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B2 OVERHEAD LINES
PS2 Latest techniques in asset management,
capacity enhancement, refurbishment

Innovative inspection techniques and digital tools for condition follow-up of overhead lines in Belgium

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SUMMARY
Since three years, the Belgian Transmission System Operator Elia has implemented a dynamic asset management system by introducing innovative inspection techniques like UAVs (Unmanned Aerial Vehicle) and digital tools (numerical check list, Artificial Intelligence, etc.). The goal of this management is:

- to detect, quickly, the abnormal degradations of assets;
- to determine the condition of each asset in order to support the development of network and meet the needs of society (integration of renewable energies, decarbonisation, etc.);
- to make the right investments, at the right time, with optimized costs and with an acceptable risk in the interest of the community;
- to switch from a time-based management system to a risk-based asset management system.

The implementation of this dynamic asset management is based on 3 fundamental pillars: digitalization of data (data base), digital tools (organization of collected data or digital data collection) and a digital system (tools for calculating health indexes). The implementation of the system through these 3 pillars has been spread over time and is based on the evolution of inspection strategy and the acquired experience over several years.
This implementation led to a great digitalization of processes and led to profound changes in habits among field staff. In order to bring about this change gradually, three steps were necessary:

- The first stage consisted in analyzing all the strengths and attention points of the condition assessment evolutions implemented over time. Based on this analysis, a new inspection strategy was put in place. To support it, it appeared that it was necessary to provide, to field agents, a document containing all degradations and standard forms in order to collect the information necessary for the analyses.
- To support the collect of right information, IT tools were developed. It was during this stage that Elia generalized the use of smartphones and UAVs for better digitalization of the collected data.
- Finally, a calculation tool has been developed to calculate the equivalent age and the health index of each asset. It is based on technical data stored in databases and information collected

digitally during conventional patrols. Then, based on the results obtained and set criteria, additional inspections can be launched. These detailed inspections increasingly involve the use of drones and artificial intelligence.

During implementation, but also in service, regular technical reviews were carried out in order:

- to check whether the inspections were carried out correctly, whether the new tools were correctly used and whether all the rules/documents issued were applied correctly;
- to check whether the implementation of drones with artificial intelligence made it possible to meet lots of the needs;
- to check whether the complete process was operational.

The obtained results, following the implementation of this new management to all overhead lines, are very satisfactory. The implementation has allowed a more fluid exchange of information, to have a centralized view of the state of the grid, allows to better target the preventive maintenance to be carried out and the places where the investments must take place. It also made possible to highlight that the development of VLOS and artificial intelligence were necessary to push resources optimization and digitalization further. Finally, a R&D program has started in order to improve the qualification of the type of corrosion by the use of hyperspectral cameras.

KEYWORDS

Asset Management, UAV, Inspection, Health Index, Digitalization

1 INTRODUCTION

The overhead lines inspections are a fundamental activity to know the condition of assets. They make it possible to detect equipment failures but also to plan preventive maintenance (painting for example). In the past, all the findings were recorded in paper or digital format at the service centers without centralization. They were used locally and in some cases were transmitted to the asset manager to take structural actions. This method has different disadvantages: the management of assets is local and can be different from a service center to another, no global overview about the health index of assets and the investment costs cannot be optimized.

With the integration of renewable energies, the decarbonisation of all activity sectors, the decentralisation of power generations, the appearance of new methods of detection, the increasing digitalization of information, etc. are leading to profound changes in the management of electricity grid. In addition to these societal challenges, there are other constraints such as the ageing of different infrastructures, the growing difficulty in obtaining building permits, the speed of information exchange via social networks, the limitation of financial resources, etc. In this situation, the previous philosophy to collect the information about the assets is obsolete.

Based on these challenges and opportunities, three years ago, Elia Transmission Belgium[1] reviewed the management of its overhead lines in order to be able to make the right investments, on the right time, with optimised costs and with an acceptable risk in the interest of the community by centralisation and structuring of technical information on the existing data base, by using of digital tools (UAV, etc.) and by introducing digital system (calculating of health index, etc.).

