21, rue d'Artois, F-75008 PARIS
http : //www.cigre.org

INNOVATION FOR SECURE AND
EFFICIENT TRANSMISSION GRIDS
CIGRÉ Belgium Conference
Crowne-Plaza – Le Palace
Brussels, Belgium | March 12 - 14, 2014

A tool for excellence in Asset Management of tomorrow

J. MARICQ, F. ROMAIN
Elia
Belgium

SUMMARY

The electricity market is changing quickly. While financial and human resources might not subsequently grow, utilities must face substantial grid developments such as interconnections between neighboring countries, grid restructuration for decentralized productions and European offshore grid, and even keep their infrastructure in good condition.

These findings show that utilities will not be able to satisfy the growing demand with current work patterns and that they must adapt to the evolution of the market. An alternative consists in the implementation of Asset Management principles and more precisely in the risk integration in the decision-making.

Risk assessment is a complex process. It requires an accurate database with appropriate data together with statistical models for analyzing these data and extracting right decisions.
Unfortunately, the tools available on the market did not comply with Elia's requirements. Therefore Elia decided to develop its own tool assessing risks and integrating them in the decision-making process.

The tool that is being developed is designed to:

- assess asset-related risks
- generate a replacement program
- generate a maintenance program
- report the condition of the grid and its components

Failure probability, the first risk component, is assessed by collecting asset malfunctions from maintenance crews and incident analyses. If data are missing, expert judgment also becomes an input. The handling of these malfunctions with statistical models leads to generic aging curves of assets. The latter are customized by applying correction factors reflecting their utilization. For instance, a transformer fully loaded will age faster than one half loaded. The global correction of the aging curve of a particular asset relative to the generic curve gives the health index of the asset. Finally, aging curves of assets are aggregate to systems such as bay, substation and circuit to compute risks at higher levels.

johan.maricq@elia.be

The second component of risk, the consequence, is assessed by scoring each type of consequence. For instance, safety issues could be scaled from no injury to death through injury without unavailability and injury with unavailability.
Both components of risks are then combined in a risk matrix. This is performed for each type of consequence as well as for the combination of consequences.

The replacement program is defined by the investment plan and the risks ranking. Assets or systems of assets with higher risks are replaced so that the amount of money or the level of acceptable risk is reached. This exercise is achieved on short, middle and long term, namely four, twelve and twenty years.

The maintenance program is defined by three types of maintenance: time-, condition- and risk-based maintenance. Health index and risks are inputs for condition-based and risk-based maintenance, respectively.

Finally, as the tool gathers many data and computation results it presents a powerful opportunity of reporting on technical characteristics and grid conditions.

In conclusion, this tool presents the following major advantages regarding asset management:

- it gathers data, computations and results in a central place
- it integrates risks in the decision-making processes in a systematic way
- it ensures coherence in the management of existing assets (maintenance and decommissioning)

KEYWORDS

Asset management, Condition, Decision-making, Health index, Investment, IT tool, Maintenance, Reporting, Risk

1. Introduction

The electricity market is changing rapidly. While financial and human resources might not subsequently grow, utilities are experiencing substantial grid developments such as interconnections between neighbouring countries, grid restructuration for decentralized productions and European offshore grid, and must keep their infrastructure in good condition.

Utilities will not be able to satisfy this growing demand with their current working methods and must therefore adapt to the evolution of the market. One way of doing so is the implementation of Asset Management principles and more precisely the integration of risk in decision making process.

The assessment of risks related to equipment and their integration into decision making processes is not unfamiliar to Elia. In 2007, the first methodology to compute risks was defined and the related IT tool, the EAR Model (Elia Asset Risk Model), was implemented. The results of the computation were used for several years for material replacement evaluation (project scoping, replacement policies, etc.).

In 2011, after a stabilization phase, the time had come to review and improve the computation methodology. The first major change was to separate the evaluation of the two components of risk, probability and consequences. Instead of being processed by a single department, each risk component was assigned to the department most competent to perform the computation. This new methodology enabled a more accurate management of the project portfolio. The second fundamental change was in the choice of aging models for the equipment. Simplified models used in the EAR Model were replaced with more complex but more realistic models, which are still in use today. Finally, the EAR Model, originally implemented in Excel, was migrated to an in-house developed application: the AM Tool. The major advantages of this new tool were the integration of data, computation and analysis of results and the communication with other IT tools and databases within Elia. The asset-related risk assessment and integration of risk in decision-making processes have been designed, implemented, tested and corrected and have now reached maturity. These proven solutions can now be used as a springboard for the creation of new features.

