

CHAPTER 3 : Quantitative and Qualitative Failure Analysis

3.1. QUANTITATIVE FAILURE ANALYSIS

3.1.1. Introduction to quantitative analysis

The quantitative analysis of a history will make it possible to identify improvement actions, therefore, to identify the failures to be explored in greater depth in order to correct and prevent them.

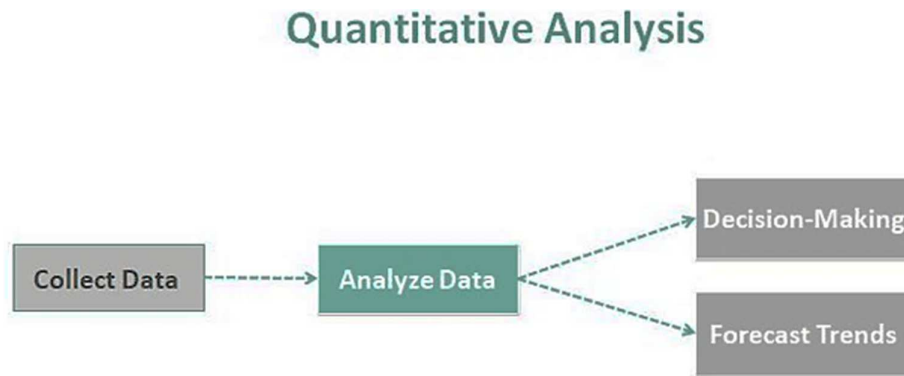


Figure 3.1. General quantitative analysis scheme.

Quantitatively analyzing the results of diagnostics thus constitutes an area of progress. The encrypted data to be entered must be as follows:

- Dates of corrective interventions (days, hours) and number N of failures. These elements will make it possible to calculate the periods of good operation ($UT = \text{Up Time}$), the time intervals between two consecutive failures ($TBF = \text{Time Between Failures}$) and their average ($MTBF$); these data will make it possible to characterize the reliability of the equipment.

- Production downtime ($DT = \text{Down Time}$) following failures, including “micro-failures”; all events are systematically recorded, even the most trivial; it is always easier to remember a major failure than a repetitive micro-failure which will ultimately lead to a serious failure; experience shows that forgetting it completely distorts a subsequent reliability study. It is also proven that micro-failures, which are part of routine and therefore easily forgotten, generate loss of availability, therefore lower productivity and of course poor quality. These data will therefore make it possible to characterize the availability of equipment.

-Maintenance intervention times (TTR = Time To Repair) and their average (MTTR); these data will make it possible to characterize the maintainability of the equipment.

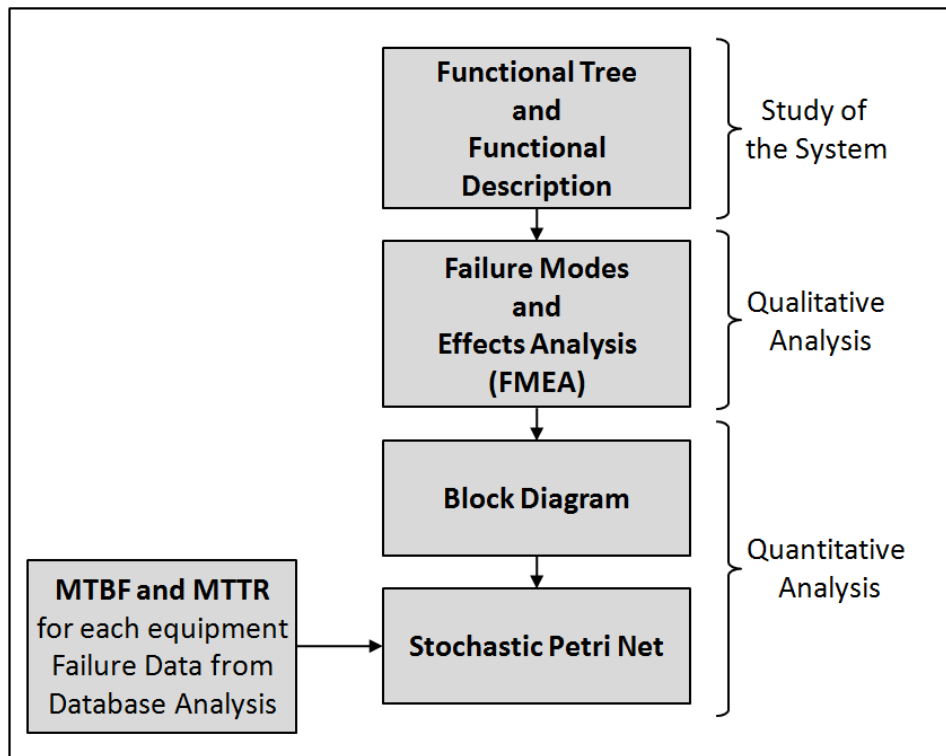


Figure 3.2. Quantitative analysis diagram.