2 DEFINITION – NEEDED NOTION

AFS	Asset Fleet Strategy is a document which determines the strategy which is pursued for the correct management of overhead lines.
RA	Real Age of the asset.
RA-Color	Real Age Color is the color associated to the real Age.
TFL	Theoretical Fleet Lifetime is the theoretical expected lifetime (in years) for a specific fleet (lattice galvanized tower, lattice not galvanized tower, copper conductor, etc.). These TFL are defined in the Asset Fleet Strategy.
TCL	Theoretical Consumed Lifetime is a percentage defined by TCL = RA/TFL.
VS	Visual Score is the first level of data's representing the condition of the Assets.
VS-Color	Visual Score Color is the color associated to a Visual Score.
HI	Health Index of the asset.
Micro View	Detailed condition assessment of a group of assets in order to determine their Equivalent Age and refine the estimation on their End of Life
EA	Equivalent Age is a condition-based age and specific for each Asset independently and is based • only on VS-color and RA-color, so before any Micro View; • on the results of a Micro View.

3 EVOLUTION OF INSPECTIONS IN BELGIUM

Before embarking on the complete data integration process, it is worth remembering that this new process took several years to implement. It is based on the experience of the past, on the implementation of a database, on the appearance of a certain number of technical tools such as tablets, drones, etc. but also linked to socio-economic factors.

In the early 2000, Asset Management was carried out, every year, by accomplishing several inspections:

- legal inspection as defined in Belgian law, to detect non-compliance of installations with the law - General Regulation on Electrical Installation;
- inspection at the base of the supports, to detect damage on the supports and insulators;

[1] The Belgian Transmission System Operator Elia is accountable for the operation of overhead lines and underground cables between 30 kV and 380 kV

- inspection along the electrical spans, to detect damage on conductors and problems related to vegetation;
- helicopter inspection, to detect damage on conductors and problems at the head of supports.

All information collected was stored, in paper format, in different service centers. They then were taking the (local) decision to repair the installations or to requesting audit of the installation to estimate the condition, in case of recurring or serious problems. The audit was carried out by a centralized department. This working method has shown that:

- the problems observed on field were not interpreted in the same way between service centers: the wearing of the fixing points of fittings could lead either to a replacement of the fitting, or to a complete audit of the link (including foundations, towers, fittings and conductors' evaluations) with a study of the future of the link, for example.
- much of the time spent on the audit consisted of gathering all information and in some cases (misclassification of information) resulted in redoing inspections already carried out. By combining the time to obtain the line outage, this process leads to quite significant delays in obtaining the results.
- no (real-time) view was possible on the entire state of the network and therefore it was very difficult to have a multi-year view of investment and on maintenance budgets.

Following the analysis of these findings, it quickly became apparent that a first step was to create a technical database (with basic data) for overhead and underground links and to use it to monitor the inspections as explained above.

In 2015, a second step was taken. Faced with the aging of overhead lines, the growing need to carry out audits of overhead lines, different interpretations of findings, network development constraints and increasing pressure on financial resources, it was decided to centralize and structure all the technical information. It was at this time that we set up the Macro View process, which aims to constitute, for each link, a computer file (word document) which includes the main technical characteristics, the maintenance history and the possible audit results. Based on this information and a panel of experts, a consolidation is carried out and a health index is determined. It is essentially based on the theoretical end of life and age of equipment but also incident rate, logged malfunctions, repairs, replacements information and feedback from maintenance crew, etc.

Table 1: First ranking of health index

Code	Status	Description	Examples
Green	OK, no detected problems	No work to be planned, continue normal maintenance	"Recent equipment"
Orange	Acceptable with normal ageing and minor adaptations necessary	Minor adaptation (change some equipment, repair some foundations, …)	Ageing equipment
Red	NOK, major adaptations or replacements are needed	Full replacement of an electrical circuit, whole parts of a tower, …	Equipment reaching their theoretical End of Life
Black	NOK, immediate danger	This link must be replaced ASAP	Equipment past their theoretical End of Life. Degraded equipment due to local condition. Degraded equipment due to lack of maintenance

This centralization at the level of the Asset Management department guarantees standardization in the interpretation of degradations and indicates the links that require major interventions. However:

- the information collected is not always updated based on new inspections
- for some links all the information available is not sufficient to take decisions. In order to complete the missing information in these reports, a new process has been set up: Micro View inspections. It consists, based on the results of Macro View reports, of carrying out essentially by climbing inspections in order to identify structural damage and evaluate the associated risks with it.