Since 2011, the AM Tool has been under development with the goal being for the tool to bring together replacement and maintenance processes: defining these activities so that the CAPEX and OPEX costs are optimized. The emphasis is placed on supporting the replacement process (long term vision, investment plan asset notes, etc.) and the accuracy in risk assessment (aging models, combination patterns, updates, consequences, etc.). Regarding the maintenance management, risks have not yet been integrated into the process: the time-based Maintenance (TBM) is currently in use. IT tools are being modified to enable the use of other types of maintenance such as condition-based or risk-based maintenance (CBM and RBM). A reporting module has also been developed to measure the KPIs of the replacement and maintenance process, quality control data, etc.

This document describes the functional scope of the application (Figure 1) and is divided into four parts:

- risk assessment
- establishment of a replacement program
- establishment of a preventive maintenance program
- reporting

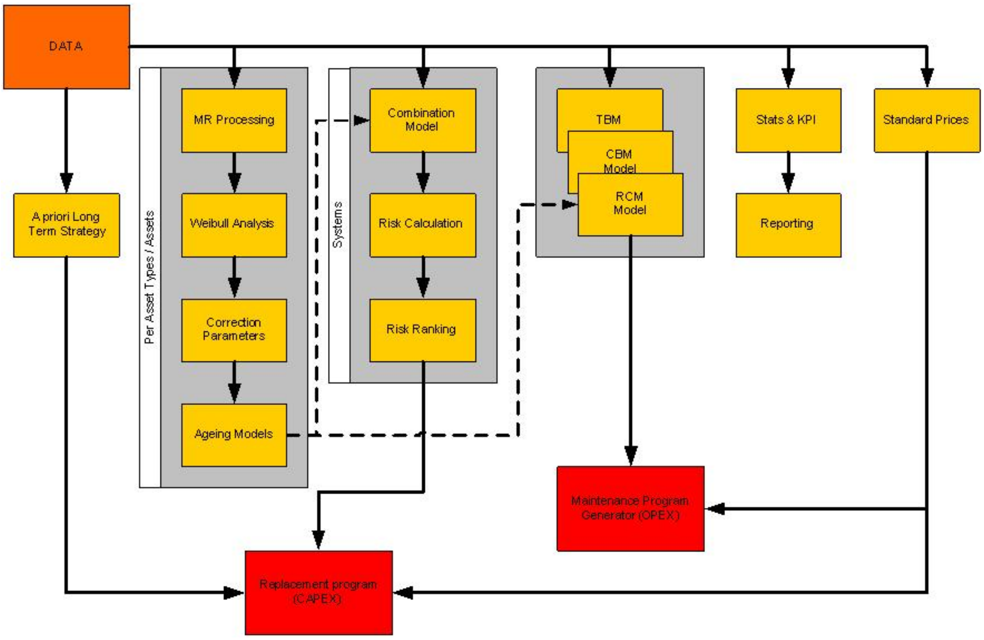

Figure 1: Functional Scope

2. Assess asset-related risks

2.1. Asset-related risks

Whatever the application, risk is simply defined as the product of a probability of occurrence and a consequence. However, in the utility industry and more specifically on electrical grids, causes of occurrences are numerous, types of consequences are various and consequently risks are countless. In the framework of the AM Tool, Elia restricted its list of managed risks to the more critical asset-related risks and their aggregation:

- financial risk
- customer risk
- safety risk
- security risk
- environment risk
- reputation risk
- aggregated risk

Each of these risks is linked to a range of consequences (chapter 2.2) that are themselves linked to several failure modes (chapter 2.3).

The aggregated risk is the weighted sum of the first six risks based on a prioritization done by Elia. Within Elia the three risks with highest priority are safety, environment and security risks. Risks are then visualized in a risk matrix, with one axis representing the probability of occurrence and the other representing the consequence (Figure 2). Each of the six risks identified above as well as the aggregation of these risks can be visualized separately. The risk at a specific time is shown in the risk matrix and the evolution of risk over time can be displayed in a separate graph (Figure 3).

The result of this analysis is a list of assets or systems of assets classified from the most to the least critical. With this list Elia can better manage risks in the project portfolio by including the replacement needs in the grid development (chapter 3).

