ATTEST

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WP5

Development of a smart environment for asset management in power grids

Tool for the definition of smart asset management strategies

D5.4

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Abbreviations and Acronyms

DSO	Distribution System Operator
TSO	Transmission System Operator
S.A.M.T.	Smart Asset Management Tool

1. INTRODUCTION

The main objective of WP5 is to develop a set of tools for smart asset management supported by a set of condition indicators related to the condition and operation of critical assets in a power grid. This Tool develops an innovative concept of explorations of the actions to take from an asset management perspective. This will assist in the area of the TSO and DSO asset management. Previously, two tools were developed: the Tool for the characterization of the assets condition and the Tool for defining condition indicators based on heterogeneous information sources. More information about these tools can be found respectively on deliverables D5.2 and D5.3. They offer information to the user about the current state of the assets from two perspectives. The first perspective is more focused on the different variables that define the dimensions of the assets which were analyzed (life assessment, maintenance, and economic impact), and the other one is based on indicators that represent, using a unique number, the different characteristics observed in the dimensions which are defined by their variables.

This deliverable describes the User Manual of the third Tool of Work Package 5. It uses the results obtained from the previous tools as inputs to generate suggestions for concrete actions which are optimized according to the observed indicators and the asset management strategy.

2. Tool for the definition of smart asset management strategies.

2.1. SCOPE

This Tool aims to suggest the actions to perform on the assets of a power grid according to their condition evaluated in the previous tools developed in this work package. These suggestions are based on a reinforcement learning algorithm that gives the user flexibility when the asset management strategy has to be modified without changes in the Tool. Also, the actions suggested can be based on the current conditions of the assets, but also, the Tool allows for analyzing future scenarios in the condition of the asset that could modify the actions suggested.

2.2. METHODOLOGY

This section describes the methodology followed for developing this Tool, whose main objective is to suggest actions to be performed according to the condition observed on the assets under study.

The Tool will start from the analysis developed in Tool 5.2. which gives the user information about the current situation of the asset that was selected. In the context of the Tool 5.3 this analysis is called "*REFERENCE SCENARIO*". Tool 5.3 offers two options of analysis:

- Option 1. Use of the *Reference Scenario* for suggesting actions for asset management (short-term perspective of analysis)
- Option 2. Use of the *Reference Scenario* and its possible future scenarios for suggesting actions for asset management (long-term perspective of analysis)

The following diagram shows the main elements of the methodology followed for the first option.