However, if this action provides a better view of the condition of the asset, it quickly becomes apparent that other means will have to be implemented, this is the third step. For these reasons, a reflection on the OHL strategy has been carried out between 2017 and 2019. This reflection, mainly based on an analysis of the FMECA type (Failure Mode Effect and Criticality Analysis) on the different OHL components, lead to the implementation of a new strategy for asset management which made it possible

to consider the impact on resources, risks and costs but also to resolve the main problems discussed above.
It is reflected by:

- a complete reorganization of inspections:
  - legal inspection is maintained;
  - the inspections at the base of the supports and along the electrical spans are merged to create the Full Scan Patrol (concerns 25% of the network every year) and Quick Scan Patrol inspections (each year concerns the rest of the network, i.e. 75%);
  - a reduction in inspections carried out by helicopters and modification of the title by Periodic Air Inspection in order to allow the introduction of other means such as the drone for example;
- digitalization of the reporting of findings through an already existing tool (Malfunction Report) or through new tools allowing all data to be transferred in digital format;
- the introduction and active management of LiDAR to collect pruning needs, where relevant, and DLR systems (Ampacimon) for examples;
- the implementation of an algorithm making it possible to calculate, for each asset, a Health Index and an Equivalent Age in order to provide the possibility of following ("in real time") the evolution of asset aging.

Finally, following the evolution of Belgian legislation, the evolution of technological means, the development of Artificial Intelligence, the resource problems among entrepreneurs to carry out the large volume of inspection of the Micro Views type (detailed inspection by climbing inspection) and the difficulty to obtain outages of links, in 2019, a new step was taken: the introduction of the drone tool both in terms of inspections and the realization of Micro View inspections.

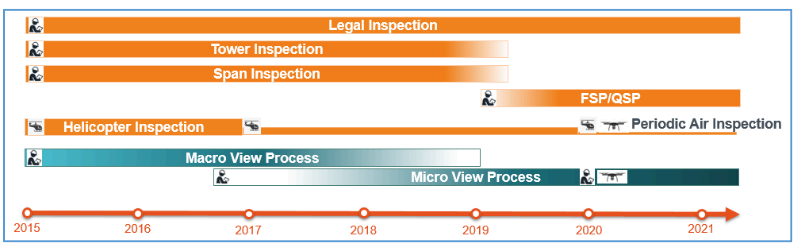

Figure 1 : Evolution of Belgian inspections

4 IMPLEMENTATION OF NEW STRATEGY

Based on the new strategy established between 2017 and 2019 [3], the condition assessment of all links in the Elia grid can be split into 5 stages as shown on Figure 2:

