Société de Calcul Mathématique SA
*Mathematical Modelling Company, Corp.*
Tools for decision help
since 1995

# Malfunctions of equipment:

- surveillance of industrial systems
  - detection of anomalies and defects
    - organization of inspections
      - repair of failures
        - management of malfunctions
          - predictive and preventive maintenance

## *Our working program*

**Summary**

This program aims at providing several tools for industrial companies:

- Surveillance of industrial systems to check that they are working properly.
- Check that the detection of anomalies and defects is correctly done.
- Decide on inspection plans for the equipment.
- Organize the repair.
- Decide the planning for predictive and preventive maintenance.

First, one must check that the information which is collected is reliable (failure or false alarm?). Then, one should ensure that one has, about all concerned equipment, the data which are necessary (for instance: date of installation, previous interventions, and so on).

The final objective of the program is to provide the companies with all necessary information, so that the industrial processes will work correctly.

# I. Presentation of the need

Companies seek to make the best use of the resources they have, to meet the needs of their customers, the deadlines, the quality of service, etc. They therefore affect important budgets for what they call "resource optimization". This is perfect in theory, but often works very poorly in practice, because nature is involved, with various pranks: The trucks are down, the computer is blocked, the roads are cut by a flood, the demand is stronger/lower than expected, the material is defective, etc.

A simple rule emerges: the more your optimization will be pushed in theory, the more fragile it will be in practice! Difficulties must be considered from conception.

The first thing to do, to properly exploit resources, is to question the quality and relevance of the available data. This is common sense, but that common sense is not as shared as we would like it to be. Many companies pretend that their information system is without reproach: the most superficial analysis shows that this is not the case.

The first work therefore concerns the analysis of the sensors' capacities (a sensor is, by definition, a device capable of receiving information). When this is done, the second task is to question the proper functioning of the available equipment and to exploit for this the data collected.

# II. The sensors

## 1. Collecting information

The information collected, for the monitoring of a system, usually comes from one or more sensors. It can be the measurement of a temperature, the passage of vehicles, a rate of radioactivity, etc. Before you decide, before you act on the system itself, you first must ask whether the information is correct or not and if it is sufficient.

This is particularly obvious if the system is supposed to be "autonomous" (like a vehicle without a driver) because its decisions are directly dependent on perceptions collected by the sensors. Nowadays, we see more and more the development of automatic systems, connected, which constantly receive and operate upon an information that is always more and more complex.

## 2. Malfunctions

There are four types of malfunctions:

- Failure: the sensor returns nothing.
- Gaps in the information: some intervals of data are missing.
- Uncertainty is too high, so the information is of little use.
- False alarm: the sensor gives a warning without real contents.

The false alarm is rarely considered as it should. The analysis of the TELERAY network (monitoring of radioactivity in the environment), which we carried out for the IRSN (2013 to 2015), showed an excessive rate of false alarms, which "penalizes" the network. The more stations there are, the more numerous false alarms there will be. At the end of the line, too dense a network could lose credibility even if redundancy is necessary.

### 3. How do we validate the information?

It is generally possible, by comparing the indications provided by various sensors, or by tracking the same sensor. It can be done statistically, with delay: for example, after a year, we compare the recordings and note that some stations did not function properly. This can be done in real time, provided that the sensors are close enough to each other and that there is sufficient overlapping in the surveillance areas: the network must have been built for that.

We have devised methods for detecting aberrant data and methods for reconstructing missing data; See our books [RDM] and [PIT] and our "Quality of Information" competence sheet: [SCM_QI].

### 4. How do we conceive the network of sensors, so that it becomes robust?

This is obviously a concern that must be taken into consideration before the implementation. It means that the malfunction of each sensor can be detected and analyzed. As mentioned above, the densification of sensors is not a good solution, because of false alarms, which, in critical situations (fires, radioactivity), require numerous checking. It is better to have simpler and less sensitive sensors. The question of sensor dependence must also be asked: Can they fail all for the same cause?

A network using several simple and independent sensors will be more robust and ultimately more accurate than a supposedly more modern and reliable single sensor. See our book [MPPR] (second edition, chapter 13: Fusion multi-sensors) on this subject.

We must be wary of the "technological" arguments of sellers, who present all new materials as ultra-reliable and ultra-efficient: they must be asked for their references over a long period of time. For a network, whose functioning is vital (e.g., train signaling), it is necessary to use proven technologies. Let us add that everything that depends on computer science is suspicious in principle, because this discipline often changes the design of its equipment.