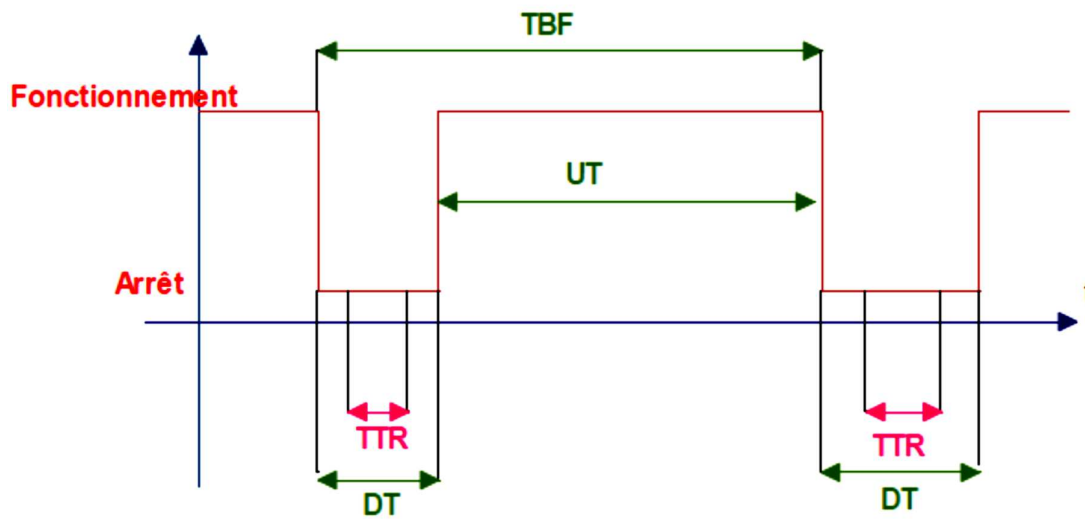


Figure 3.2. Failure time in quantitative analysis.

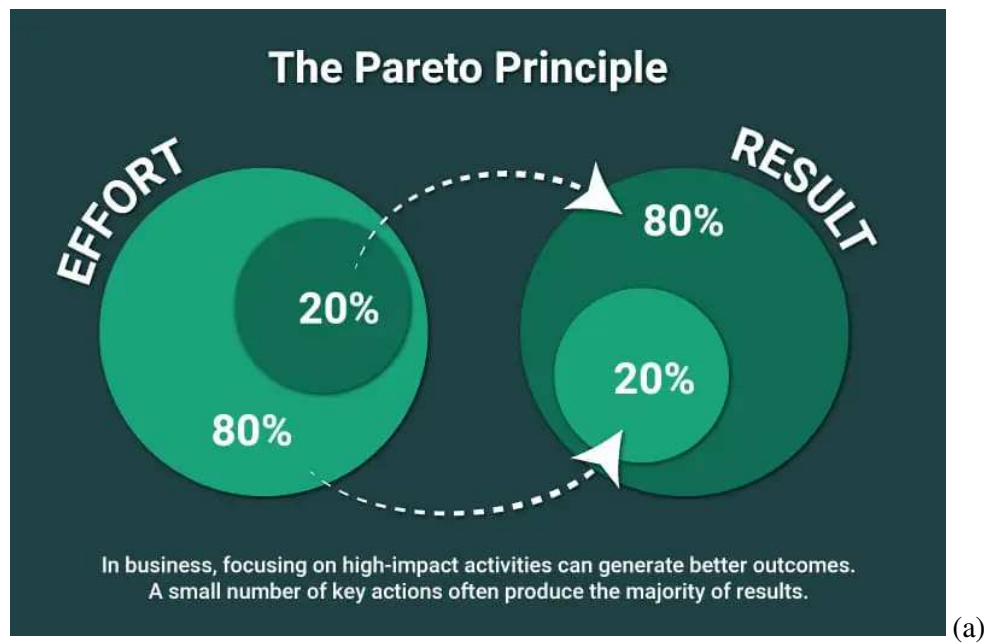
3.1.2. ABC method (Pareto Chart)

Among the multitude of concerns that arise for a maintenance manager, he must decide which failures must be studied and/or improved first. To do this, it is necessary to identify those which are the most important and whose resolution or improvement would be the most profitable, particularly in terms of downtime costs. The difficulty lies in the fact that what is “important” and what is “less important” are not always clearly distinguished.

The ABC method provides an answer. It allows investigation that highlights the most important elements of a problem in order to facilitate choices and priorities. We classify the events (breakdowns for example) in descending order of costs (downtime, financial cost, number, etc.), each event relating to an entity. We then establish a graph corresponding to the percentages of cumulative costs with the percentages of cumulative types of breakdowns or failures. In the diagram Figure 6.2, we observe three zones.

1. Zone A: 20% of breakdowns cause 80% of costs;
2. Zone B: the 30% additional outages only cost an additional 15%;
3. Zone C: the remaining 50% of breakdowns only concern 5% of the overall cost.

Conclusion: it is obvious that the preparation of maintenance work must focus on breakdowns in zone A.



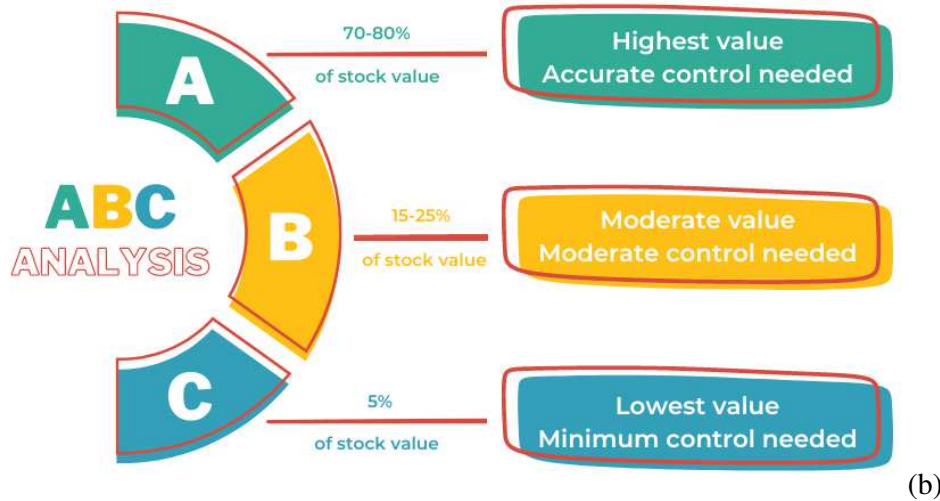


Figure 3.2. ABC Curve or Pareto Chart

In maintenance this method is very useful for determining emergencies or the most profitable tasks, for example:

- Pay particular attention to the preparation of interventions on the most frequent and/or costly failures (documentation, operating ranges, contracts, scheduling, etc.) ,
- Research the causes and possible improvements for these same failures,
- Organize a store according to parts release frequencies (number of parts and location),
- Decide on the maintenance policy to apply on certain equipment based on maintenance hours and costs.