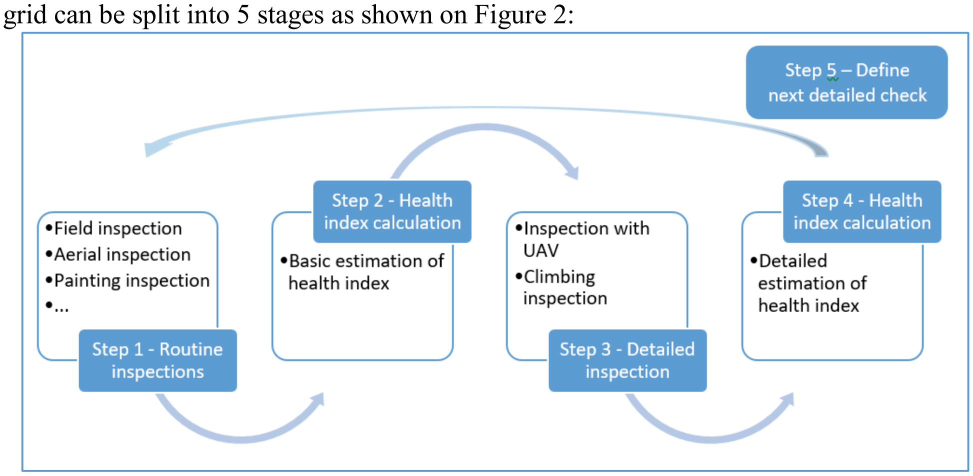

Figure 2 : Process for new strategy

4.1 Step 1 – Routine inspections

The first step is fundamental for the whole process to work. It consists of collecting two types of information:

- Abnormal degradation linked to the operation of the link such as broken insulators, broken strands, etc.
- Degradation which is more related to long-term aging processes, such as wearing of the fixing points of fittings, degradation of the paint on the supports, etc.

Depending on their classification, these degradations will be used to:

- define short-term actions for abnormal degradation;
- define health indexes, failure probability curves for each type of equipment and long-term actions.

This information gathering is carried out through all the inspections planned each year, namely [1]:

- Quick Scan Patrol (from the ground) which consists of rapidly inspecting 75% of the network every year and essentially identifying abnormal degradations;
- Full Scan Patrol (from the ground) which consists of, in addition to the abnormal degradation identification, thoroughly inspecting 25% of the network every year in order to collect detailed information on the condition of the asset;
- Periodic Air inspection, which consists of inspecting strategic lines and lines with difficult access by using helicopters or drones mainly in order to identify abnormal degradations;
- Paint inspection in order to evaluate the ageing of the protection system and the painting needs and to detect structural problems on the supports.

Today this collection of information is fully supported by various IT tools which are available on computer or via smartphones:

- A degradations Handbook [1] [2] is made available to agents. It is essential to follow the instructions that are provided in this document. In this way, the situation observed can be correctly transcribed in the analyses. It includes in particular:
    - The various degradations that can be observed on the assets.
    - The visual score that will be used to interpret the observed degradation. This allows to speak the same language wherever you are in the organization.
    - Whether the creation of a Malfunction Report (MR) is necessary and the intervention time.
    - The various documents that must be completed during the patrol in order to collect all information necessary to organize the repair. This makes it possible to avoid sending the agent back on site a second time → Efficiency gain.
- The Malfunction Report (MR) tool which allows degradation to be entered via smartphone directly into the IT tools on the related asset with appropriate classification for reporting purposes. It also allows the inspector to associate photos and any completed documents. Subsequently, these MR's will be used to determine the failure probability curves.
- The e-Forms tool, which allows the inspector to complete a checklist adapted to the asset and the type of inspection that is in progress (FSP or QSP). This checklist is made up of questions (linked to the degradation handbook) which are grouped by asset sub-part (head of the support, arm, etc.) and which will then be automatically used to determine the health index and the equivalent age.
- Different IT tools that support the new process so:
    - Dashboards to follow different indicators;
    - Excel files to introduce specific information after analyzes of Micro View results, for example.

4.2 Step 2 – Health index calculation (Basic)

The second step of the process consists of converting the results automatically through software:

- that will search for all the information stored in different places (database and inspection reports);
- that converts this data into Equivalent Age and Health index for each asset according to the methodology explained below;

- and which groups them by asset type and by line sections in order to give a view on the state of the network with an appropriate granularity level.