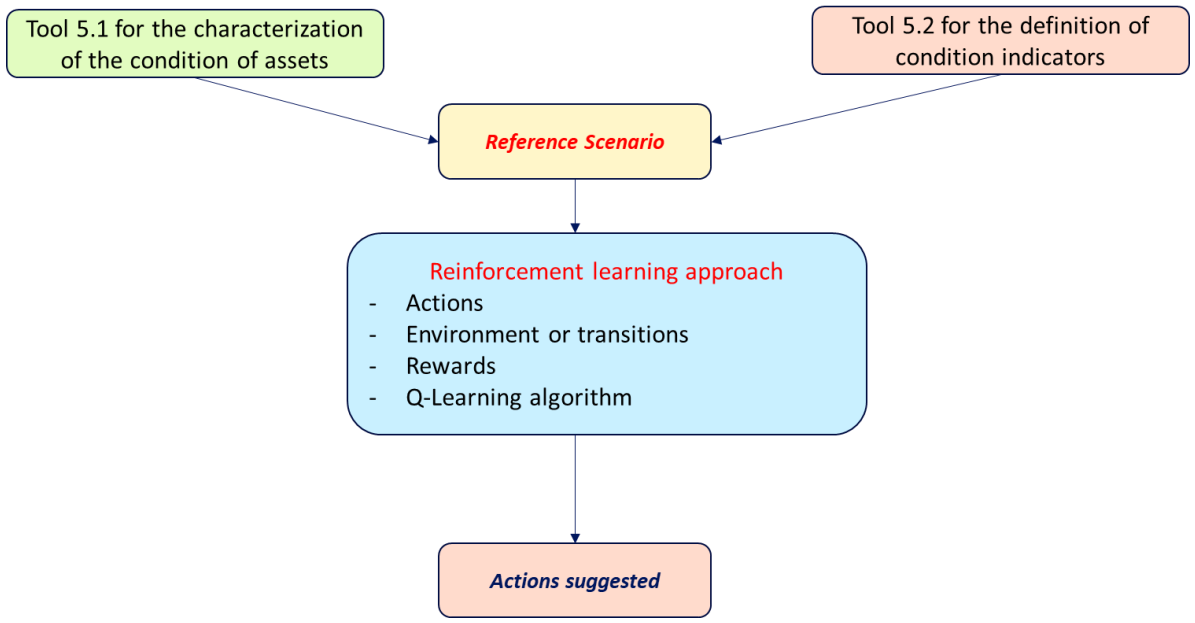


FIGURE 1 ELEMENTS OF THE METHODOLOGY USED IN OPTION 1

Once the analysis of the set of interesting assets for the user is finished, it configures the reference scenario that Tool 5.3 uses as the starting point. The values of the indicators are converted into labels

according to the following criterion. Label L (Low) covers the interval of values [0, 0.25], label M (Medium) covers the interval (0.25, 0.5], and label H (High) covers the interval (0.5, 1]. The number of labels and/or their ranges can be changed if desired.

The reference scenario consists of 1 to 4 dimensions, and each asset has an indicator defined for each dimension and thus, there is a label for each indicator. The Tool has been developed having in mind a basic reference scenario with three dimensions (life assessment, maintenance strategy, and economic impact), where each asset has three labels.

The next step is to select the action according to the labels of the asset. The selection of the action is obtained from a Q-matrix resulting from a previous execution of a reinforcement learning algorithm (Q-learning) which will be described later. The Q-matrix is made up of all the possible combinations of three labels placed in its rows, and suggested actions in its columns. In the intersection of each row and column, there is a numeric value called Q-value. The action selected will be the one with the highest Q value in a row.

The methodology of option 2 is similar but extends to future scenarios. There are six separate scenarios, each spanning five years. These scenarios are created from the reference scenario using a Montecarlo parameter selection method. Configuration files that allow for the definition of the interval of values of some variables are used by the Montecarlo method. Once the scenarios are created, each one is treated as indicated for the reference scenario. The next figure shows the elements and flow of information of this second option of the methodology.

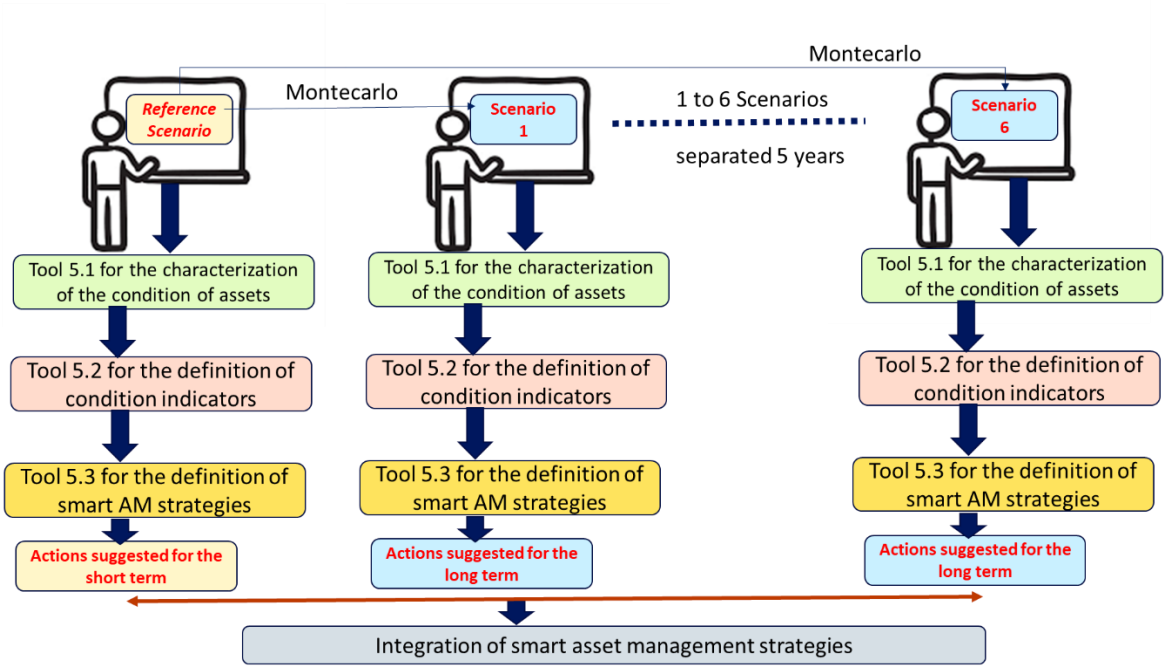


FIGURE 2. ELEMENTS OF THE METHODOLOGY USED IN OPTION 2

Once the suggested actions are collected from running the future and reference scenarios, they are combined using a majority vote criteria in a unique suggestion.