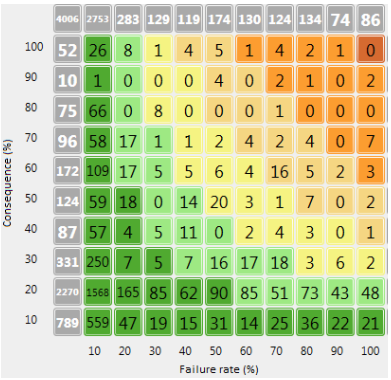

Figure 2 – Risk matrix

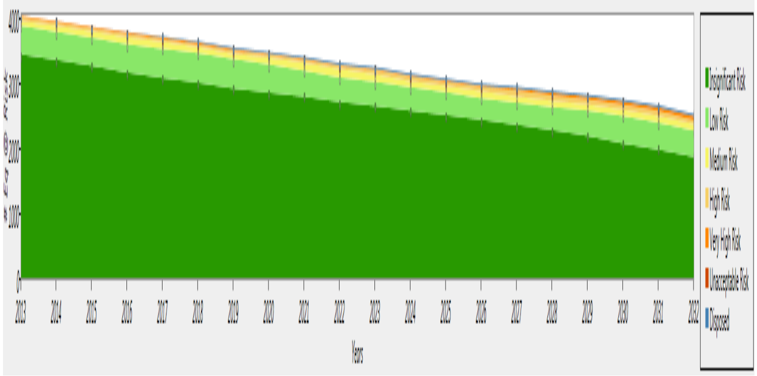

Figure 3 – Evolution of the risk matrix over time

2.2. Consequences

Each risk considered as critical by Elia is linked to a range of consequences. Below, examples of consequences for two risks have been non-exhaustively developed for illustration:

1. Consequences of financial risk:
    - OPEX
    - CAPEX
    - penalties in case of energy not supplied

2. Consequences of environmental risk:
    - soil pollution
    - greenhouse gas emissions

Consequences are assessed within the appropriate department. For example, the OPEX consequence is assessed by asset managers in collaboration with maintenance crews. The assessment consists of associating standardized maintenance duration (and their costs) to assets and average costs for the utilization of tools, cars, etc. On the other hand, soil pollution is assessed by the environment department. The consequence in this case corresponds to the cost of cleaning up the soil and the penalties for the non-respect of legal constraints.

Furthermore, consequences can be amplified depending on the circumstances. In the example of the OPEX consequence, a standardized cost is linked to the maintenance of an asset. However, if Elia no longer owns any spare parts for that asset, maintenance would be more expensive due to the manufacturing of customized spare parts, delays, etc. Therefore Elia uses parameters called ‘aggravating factors’ to address this issue. An example of an aggravating factor is the ‘SLI’ – Service Level Index:

- Value 1: still supported by the manufacturer and spare parts are available
- Value 2: still supported by the manufacturer but no spare parts are available
- Value 3: no longer supported by the manufacturer and no spare parts are available

2.3. Failure (probability of occurrence)

Each consequence is linked to several failure modes. Below, examples of occurrences for two consequences have been non-exhaustively developed for illustration:

1. OPEX consequence is the result of the following occurrences:
    - preventive maintenance
    - corrective maintenance

2. Soil pollution consequence is the result of the following occurrences:
    - legal constraints on oil pits
    - explosion of assets containing oil or gas
    - leakage from assets containing oil or gas

In this second example, the legal constraints on oil pits outline that all Elia transformers must be put on oil pits by 2015. This means that the probability of occurrence leading to the consequence of soil pollution and more specifically to penalties for the non-respect of legal constraints does not exist before 2015 but will exist from 2015 onwards. Thus, the probability distribution could be drawn as shown in Figure 4.

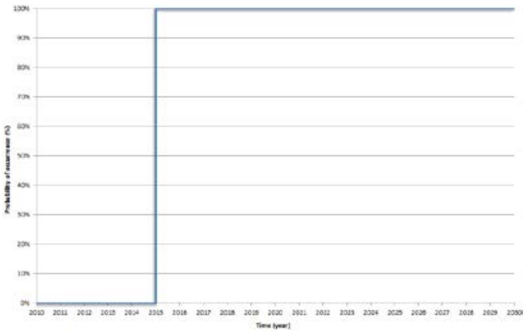

Figure 4 – Probability distribution related to legal constraints

In the example of the OPEX consequence, in order to assess the corrective maintenance occurrence a three phase process has been established:

1. Collection of useful information for the computation of asset aging (chapter 2.3.1).
2. Computation of asset aging (chapter 2.3.2).
3. Computation of system aging (chapter 2.3.3)

2.3.1. Experience feedback

The first step in determining the parameters of aging curves consists in data collection. The data collected is tangible and relevant data, ideally coming from experience feedback and expert judgement which will be described in the following sections, chapter 2.3.1.1 and chapter 2.3.1.2, respectively.