In order to determine the Equivalent Age and the Health Index of each asset, the following logic is applied:

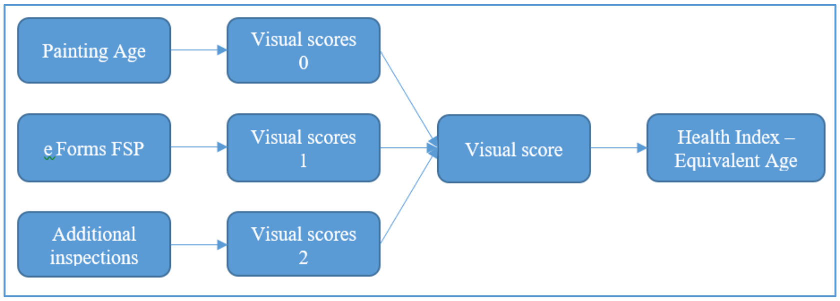

Figure 3: Process to determine Equivalent Age and Health Index of each asset

- For each inspection carried out, a certain number of Visual Scores are determined:
  - For the Painting Age, the visual score is determined by comparing the time since the last maintenance to a theoretical maintenance cycle (defined in the Asset Fleet Strategy for each fleet) broken down into different periods to which a color is associated

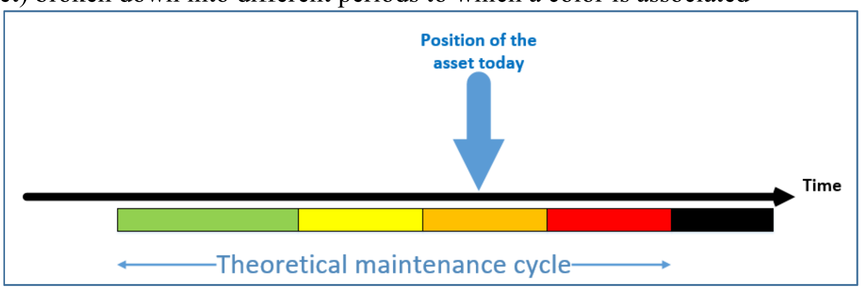

Figure 4: Visual score in link with maintenance cycle

  - For the other inspections, the visual score is obtained by combining
    - several visual scores defined in the handbook for the e-Forms FSP inspections;
    - via another analysis for the additional inspections

    through formulas: using operators such as maximum, average value, etc.

  The result of the visual score calculation is a color, always stored in a named variable: VS-Color x.
- The second step is, for each type of asset (Tower, concrete pole, hook, etc.), to convert this set of Visual Scores into one Visual Score (VS-Color with a lower bound ($L_{Lower\ VS\text{-}Color}$) and upper bound ($L_{Upper\ VS\text{-}Color}$)) which reflects the condition of the asset. This combination is carried out through pre-established rules based on the acquired experience.
- The third step consists of determining the Equivalent Age of asset based on the calculated VS-Color. To do it, a RA-Color is determined by comparing the Real Age of the asset to a Theoretical Fleet Lifetime (defined in the Asset Fleet Strategy for each fleet) broken down into different periods to which a color is associated

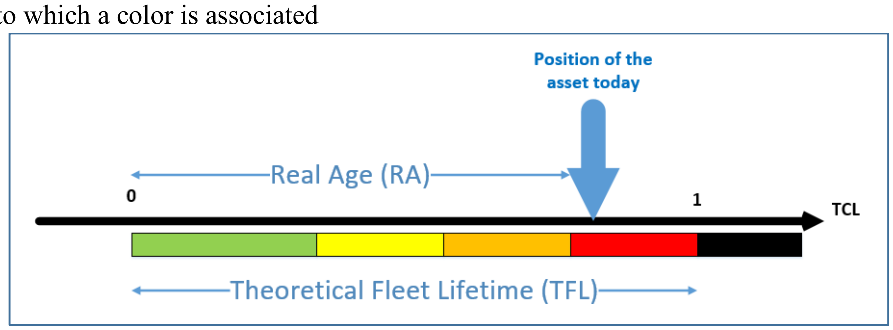

Figure 5: TCL in link with the TFL

The result of the Real Age calculation is a color, always stored in a named variable: RA-Color x. It is possible to calculate the Equivalent Age.