Be careful, however: this method does not solve the problems, but it draws the technician's attention to the groups of elements to be studied as a priority.

a. Pareto charts in N, Nt and \bar{t}

The maintenance department can exploit this method by going much further:

- We draw up a table grouping the sub-assemblies, the number of failures N, the downtimes per sub-assembly Nt and the average downtime \bar{t} .
- We develop the bar diagrams N, Nt and \bar{t} ; they will make it possible to determine the priority of handling of the sub-assemblies by the maintenance department.
- The N-shaped graph points towards improving reliability.
- The graph in Nt is an availability indicator, because Nt estimates the loss of availability of each subset.

-The graph \bar{t} points towards maintainability, i.e. improving the ability to maintain.

b. Application :

A machine has 10 sub-assemblies for which the breakdown history has been recorded. The company, which uses this machine, wishes to increase its productivity by reducing serious breakdowns. To do this, she asks the maintenance department to define priorities for improvements to be made to this machine. The machine history provides the following table.

Table 3.1. Machine history.

Subset	A	B	C	D	E	F	G	H	I	J
Number of hours of stops	26.5	11	1	57	56.5	1	17	1.5	9.5	1
Number of failures	4	15	4	4	3	8	12	2	3	2

Correction:

A- ABC Diagram:

From the previous table, we draw the table of costs and cumulative breakdowns.

Table 3.2. Costs and cumulative failures (Application).

Subset	Cost ranking (in h)	Accumulation of costs (in h)	% of cumulative costs	Number of failures	Accumulation of failures	% of cumulative failures
D	57	57	31.3	4	4	7
E	56.5	113.5	62.4	3	7	12.3
A	26.5	140	76.9	4	11	19.3
G	17	157	87.2	12	23	40.3
B	11	168	92.3	15	38	66.7
I	9.5	177.5	97.5	3	41	71.9
H	1.5	179	98.3	2	43	75.4
C	1	180	98.9	4	47	82.4
F	1	181	99.4	8	55	96.5
J	1	182	100	2	57	100

From the table above, we construct the Pareto chart (figure 5). The red boxes give us the limits of zones A, B and C. It is therefore obvious that an improvement in reliability on subassemblies D, E and A can provide up to 76.9% gain on breakdowns.

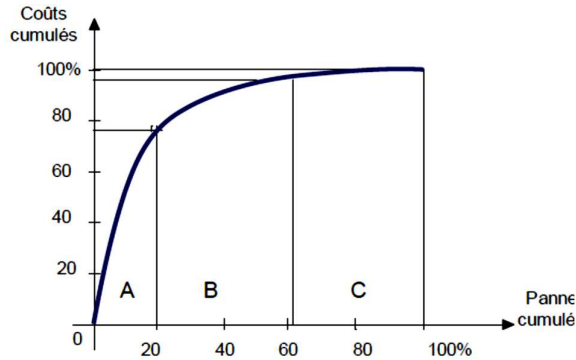


Figure 3.3. Pareto Chart Application.

B – Diagrams in N, Nt and \bar{t}

The table below illustrates the relationship between the number of failures N and the number of hours of stops Nt in addition to the average downtime for each failure \bar{t} .

Table 3.3. Average downtime for each failure \bar{t}

Subset	N	Nt	\bar{t}
A	4	26.5	6.625
B	15	11	0.73
C	4	1	0.25
D	4	57	14.25
E	3	56.5	21.83
F	8	1	0.125
G	12	17	1.42
H	2	1.5	0.75
I	3	9.5	3.17
J	2	1	0.5

The N-shaped graph in the figure 3.4 below points towards improving reliability: here we see that subsets B and G are those on which priority action must be taken. Different actions are possible: technical modifications (quality of components), driving instructions, increased

surveillance (routine maintenance), systematic preventive actions initially, conditional thereafter.

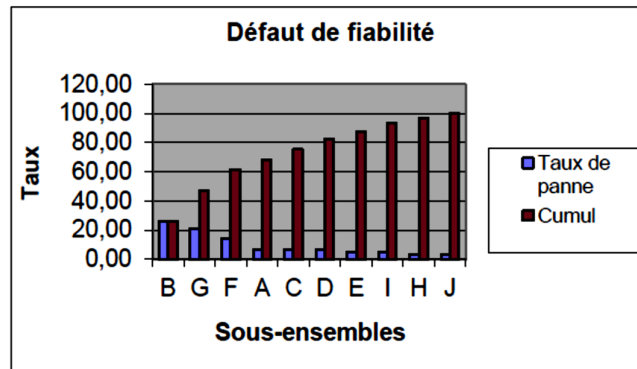


Figure 3.4. Highlighting the least reliable elements.

The Nt graph in the figure 3.5 below is an availability indicator, because Nt estimates the availability loss of each subset. It therefore makes it possible to select the order of handling of the types of failure according to their criticality (here subsets D and E).