2.3.1.1. Malfunction reports analysis

Four data were identified as necessary and sufficient for the computation of asset aging. These are:

- defective part of the asset
- malfunction type
- malfunction cause
- malfunction date

With the exception of the malfunction date, which is automatically generated by IT tools, these fields are filled by exhaustive and clever pick lists. Clever pick lists vary or restrict the contents of the lists based on the choices made in the previous lists. In this manner, Elia reduces potential errors during the encoding of malfunction reports.

This information is effectively sufficient as it gives Elia the opportunity to distinguish:

- minor and major malfunctions
- malfunctions due to material and external events
- malfunctions due to normal wear and random failure
- level of unavailability

Several years will be needed to collect enough data and obtain the relevant samples. An alternative will be developed and implemented in the close future to cope with this lack of data: the Monte Carlo process that artificially enlarges small samples from available information.

2.3.1.2. Expert judgment

As mentioned above, aging parameters are also defined by expert judgment. A form will be soon developed and implemented in the AM Tool to extract the asset aging behaviour from expert judgement in an objective and systematic manner. This form will include typical questions such as:

- What is the lifetime of the asset?
- How many minor malfunctions occurred from 0 to 20 years?
- How many minor malfunctions occurred from 21 to 40 years?
- How many minor malfunctions occurred from 41 to 60 years?
- How many major malfunctions occurred from 0 to 20 years?
- How many major malfunctions occurred from 21 to 40 years?
- How many major malfunctions occurred from 41 to 60 years?

2.3.2. Aging parameters

The second step in determining the parameters of aging curves is further divided into three sub-steps:

1. the computation of aging curve parameters per group of assets based on malfunction reports and expert judgment (chapter 2.3.2.1)
2. the update of aging parameters per group of assets based on experience feedback (chapter 2.3.2.2)
3. the computation of aging curve parameters per individual asset based on its usage (chapter 2.3.2.3)

2.3.2.1. Theoretical parameters

The aging curve is first calculated for a group of assets with similar specifications. These related parameters are called generic aging parameters.

The malfunction of a specific group of assets is modelled by the 2-parameter Weibull distribution that gives a time dependent failure rate, λ (Figure 5). The Weibull distribution is obtained from the two parameters β and η, representing the aging velocity and the elbow of the curve, respectively. The first zone of the curve during which the failure rate stays almost constant corresponds to the useful lifetime of the asset and the second zone during which the failure rate exponentially increases corresponds to failures caused by wear. Infantile illnesses are not taken into account.

The reason Elia works with the failure rate and not pure probabilities is that Elia associates a number of malfunctions over a specific amount of time with a consequence given per malfunction.

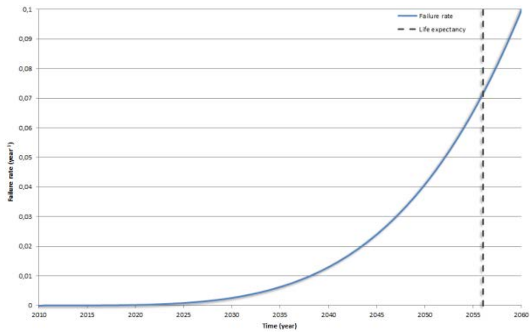

Figure 5 – Two-parameter Weibull distribution: failure rate $\lambda(t)$ (β = 5, η = 50)

The 2-parameter Weibull distribution is not the most appropriate choice for describing the aging of all assets. This distribution imposes a zero failure rate at the beginning of the lifetime, which can introduce bias in the curves. A 3- or 4-parameter Weibull distribution would be more adapted in this case. In literature, electronic assets generally age according to an exponential distribution combined with a 3-parameter Weibull distribution. Additionally, assets could age according to other distributions: the log-normal distribution is applicable to underground cables. The automatic choice of the best distribution for a group of assets based on statistical hypothesis testing is being investigated and the AM Tool will be adapted accordingly in the close future.