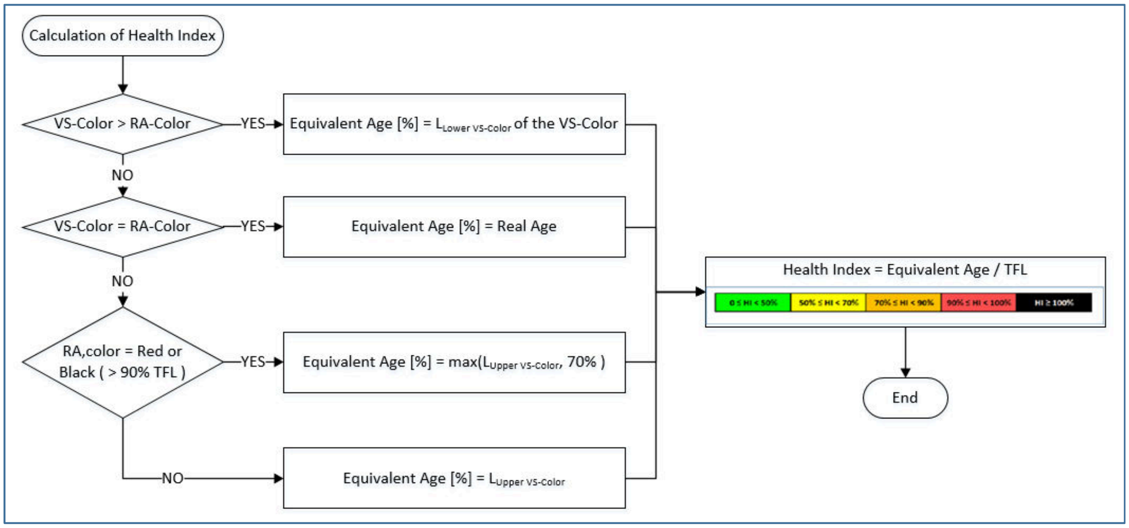

Figure 6 : Calculation of Health Index

Note: It is possible to group the results to give a more global view of the network elements with an appropriate granularity level (by asset type, by line section, etc.).

4.3 Step 3 – Detailed inspection

In order to anticipate the end of life of asset and to ensure that certain asset don't show an abnormal ageing process, a trigger has been placed in the program to take out all the asset that should undergo a detailed inspection in order to refine the estimate of Equivalent Age. This trigger can be different depending on the type of used material. Typically, it is found at a minimum of 80% of Theoretical Fleet Life.

Initially, these detailed inspections (looking only at structural damages) were performed while climbing into the towers. However, considering that:

- the volume of asset to be inspected is not negligible (in a first phase 1000 lattice towers in 3 years),
- obtaining the outages is increasingly difficult because of the integration of renewable energy and simultaneous project executions,
- resources are limited to carry out inspections (same resources as for investment projects),
- drone technology and artificial intelligence are available (with high accuracy) to carry out inspections of supports and equipment,

it was decided to realize

- initially, visual inspections by drones (line in service) in order to target the supports which would require a climbing inspection. This inspection corresponds to a representation of the structure with the location of all observable damages (structural and non-structural).
- then, and only for towers with significant structural degradation, to carry out climbing inspections (line out of service) in order to determine the effective losses of the steel cross-section.

4.4 Step 4 – Health index calculation

First, it is important to note that not all the information collected will be used to determine the Equivalent Age. Only structural damage will be considered. The other information will be used at a later stage during the implementation of actions plans.

Based on the location of structural defects, the severity of the degradation (surface rust, penetrating rust, perforating rust, etc.), the number of damages on tower, the type of used steel, etc. a conversion table is used, and it is possible to obtain a refined Equivalent Age.

Based on this refined Equivalent Ages, health indexes are refined and scenarios with their associated end of life will be defined (based on condition and reparability). Those results will be integrated in the long-term vision of the surrounding grid and a consolidation meeting with different departments will agree on an appropriate grid solution based on risks and financial optimization.

Several scenarios may arise:

- Either the line will be dismantled;
- Either the line will be restored to extend its life and/or satisfy with new needs;
- Either the line's condition allows to maintain it in state and put it under survey (Step 5).

4.5 Step 5 – Define next detailed check

If the approved grid solution does not result in the demolition or full replacement of the concerned assets on relatively short term, the asset manager will define the next expected detailed inspection period while routine inspections will continue to monitor the condition to fine-tune the action plans.