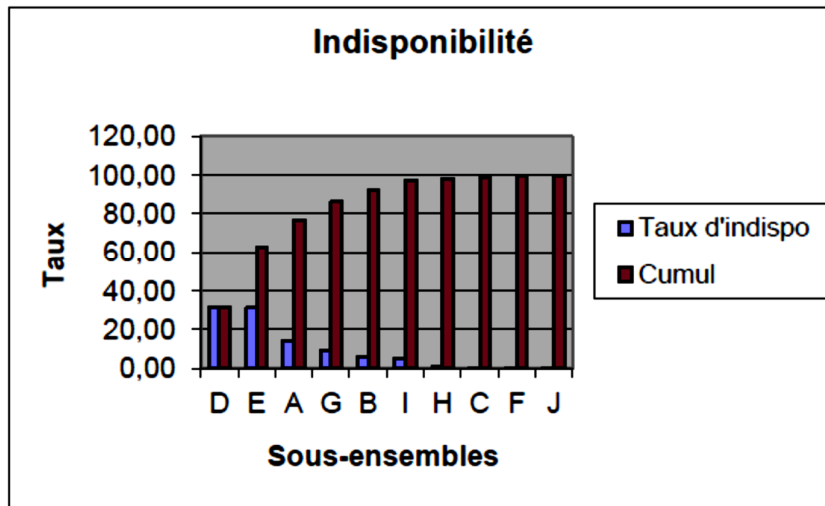


Figure 3.5. Highlighting the least available elements.

The graph in \bar{t} the figure 3.6 below points towards maintainability, that is to say the improvement of the ability to be maintained. Here, subassemblies E and D present almost 80% of the repair difficulties.

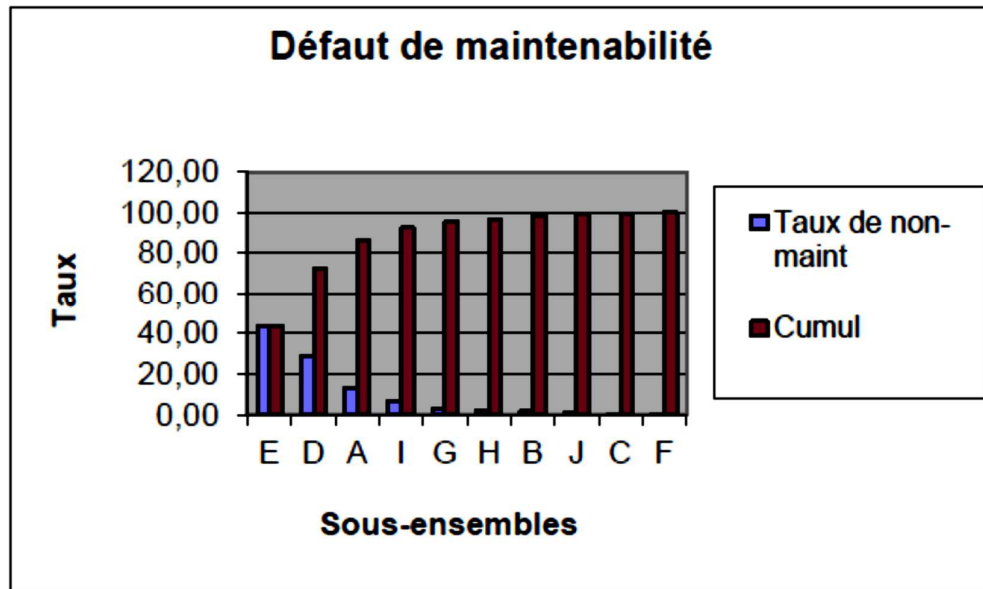


Figure 3.6. Highlighting the least maintainable elements.

After analysis of \bar{t} (maintenance waiting, travel, diagnostic time, part waiting, etc.), it will be possible to act on:

- Logistics (means of troubleshooting, handling, etc.) ,
- The organization of maintenance (intervention ranges, staff training, standard exchanges, etc.) ,
- Improving maintainability (accessibility, modular design, etc.)

3.1.3. Noiret abacus

The Noiret abacus is a scientific calculation tool that helps guide the choice of maintenance policy based on:

- Characteristics of the equipment.
- Its use.

The result is a recommendation offering three possible options:

- Recommended preventative
- Possible preventative
- Preventative not necessary

However, this result must be supplemented by an economic analysis relating to the cost of the various maintenances and the estimated return on investment that preventive maintenance can provide. It is only a decision support tool and not a decision tool.

a. Principle and application:

The Noiret abacus is based on the following criteria based on application's examples:

- a) Age of the equipment.

Table 3.3. Age of Equipment.

Age (years)	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	1
points	10	14	18	22	26	30	34	38	42	46	50	54	58	62	66	70	74	78	82	86	90

Calculation formula : Points = 90 – age*4

0 years = less than 1 year

- b) Noiret abacus interdependence: to what extent is it vital for production

Table 3.4. Interdependence of the Noiret Abacus.

Criteria	Points
Essential equipment and continuous operation	70
essential equipment and sub-continuous operation	60
essential equipment and discontinuous operation	50
Equipment without downstream or upstream buffer	40
Semi-independent material	30
Independent material	20
Double material (or plus)	10

- c) Cost of the Noiret Abacus application.

Table 3.5. Cost of the Noiret Abacus.

Criteria in €	Points
Less than 3000	5
[3000 to 15000[15
[15000 to 30000[25
[30000 to 45000[35
[45000 to 150000[45
15000 and more	55

d) Complexity and accessibility of Noiret Abacus application.

Table 3.6. Complexity and accessibility based on Noiret Abacus.

Criteria	Points
Low complex and accessible material	5
Very complex and accessible material	25
Low complex and inaccessible material	25
very complex and inaccessible material	45

e) Robustness and precision of Noiret Abacus application.

Table 3.7. Robustness and precision based on Noiret Abacus.

Criteria	Points
Robust	5
Current	10
Robust and precise	15
Low robust (delicate)	20
Overload work	25
Delicate and precise	30

f) Origin of the example application: Algeria or Foreign

Table 3.8. Origin of the products.

