered an asset and therefore entered into the CMMS
- e) The maintainer & other personnel expected to use the system should be trained
- f) Where relevant, the organisation structure & resource should be provided to deliver the benefit.

Before completion of handover of the system evidence of the benefit of actions taken which successfully prevented asset failures should be gathered and accepted by the maintenance representatives as true benefits.

3.3.2 *An operational and or a maintenance concept for the CM system shall be developed and agreed with the end user. The Category 1 standard S1217 'Integration of Human Factors into Systems Development' describes how to develop these concept documents.*

An Operational Concept for the CM system should be developed for the system which ensures the output from it will be used and intended benefits will be delivered; it is unfortunately common for CM systems to be implemented, but only a fraction of their full potential used because the system has not been designed to meet the requirements of the end user and their processes.

When tendering and placing contracts it is important to consider the possibility of future expansion of the system to ensure this is covered in commercial agreements so there is a framework already agreed for doing so. If this is not done then in circumstances where it may be economically desirable to expand an existing system this may not be possible due to strict public sector procurement law and without a long and expensive tendering exercise; the cost of this may prevent CM being an economically viable option in some circumstances.