5 PRACTICAL EXAMPLE

This process has been implemented in different phases. At the end of 2020, an overhead line was selected to assess whether the entire process met the expectations and whether the issues discussed in Chapter 3 were under control.

5.1 Description of the overhead lines

Figure 7: Tower

The technical characteristics of the overhead lines are:

- Year of construction: 1923
- Voltage level: 70 kV
- Tower
    - Type of tower: Lattice tower
    - Type of steel: Not galvanized steel
    - Number of circuits: 2
    - Number of earth conductor: 1
    - Theoretical Fleet Lifetime: 100 years
    - Real Age: 97 years
    - Theoretical Consumed Life = 97 %
- Circuits conductors
    - Type of conductor: Copper
    - Section: 54 mm²
- Earth conductor
    - Type of conductor: Bronze
    - Section: 35 mm²

5.2 Application of new process

In 2019, the line considered was inspected according to an inspection of type Quick Scan Patrol which consists of completing light checklists and creating Malfunction Reports for all the observed degradations.

The next year, the line was inspected with an inspection of type Full Scan Patrol. Detailed checklists (linked to the condition of the asset) were completed using a smartphone as well as the Malfunction Reports of the degradations which require short-term intervention. The completed checklists were stored in the asset condition database (with a copy on pdf format on a server) and the information sent to the IT tool which determined the Visual Scores, Equivalent Age and Health Index based on the handbook and established rules.

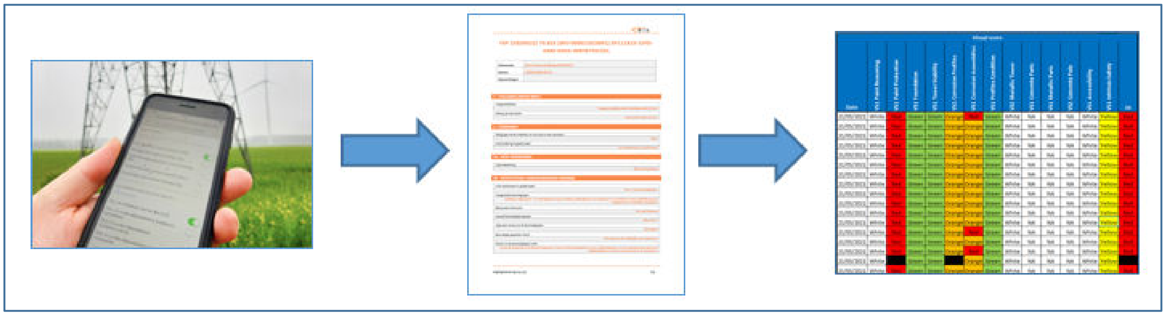

Figure 8: Steps 1 + 2 in the process

By analyzing the obtained table, we see:

- that there are problems with the painting of the supports (VS1 Paint Protection)
- that problems are detected in the level of corrosion of the profiles (VS1 Corrosion profiles) and the corrosion of the assemblies (VS1 Corrosion Assemblies).

The compilation of all this information led to a red health index for most towers, or even black for some of them (last column).

Considering that the line is older than 80% of the Theoretical Fleet Lifetime and that the signals indicated a degradation of profiles and assemblies (following in particular a first climbing inspection on a limited number of supports), it was decided to launch an inspection (on additional supports) by drone, followed by a climbing inspection in order:

- to confirm the condition
- to compare the obtained results by a climbing inspection with the obtained results by a drone inspection (the analysis of the drone pictures was made through an Artificial Intelligence).

Based on the obtained results, a recalculation of the equivalent age was carried out and a new estimation of the health index was carried out. From this calculation, it appeared that the equivalent age of most of the supports was between 95 and 99 years. Following these results, a grid analysis was carried out and it was decided to dismantle the concerned link.