2.3.2.2. Bayes

The establishment of the aging parameters from expert judgment or the update of the aging parameters from malfunction analyses involves the application of the Bayes' theorem.

2.3.2.3. Health index

Finally, aging curves are corrected according to the actual usage of the assets (Figure 6). In this phase, the aging curve of a specific asset is corrected based on defined parameters: load, pollution, environment, climate, know-how, manufacturers support, etc.

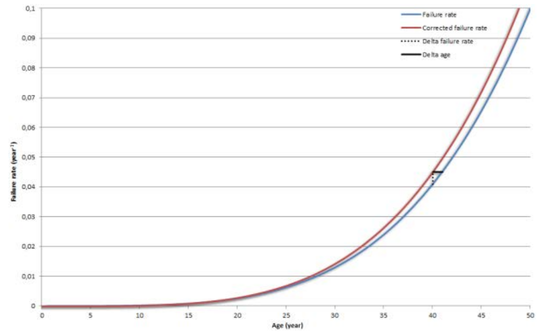

Figure 6 – Health index

In the example above (Figure 6), by adding the correcting coefficient the failure rate of the concerned asset rises in comparison to that of similar assets. This increase could also be translated into a virtual age. The virtual age would indicate that the asset has the physical condition of 42-year-old asset while in reality it is only 40 years old. Elia designates the health index as the delta between the virtual age and the real age.

2.3.3. Combination models

In some applications risks have to be assessed at a more macroscopic level than that of the equipment. Therefore the third and final step in defining the parameters of the aging curves consists of assessing risks at the following levels in the AM Tool:

- HV bay, LV bay and HV/LV bay
- dipole
- circuit
- substation
- voltage level
- electrical zone
- regulatory zone
- geographical zone
- transmission zone (TSO or DSO)
- whole grid

Through a graphical interface, end users define combination models corresponding to each level. The failure rates of assets making up these systems are then automatically combined. For example, Elia has defined the following combination models at bay, dipole and circuit level:

- fail safe model (FS)
- fail dangerous model (FD)

The FS model corresponds to the probability that a system does not properly perform its function of electricity transport. In the case of protection equipment this corresponds to the serialization of protections P1 and P2 because failures that lead to electricity transport interruptions are mainly due to nuisance tripping. The FD model corresponds to the probability that a system does not trip a fault. Again in the case of protections this corresponds to the paralleling of protections P1 and P2 because failures that lead to the absence of a tripping order must occur simultaneously on both protections.

When analysing substation and zone models Elia uses indicators rather than combinations because the logical combinations no longer make sense due to the N-1 grid topology (no different impact in case of a failure compared to the normal situation). For example, one indicator Elia works with is a resultant failure rate equal to the median of the failure rates of the underlying assets or systems.

Combination models could also be applied to probabilities, reliabilities, lifetime expectations and replacement years.

3. Generate a replacement program

Once risks are calculated on all assets and systems and ranked from the lowest to the highest, Elia is able to estimate the number of assets and systems to be replaced in order to decrease, increase, or maintain the current level of risk. Related budgets are deduced from standard costs and an investment plan covering the next 12 years (three regulated periods) is established.

Elia is also able to estimate the technical end of life of bays and substations. This information, in association with grid connection or disconnection requests and net exploitation needs, becomes very useful when defining a long term vision of the evolution of the grid and implicitly a long term replacement program (over 30 years). The fine-tuning of the replacement year can be done based on related risks. When analyzing a specific substation, if risks are low then the replacement year could be reasonably postponed. Contrariwise, high risks could lead to shorter lifetimes.
These steps are supported by the AM Tool as it transfers the calculated risk values to the IT tool dedicated to grid development via asset notes. Asset notes are notes specifying specific needs. Elia has defined four types of asset notes:

- disposal notes, identifying assets that are too old or too risky
- upgrade notes, identifying assets with specifications that are incorrect in relation to their functions
- need notes, identifying the need to install new assets
- constraint notes, outlining constraints Elia is faced with during projects

Finally, Elia is able to optimize a long term strategy. To be specific, a module in the AM Tool could provide the best replacement distribution curve (Figure 7) so that risks and investment budgets (Figure 8) remain constant and the current age pyramid of the assets or systems (Figure 9) becomes smooth (Figure 10).