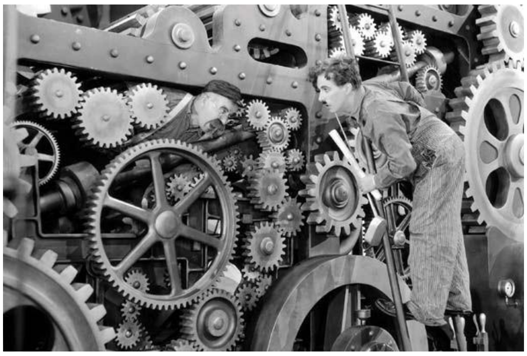
The industry should ask the provider who installs the sensor network to guarantee the latter over a long period of time (at least ten years), including annual checks and calibrations, which are necessary, in particular during the initial period. It is no longer a matter of selling equipment, but a service, which must be impeccable and guaranteed over a long period of time.

### 5. Optimizing the network of sensors

It is legitimate to "optimize" a network of sensors: no shortages, no redundancies. But this must be the result of a thorough study: Are there portions of the territory that are not covered? On the other hand, is there a feeling that some sensors are redundant? This is the case if the data they provide can always be reconstructed from the neighboring sensors, taking into account any failures of these. But a redundant system is obviously more robust to failures: redundancy is the key to robustness.

## III. Equipment

### 1. Malfunctions



Equipment may be dependent on information it is supposed to receive (such as signaling, for a train). Such equipment may have malfunctions for two main reasons:
-It does not receive the appropriate information.
-It does not respond correctly to the information received.
It is therefore necessary to have tests to allow the study of both situations separately.

In many cases, the equipment is purely passive (miscellaneous piping, power lines, rails, etc.). The "Dynamic Investigation Program", which we implemented for Air Liquide in 2011, allows the verification of such equipment, as we now describe.

### 2. Dynamic Investigation Program

Consider the special case of very numerous equipment, of various characteristics, spread over a wide territory: water pipes, gas, equipment such as transformers, signaling of trains, rails, etc. The operator's concern is, for a given budget, to reduce future failures.

The "Dynamic Investigation program" responds to this need. Take the example of the pipes. The operator generally has a large quantity of information (age of the pipeline, type of fluid transported, diameter, length, depth of burial, name of the company which installed it, etc.), more or less correctly identified.

Each time an inspection is performed (and in particular when a pipeline is defective), each time some work is carried out, a score between 0 and 10 is assigned to the relevant pipeline (0: Very poor condition, 10: Perfect). An inspection plan is then defined, which consists of first analyzing the pipes with the lowest grades, and all those that are similar to these, from the point of view of the criteria recorded (same year of laying, same diameter, same use, etc.). In simple language, all pipes of the same type are expected to be plausible candidates with poor quality.

Once these pipelines are inspected, they are assigned a mark, which is re-injected into the inspection plan. It is possible, for example, that a given set of pipes, which one would have thought to be generally defective, presents in reality only rare defects. We therefore correct our previous opinion on the poor quality of a particular population.

Databases, even enriched by experience feedback, may be insufficient and incomplete (for example, if the measures are always done where they are useless). It is necessary to validate and if necessary, correct the inspection plan.

At each step, the PID gives the operator a list, constantly updated, which can be summed up as follows: Given all the information available, here are the inspections that we consider priority.

This knowledge, always updated, of the state of its heritage is essential for the operator, beyond the inspection plan: it will allow for example to justify the financial needs for the following years.

The PID is part of the asset management: an economic value is attributed to a set of pipes, rails, power lines, etc. This is legitimate because this heritage, which must be maintained, can be sold to another operator.

### 3. Anticipate the consequences of malfunctions

In case of malfunction, the system will run "in degraded mode": you must know how to anticipate the consequences: what fraction of the activity can be ensured, and how long will it take to return to normal? Can the impact of failures be minimized by appropriate procedures?

Here again, the analysis of a history makes it possible to get an idea of the consequences of possible failures and to foresee remedies. With the HT power grid being "meshed", RTE almost always manages to ensure continuity of service, even if a line breaks down. In the same way, SNCF knows how to organize a "bypass" if a train is immobilized in full track. SCM has contributed to the organization of contingency plans for the Ministry of the Interior, General Secretariat for Administration, in 2016-2018. The consequences of failures are generally easy to anticipate; the likelihood of occurrence is much less, especially if the history is poor and working from "expert information".

### 4. Simulations

Most organizations, companies, institutions, have simulators to analyze the operation of complex systems, but they are rarely properly equipped to consider all anomalies (failures, uncertainties, false alarms) that can affect the different sensors and equipment. Our working program is therefore intended to complement the simulators so that they can incorporate all these difficulties. It was launched in collaboration with IRSN in 2014.

A second fundamental element is the presence of the man in the loop. In some cases, the sensors are there to provide information, and man takes the decision. In other cases, it is considered that man is unreliable (in particular, he can respond too early or too late, with a risk of amplification of problems) and that, as a last resort, an automated system must make the decisions. Our role here is to simulate both modes of operation, so that we can properly analyze the pros and cons in each case.