Criteria	Points
Algerian High-end series	20
Algerian small series	40
Foreign with SAV in Algeria	50
Foreign Without SAV in Algeria	70
Foreign without technical service	90

g) Its use over time

Table 3.9. The use over time of the Noiret Abacus .

Criteria	Points
Labor at 1 workstation	75
Labor at 1 workstation	175
Labor at 1 workstation	250

h) The consequences of the Noiret Abacus failures on the products

Table 3.10. Its consequences on the products .

Criteria	Points
Saleable products	10
Products to be taken back	35
Lost products	55

i) The production deadlines associated with the Noiret Abacus.

Table 3.11. Noiret Abacus and the production deadline .

Criteria	Points
Free time (stock constitution)	25
Tight deadline	100
Imperative deadline (risk of late penalty)	150
Imperative deadline (risk of costumer loss penalty)	225

Each criterion comes in several options, each of which corresponds to a certain number of points.

The points thus obtained are added together.

Note: only one choice is eligible per criterion; it is therefore necessary to take the one which is the most representative of the equipment.

b. Use :

The points for each criterion are added.

Table 3.12. Points of each domain and their recommendations .

Domain	Recommendation
0 to 510	Not necessary Preventive
511 to 559	Possible Preventive
600 to 910	Recommended Preventive

Example: Table 3.13. Criteria of product and its points .

Criteria	Points	Criteria	Points
5-year-old material	70 pts	Delicate and precision	30 pts
Semi independent	30 pts	Products to be taken back	30 pts
Value: €40,000	35 pts	2 -station walk	175 pts
Very complex and accessible	25 pts	Tight deadline	100 pts
Algerian small series	40 pts	TOTAL	540 pts Preventative possible

Graphical method uses charts

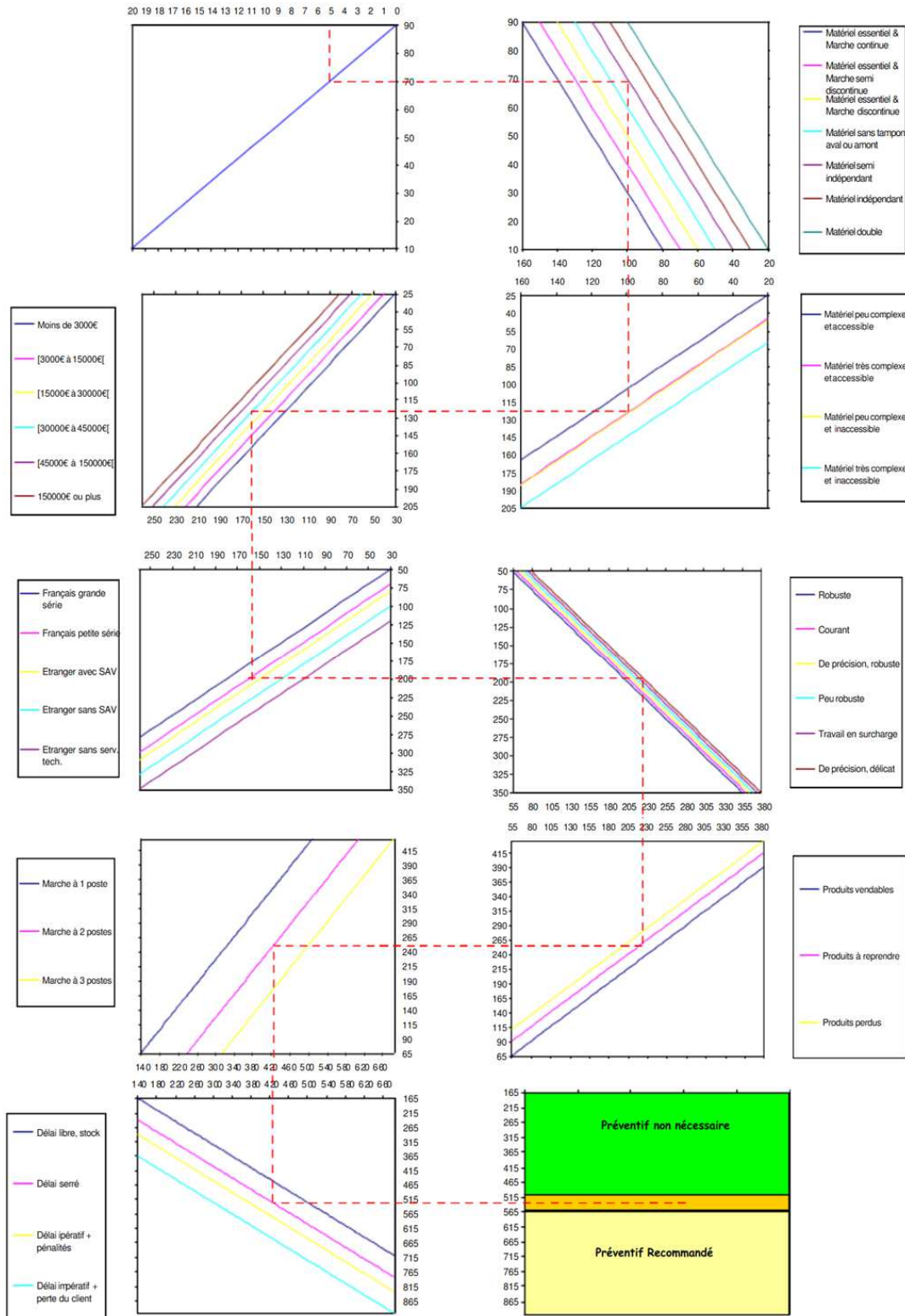


Figure 3.7. Example of Noiret Abacus Synthesis.