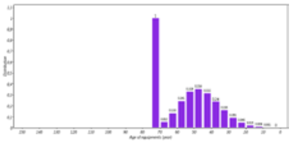

Figure 7 – Replacement distribution

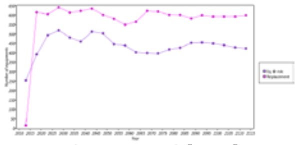

Figure 8 – Risk and investment budget

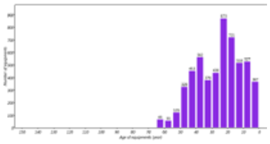

Figure 9 – Age pyramid (2013)

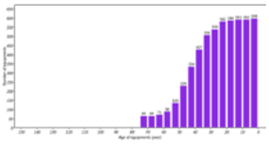

Figure 10 – Age pyramid (2113)

4. Generate a preventive maintenance program

Preventive maintenance can be defined as:

- a procedure of inspecting, testing, and reconditioning a system at regular intervals according to specific instructions, intended to prevent failures in service or to retard deterioration
- actions performed at predetermined intervals or according to prescribed criteria and intended to reduce the likelihood of failure or degradation of nominal functioning

and leads to the following advantages:

- increased system quality
- extended equipment life
- reduced risk of safety, health and environmental incidents
- decreased total cost of long-term maintenance

However, in order to benefit from these advantages, preventive maintenance must be integrated in the risk-based decision-making process so that asset condition evaluated during maintenance is integrated in the risk assessment and in the establishment of the replacement program

Moreover, risk analyses can provide sufficient information for fine-tuning the maintenance program. For example, Elia analyses grid incidents to identify generic failures and plan maintenance activities on other similar assets. In this way, potential failures can be avoided in the future.

The maintenance program is generated by a specific module of the AM Tool. This module manages:

- inspections (legal controls, substation inspections, tower foot patrols, etc.)
- maintenance and overhaul (with or without outage)

The AM Tool is capable of simultaneously managing the following types of maintenance:

- time-based maintenance (TBM)
- condition-based maintenance (CBM)
- risk-based maintenance (RBM)
- run-to-failure maintenance

The end-user can translate his maintenance policy into rules via a graphical interface. A maintenance program would then be generated and work orders sent to maintenance crews for validation (based on capacity) and application.

5. Report the condition of the grid and its components

In order to follow up on the evolution of the condition of the grid as well as the completion of investment and maintenance programs Elia has set up reports and KPIs. Some examples are given in the following sections.

5.1. KPI related to the investment program

The graph (Figure 11) below shows the level of completion of replacement policies compared to their criticality. This graph is useful in the portfolio steering.

5.2. KPI related to maintenance program

This graph (Figure 12) gives the number of assets needing and not needing maintenance in the current year and the number of assets for which maintenance is already planned. Figures are also given in man-hours.

5.3. Life time pyramids

End users of the AM Tool can also access a chart (Figure 14) displaying the age pyramid of a range of assets. On the same graph, the user can see the assets that have been covered by a replacement need (in red).

5.4. Assets on a map

The AM Tool offers the opportunity to visualize asset information on a map (Figure 13). This feature is still in development.

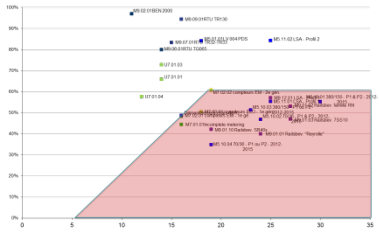

Figure 11 – Investment program KPI

Figure 12 – Maintenance program KPI

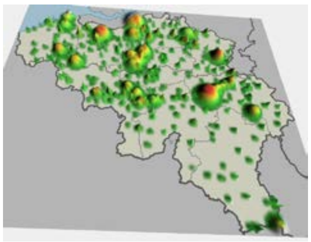

Figure 13 – Map visualization

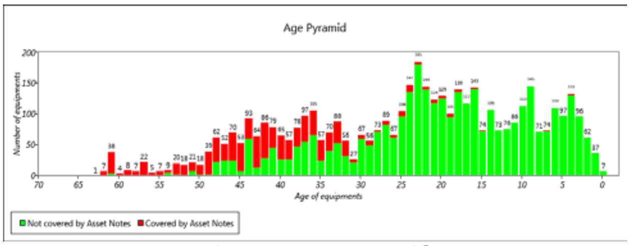

Figure 14 – Age pyramid

REFERENCES

None.