### 5. Preventive Maintenance, Predictive Maintenance

From a history of equipment (date of installation, dates of inspections, main interventions), preventive maintenance can be correctly defined. One starts by evaluating a lifetime for each equipment; it usually depends on many factors, such as exposure to weather and conditions of use. Then, an intervention (inspection or replacement) is decided shortly before the presumed expiration of this lifespan. This is what we did for RTE in 2018: definition of preventive maintenance for "circuit breakers". This is done on probabilistic criteria and requires the existence of a history.

Predictive maintenance requires a device which will provide a warning; it takes "Early Warning Signals" that say, for example, that this temperature is excessive, or some current is too strong. But then we fall back on the difficulties mentioned previously: the sensors that are at the origin of these weak signals need to be themselves reliable. This type of maintenance therefore requires analyzing large, heterogeneous, unreliable, sets of data.

## IV. Recommendations to Companies

We recommend that companies keep track of the characteristics of the equipment they install, in a usable form. These features obviously exist at the time of installation, but if they are kept only in the form of a yellow order on the bottom of a cupboard, this poses problems of practical implementation on the day when one needs them.

We all know that any equipment will have malfunctions, one day or another (this is part of the laws of Nature) and that it is necessary to have the information needed to anticipate or to remedy it. Similarly, it is necessary to keep a usable trace of all the interventions that are made (for example the replacement of some parts).

## V. Our publications

### 1. Books

[IEPE] Bernard Beauzamy : Introduction à l'Etude des Probabilités Expérimentales. Ouvrage édité et commercialisé par la Société de Calcul Mathématique SA. ISBN : 979-10-95773-02-3. ISSN : 1767-1175, janvier 2023.

[MPPR] Bernard Beauzamy : Méthodes Probabilistes pour l'étude des phénomènes réels. SCM SA, ISBN 2-9521458-0-6, ISSN 1767-1175, mars 2004 ; seconde édition, juin 2016 (in French).

[RDM] Bernard Beauzamy et Olga Zeydina : Méthodes probabilistes pour la reconstruction de données manquantes. SCM SA, ISBN : 2-9521458-2-2, ISSN : 1767 – 1175, avril 2007 (in French).

[PIT] Olga Zeydina et Bernard Beauzamy : Probabilistic Information Transfer. SCM SA. ISBN : 978-2-9521458-6-2, ISSN : 1767-1175, May 2013.

### 2. Articles


[1] Emmeric Dupont (NEA), Bernard Beauzamy (SCM), Hélène Bickert (SCM), M. Bossant (NEA), Carmen Rodriguez (SCM), N. Soppera (NEA): Statistical Methods for the verification of databases. Publication de la Nuclear Energy Agency de l'OCDE, 2011.
http://www.oecd-nea.org/nea-news/2011/29-1/29-1-int-e.pdf#page=32

[2] O. Zeydina (SCM), A.J. Koning (NEA), N. Soppera (NEA), D. Raffanel (SCM), M. Bossant (NEA), E. Dupont (NEA), and B. Beauzamy (SCM): Cross-checking of large evaluated and experimental databases, Science Direct, Nuclear Data Sheets 120 (2014) 277–280.
http://www.scmsa.eu/archives/NEA_SCM_2014.pdf

[3] Emmeric Dupont (NEA): Exfor: Improving the quality of International Databases. NEA News, 2014, 32.1, page 28.
http://www.scmsa.eu/archives/EXFOR_NEA_News_2014_32.pdf

[4] V. Khalipova (SCM), G. Damart (SCM), B. Beauzamy (SCM), G. B. Bruna (IRSN): Malfunctions in radioactivity sensor's network. ANIMMA 2017 Proceedings.

[5] Gottfried Berton (SCM): Verification of the databases EXFOR and ENDF. Nuclear Energy Agency, JEFF Meetings - Session JEFF Experiments, November 28 - December 1, 2016.
http://www.scmsa.eu/archives/SCM_NEA_JEFF_Meeting_2016_11.pdf

[6] (2017) Guillaume Damart (SCM), présentation lors de la conférence ANIMMA (Advancements in Nuclear Instrumentation Measurement Methods and their Applications), à Liège (Belgique) : dysfonctionnements dans les réseaux de capteurs (article en collaboration avec l'IRSN). http://www.scmsa.eu/archives/SCM_ANIMMA_Presentation_2017_06_21.pdf

[7] (2017) Gottfried Berton, SCM SA, and Oscar Cabellos, NEA: Checking the resolved resonance region in EXFOR database JEFF Meetings - Session JEFF Experiments. November 20 - 24, 2017, Boulogne-Billancourt, France


### 3. Associated Competence Sheets

[SCM_QI] Quality of Information: SCM's competence sheet
http://scmsa.eu/fiches/SCM_Quality_Information.pdf