Coefficient table:

Based on the same criteria as Noiret's abacus but with coefficient points considering that the total points obtained were located in three zones:

- First zone below 500 points: no need for preventative;
- Second zone between 500 and 540 points: possibility of preventive action;
- Third zone below 540 points: prevention is necessary;

3.2. QUALITATIVE ANALYSIS AND FAILURE DIAGNOSIS.

3.2.1. *Diagnosis and expertise*

Diagnosis is “the identification of the probable cause of failure using logical reasoning based on a set of information coming from an inspection, a check or a test”. The NF EN standard 13306 goes further, since it indicates that the diagnosis of a breakdown is “all the actions carried out to detect the breakdown, its location and the identification of the cause”. We therefore go as far as assessing the failure. Fault location is the set of actions carried out to identify faulty equipment at the appropriate tree level.

3.2.2. *Conducting a diagnosis*

It requires a large amount of information collected:

a. Manifestation of the failure

The manifestation (or effect) of the failure is manifested by its amplitude (partial or complete), its speed (it is progressive or sudden), its character (it is permanent, fleeting or intermittent).

b. Symptoms

Symptoms can be observed in situ, without dismantling, by users of the equipment or by the maintainer: VTOAG, measurements, quality defects. VTOAG is the natural use of the individual's five senses. They should never be neglected, because they are capable of contributing to the establishment of a diagnosis.

* The view (V):

- Detection of cracks, leaks, disconnections,
- Detection of mechanical damage.

* Touch (T):

- Sensation of heat, vibration,
- Estimation of a surface condition.

* Smell (O):

- Detection of the presence of particular products,
- “Burnt smell”, hot clutch,...

* The auditory (A):

- Detection of characteristic noises (friction, hissing).

* Taste (G):

- Identification of a product (leak).

Symptoms can also be observed after dismantling: measurements, observations of breakage, surface condition, non-destructive tests, etc.

c. Experience

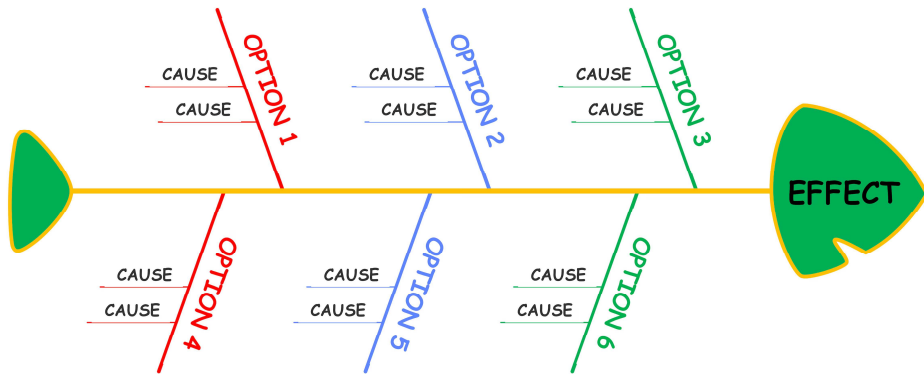
When tackling a hardware failure problem, the maintainer cannot afford to navigate by sight. He already knows the probabilities of failure occurring on equipment. For example, on a SAP (Automated Production System), we know that it is the operational part which will cause the most breakdowns (Pareto Diagram).

d. Expertise

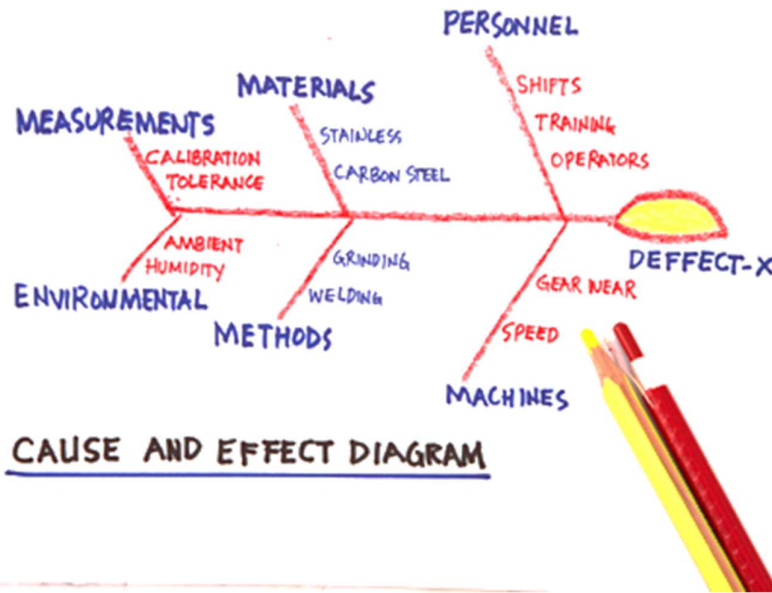
The diagnosis is constructed like a police investigation: the maintainer starts from information and symptoms, and from his experience, he formulates hypotheses assigned a more or less significant level of probability, tests these hypotheses in order to build certainty. It has diagnostic tools for this. The most used are:

3.2.3. The Causes – Effects diagram,

This tool was created by Ishikawa, professor at the University of TOKYO in the 1960s and designer of a total quality management method. The cause-effect diagram is a graphical representation of the classification by family of all possible causes that can influence a process. These 5 families of causes cause non-quality in a manufacturing process. Their name begins with the letter M, hence the name 5M. Ishikawa proposed a “fishbone” graphical representation shown in the following figure:



(a)



(b)

Figure 3.8. Causes- Effects diagram: (a) global, (b) example.

The Cause-Effect diagram is therefore the image of the identified causes of a potential malfunction that may occur on a system. It is intended to be as exhaustive as possible by representing all the causes which can have an influence on operational safety. The 5 large families or 5 primary factors are informed by secondary and sometimes tertiary factors; The different factors must be prioritized.