5.3 Conclusions

In general, the application of the new inspections and the dynamic assets management give full satisfaction. However, some points for improvement have been detected and are the subject of the following lines:

- Step 1 – Routine inspections
  - The degradation survey process (Malfunction Report + Handbook) put in place allows for better knowledge of the condition of assets.
  - It is not possible to observe all the damage from the ground (limited viewing angle).
  - Through the approved handbook, the implementation of a color code reduces discussions around the severity of the degradations and finally on the consequence.
  - It is important to ensure the training of personnel by ensuring:
    - that agents understand the entire process and the impacts;
    - that the technical bases on inspections, detection of damage, etc. are present;
    - that the tools are known and correctly used;
    - to refresh knowledge.
- Step 2 + 4 – Health index calculation (Basic)
  - The process of transcribing the results between the FSP reports and the IT tool (that calculates the Equivalent Age and the Health Index) appears to be in order.
  - The process is relatively young, and it is necessary to analyze the results to ensure the accuracy on long term.
  - In order to improve the quality of Visual Scores, especially above safety limit plates, it will be necessary to study the possibility of using the collected data during other inspections, such as Periodic Air Inspection, Legal Inspection, etc.
- Step 3 – Detailed inspection

- Artificial Intelligence applied to the data collected by the drone gives +/- 6 to 7 times more degradation than the climbing inspection (logical given that during the climbing inspection we only look at structural problems). This gives a better view of all the degradations.
- The location of the data on the silhouettes is good from silhouettes provided by Elia. In order to take into account the modifications made during the life of the asset and to increase the precision, it was requested to reconstruct them via the Artificial Intelligence. The accuracy of localization is above 80 %.
- An attention point is the classification of corrosion when analyzing degradation through artificial intelligence. In fact, when we do a climbing inspection, the rust is stripped in order to measure the remaining thickness of steel. This operation cannot take place with a drone. It follows that for the same defect, the drone underestimates the severity as shown in the figure.

Figure 9: Same damage seen by drone (Left picture) and by climbing inspection after striping (Right picture)

6 NEXT STEPS

- Elia will review its overhead lines inspection strategy in order to make more efficient use of all the data collected during inspections (helicopter inspection, legal inspection, etc.).
- The use of drones is confirmed and the improvement of artificial intelligence for a better classification of degradations will be continued. The next month's/years the BVLOS (= Beyond the Visual Line Of Sight) drone inspection program will be developed to reinforce remote maintenance on OHL Assets.
- The dimension of sustainability will be further developed in order to integrate and/or objectify this dimension in our daily analysis.
- Elia will continue to:
  - implement new applications (e.g. LiDAR) for vegetation management in order to improve the process to translate inspections results to pruning works. This is an enabler to evolve from time based to risk-based maintenance for vegetation management.
  - investigate new R&D techniques in order to assess their possibilities: new monitoring techniques for OHL assets (hyperspectral cameras, vibration monitoring on OHL towers etc.), DLR on HTLS conductors, use of satellite images to investigate changes in the environment of the OHL assets….
  - implement digital tools, artificial intelligence and machine learning to move from condition-based management to risk-based management

7 CONCLUSIONS

The implementation of a new strategy for overhead lines management leads to the introduction of dynamic asset management. This management has made it possible to build a both global and detailed view of the condition of the assets on the network and to determine the most efficient inspection program considering costs, resources, risk and outage time.

During the change program, it became apparent that, in order to support this strategy, it is necessary to digitize the information in the inspection process. This implementation of the new strategy, developed by the Asset Manager in close collaboration with the field agents, is a significant change process.

This digitization was based on several initiatives: implementation of new checklists using smartphones, the publication of guidelines, the organization of trainings to record and evaluate degradations, the actively use of new applications (LiDAR, drone, etc.) and the development of artificial intelligence to transfer datasets to relevant information about the condition of the asset.

The entire process leads to an efficient decision-making process to launch short term actions (reparations…) and long term strategies (End of Life management…). After the implementation process of different new initiatives, REX (= Return of Experience) exercises with different departments to evaluate the results, process and tools, were organized to adjust were necessary. In general, Elia is very satisfied with the overall process and the new strategy for overhead lines.

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