[SCM_MR] Robust Methods: SCM's competence sheet
http://scmsa.eu/fiches/SCM_robust_methods.pdf

[SCM_Risks] Risk Evaluation: SCM's competence sheet
http://scmsa.eu/fiches/SCM_Risks.pdf

## VI. Conferences organized by SCM

- Malfunctions in sensors' networks. Conference jointly organized by the Institut de Radioprotection et de Sûreté Nucléaire and SCM, November 2015.
  http://scmsa.eu/archives/IRSN_SCM_CLQ_2015_11.pdf

- Malfunctions of equipment: Preventive Maintenance. Conference organized by SCM, November 2018.
  http://www.scmsa.eu/archives/SCM_CLQ_2018_11.pdf

## VII. Recent Contracts

In general, virtually all contracts handled by SCM since 1995 have identified anomalies in the available information, often resulting from malfunctions in acquiring this information. We extract the newest ones. Titles are in French.

- European Environment Agency, 2006-2013: Probabilistic methods for water quality
- Veolia Environnement, Western Region, 2007: Detection of malfunctions in sensor networks
- Institute of Radioprotection and Nuclear Safety, 2007-2011: Applications of Probabilistic Hypersurface to nuclear reactor safety problems
- International Stainless Steel Forum, 2008: General analysis of the information system and recommendations relating to the statistical processing of data
- Areva, 2010: Probabilistic methods for the study of radioactive waste storage
- Nuclear Energy Agency (OECD), 2010-2012 and 2014, 2015, 2016, 2017: Detection of aberrant data in databases
- Air Liquide, 2011: Construction of a “proximity index” between pipelines
- ArcelorMittal, 2011-2012: Probabilistic methods for prioritizing parameters in an industrial process

– IFSTTAR, 2011-2015: Improvement of GPS positioning in urban situations
– GDF-SUEZ, 2012-2013: General analysis of data quality, gas distribution
– Areva, 2012-2013: Analysis of uncertainties in an industrial process
– IRSN, 2012: Preliminary statistical analysis of radioactivity data in the environment
– DCNS, 2013: Probabilistic methods for improving a welding process
– RFF, 2013: Improvement of the criticality measurement tool for Transilien lines
– COSEA (South Europe Atlantic High Speed Line), 2013: Estimated duration of return of extreme floods
– IRSN, 2013, 2014, 2015: Analysis of the operation of the TELERAY network: monitoring of ambient radioactivity
– IRSN, 2014: Analysis of “residual risk” in nuclear safety
– IRSN, 2014-2015: Tool to help verify nuclear material accounts
– EDF/SEPTEN, 2015: Taking uncertainties into account in Probabilistic Safety Studies
– IRSN, 2015-2016: Malfunctions in sensor networks
– TELCAP company, 2015: Beacon malfunctions in telecommunications networks
– RATP, 2016: Critical equipment replacement planning
– ANDRA, 2016 and 2017-2018: Method for optimizing the placement of sensors in a radioactive waste storage site
– Taxis G7, 2016: Study of a device intended to correct address errors
– Syndicat des Eaux d’Ile de France, 2017: Methodological support for network analysis
– RATP, 2016-2018: Modeling train behavior in emergency braking situations
RATP, 2017: Creation of a tool to simulate the delivery times of work trains, taking into account equipment breakdowns

- RTE, 2017-2018: Critical analysis of the “disconnector” replacement policy
- Atlandes (A63 motorway), 2018: Critical analysis of vehicle counters on exit ramps
- Carrier, 2019: Statistical analyzes of position data emitted by containers

- Atlantic Group, 2019: Probabilistic analysis of calls to the After-Sales Service (calls to the Consumer Service)
- Framatome, 2020: Writing of a safety demonstration for a control card
– PSA, 2020: Critical analysis of reinsurance thresholds
– Coldway Technologies, 2020: Carrying out a safety demonstration
- Air Liquide, 2021: analysis of the lifespan of certain components
- SARP Industries, Limay site, 2021: Study of parameters influencing CO2 production
- Eiffage Rail, 2021: Tools for analyzing equipment reliability
- RATP, 2021: Modeling train behavior in emergency braking situations
- Terèga, 2021: Probabilistic methods for verifying the integrity of pipes
- Bouygues Energies & Services, 2022: Methodological support for the design of a "Malfunctions and Maintenance" information system
- Befesa Valéra, 2022: Hierarchy of parameters involved in adjusting an oven
- RATP, 2022: Analysis of the stability of old embankments; Archimedes' approach
- Léon Grosse, 2022: Analysis of "hail" risk
- CMA-CGM, 2023: Critical analysis of methods in operational research
- Neext Engineering, 2023: Critical analysis of an SMR project