The interest of this diagram is its exhaustive nature. It can be applied to existing systems (evaluation) as well as to systems currently being developed (validation). We can add secondary and tertiary factors to the previous diagram which will complement the primary factors. This tool can be adapted to help with diagnosis in the following way:

- Definition of the effect studied by gathering as much data as possible.

- Identification of all possible causes; brainstorming¹ is an effective tool for this research phase.
- Typological classification of causes.
- Hierarchy of causes in each family in order of importance .

3.2.4. *The cause tree or fault tree*

The Fault Tree Analysis technique, introduced in 1962 by Bell Laboratories, is widely used across safety, management, and engineering domains to solve diverse problems through structured visual analysis. It is a deductive diagram which goes from the effect to the cause and which aims to find all the combinations of elementary (primary) failures which can lead to a breakdown.

a) Root causes analysis (RCA)

Root Cause Analysis (RCA) is a systematic problem-solving method designed to identify the fundamental causes of issues rather than merely addressing surface-level symptoms. Root Cause Analysis is a process of discovering the underlying causes of problems to develop effective, preventive solutions. It assumes that systematically addressing root causes is more efficient than repeatedly treating symptoms. The RCA focuses on how and why something happened, not who is responsible in addition that it recognizes that multiple root causes can exist, provides actionable insights for prevention and necessary to be methodical and evidence-based. The RCA is based on the 5 "Why?" iteratively asked to dig deeper into problem origins. RCA is widely used across: Manufacturing, Healthcare, IT Operations, Telecommunications, Accident Investigation, Industrial Process Control.

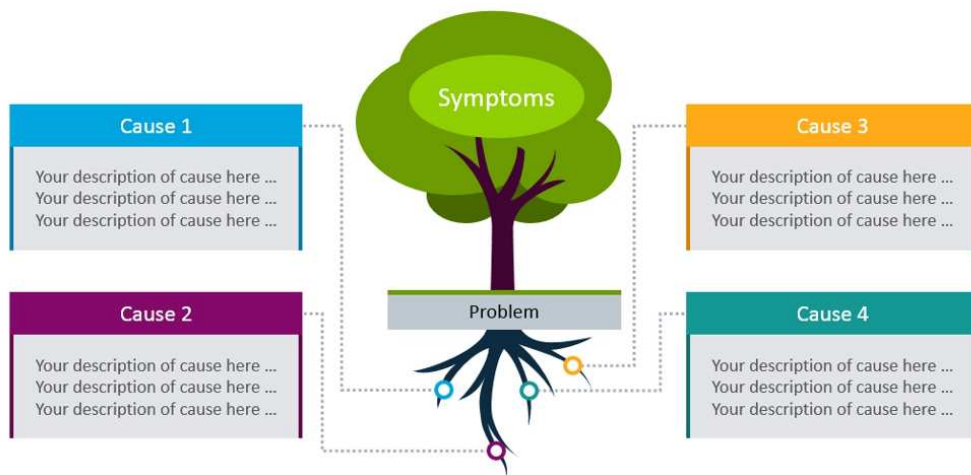


Figure 3.9. Root Cause Analysis Tree (Symptoms-Problem-Causes).

b) Symbolism

This tool uses symbolism that is also used on logic circuits. We also speak of a troubleshooting flowchart. This symbolism is shown in the following figure 3.10:

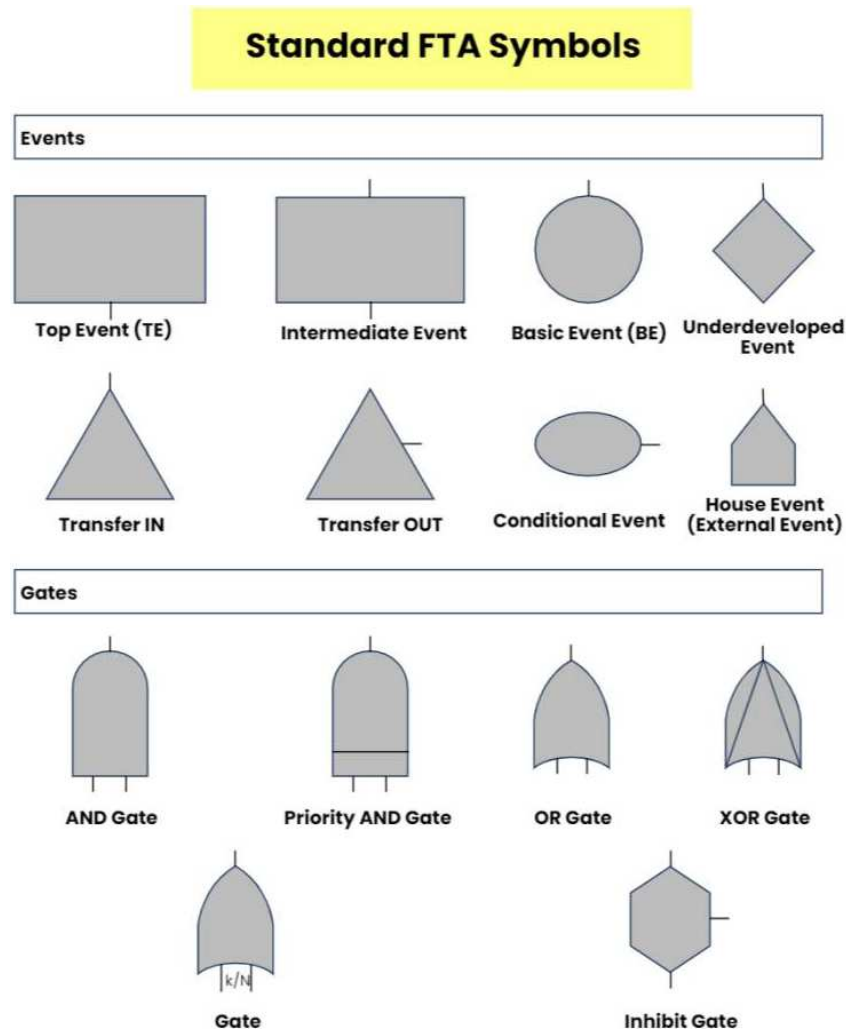


Figure 3.10. Cause tree or Fault tree symbols.

1. Basic Symbol Types

Fault Tree Analysis uses two primary symbol categories:

- Event Symbols
- Logic Gate Symbols

2. Event Symbols

- **Rectangle:** Represents a negative event, typically located at the top of the tree.
- **Circle:** Indicates a base event at the bottom tier that requires no further breakdown.
- **Triangle:** Signifies a transfer of a fault tree branch to another location within the tree.

3. Logic Gate Symbols

- **AND Gate:**
 1. Represents a condition where **all input events** must occur for the output event to happen.
 2. Indicates simultaneous occurrence of events.
- **OR Gate:**
 1. Shows that **any of the input events** can lead to the output event.
 2. Means the event occurs if one or a combination of input events exists.

c) Construction of the fault tree

To construct a fault tree, one can use the diagnostic flowchart and/or diagnostic sheet shown in the following figure 3.11 and its application example in figure 3.12. Note that this construction is entirely qualitative:

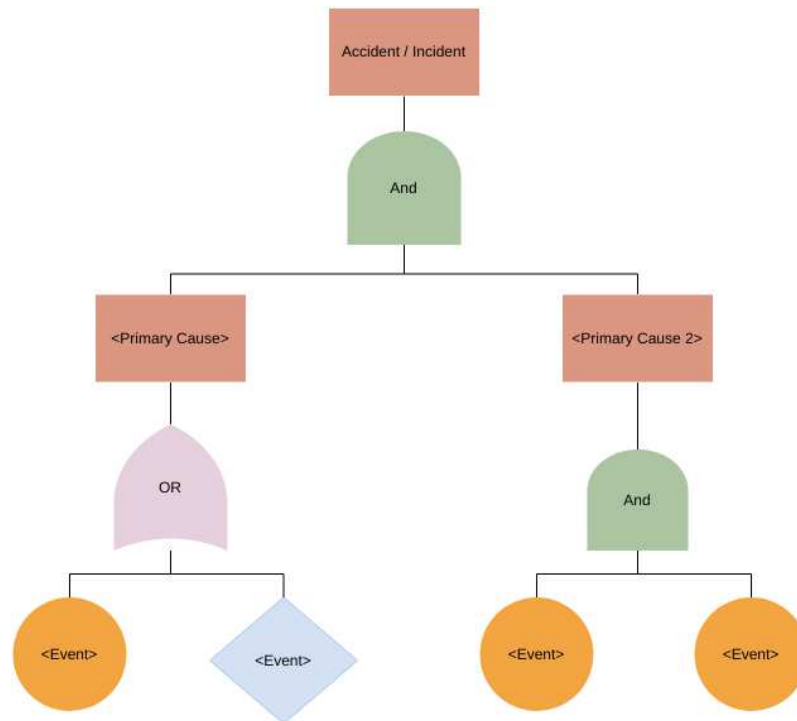


Figure 3.11. Fault tree flowchart.

Example :

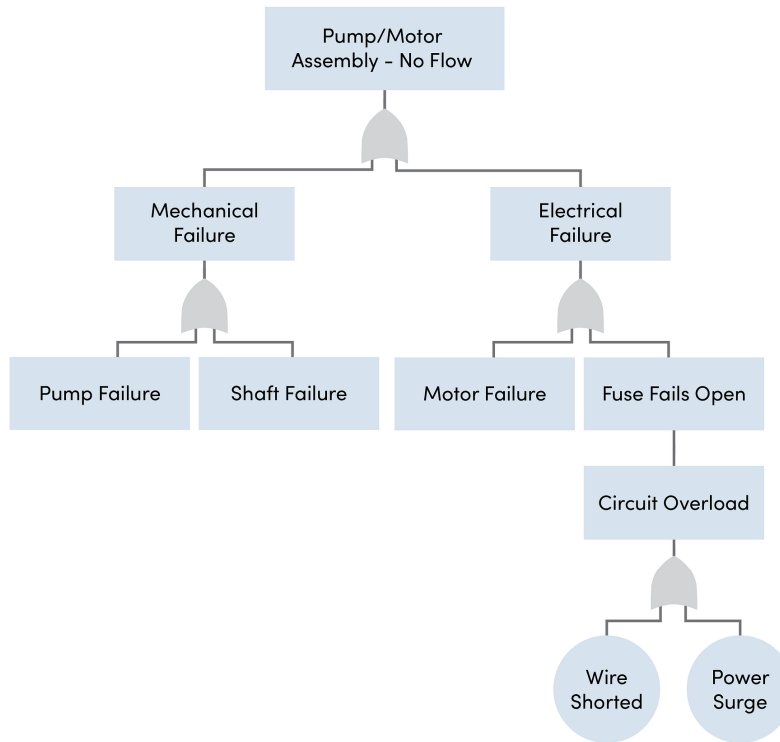


Figure 3.12. Fault tree flowchart example.

3.3.CONCLUSION

This chapter discussed the Quantitative and Qualitative Failure Analysis represent complementary approaches to understanding system risks and potential failures. Qualitative analysis provides subjective insights using descriptive scales and expert judgment, while quantitative analysis offers data-driven, numerical assessments of failure probabilities and potential impacts.

The follower chapter will present the diagnosis in maintenance and reliability that is a critical process of identifying, understanding, and predicting potential system failures. It involves systematic evaluation of equipment performance, analyzing historical data, and implementing proactive strategies to prevent unexpected breakdowns.