2.3 Notes about reinforcement learning

Reinforcement Learning (RL) is a machine learning technique that enables an agent to learn in an interactive environment by trial and error using feedback from its own actions and experiences.

According to [1], reinforcement learning is learning what to do —how to map situations to actions— so as to maximize a numerical reward signal. The learner is not told which actions to take but must discover which ones yield the most reward by trying them. In the most exciting and challenging cases, actions may affect not only the immediate reward but also the next situation and, because of this, all subsequent rewards. These two characteristics—trial-and-error search and delayed reward—are the two most important distinguishing features of reinforcement learning.

The fundamental elements that configure an RL problem are:

- Environment — Physical world in which an agent operates
- State — Current situation of the agent
- Reward — Feedback from the environment
- Policy — Method to map agent's state to actions
- Value — Future reward that an agent would receive by taking action in a particular state
- Goal — Objective desired

The figure below illustrates the action-reward feedback loop of a generic RL model.

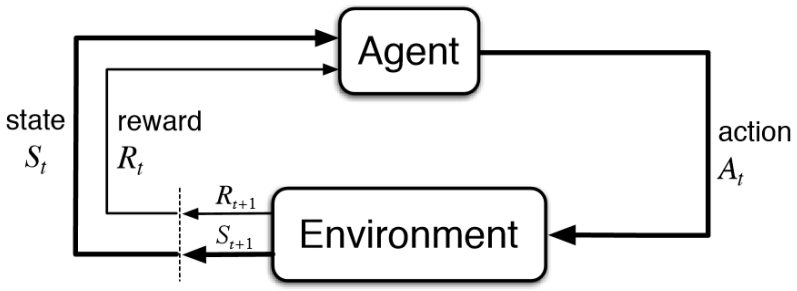


FIGURE 3. BASIC ELEMENTS OF REINFORCEMENT LEARNING

An agent is in an environment and in a state in reference time t (S_t). The agent can perform an action in the environment (A_t), and as a consequence of this, the state changes to $S_{t+1,}$ and at the same time, a reward is obtained R_{t+1}. This reward could be positive or negative. Negative means the effect is not desired, and positive means the effect is desired. The agent wants to get the highest possible value of cumulative rewards, and it will try to prevent actions causing a negative reward (penalization). In essence, positive values guide the agent through actions that can contribute to reaching the Goal, and negative values deviate the agent from the way to reach the Goal.

One of the main advantages of this method is that it does not require historical information for learning, in contrast to other machine learning approaches. In the context of the ATTEST project and the Tool to be developed, reinforcement learning has been considered as an appropriate method to associate the condition of the assets with actions to be taken. Also, the algorithm is estimated to be very flexible to

easily adapt of new asset management strategies. The alternative to the use of RL could be the association of rules previously defined connecting conditions of the assets and actions, but any modification in the strategy of the company should involve a rewriting of these rules.

There are a lot of different ways/algorithms to implement the ideas of reinforcement learning in the machine learning area. However, in this Tool, one of the more straightforward and popular algorithms was selected: the ***Q-learning*** algorithm.

Q-learning is a model-free reinforcement learning algorithm used to learn the value of an action in a particular state. It does not require a model of the environment (hence "model-free"), and it can handle problems with stochastic transitions and rewards without requiring adaptations. Q-learning seeks to find the best action to take, given the current state. It is considered off-policy because the q-learning function learns from actions that are outside the current policy, such as taking random actions, and therefore a policy is not needed. More specifically, Q-learning seeks to learn a policy that maximizes the total reward. These principles fit well with the objectives found by the Tool.

Q-learning is a very popular algorithm, and detailed information about it can be found in many scientific publications, for example, in reference [1].

The Q-learning algorithm has been implemented through following steps:

- Definition of possible actions to do in the assets from an asset management point of view
- Valid transitions from a state of the asset (condition) to other states (or conditions)
- Definition of rewards guiding the process of learning
- Definition of the Goal to reach

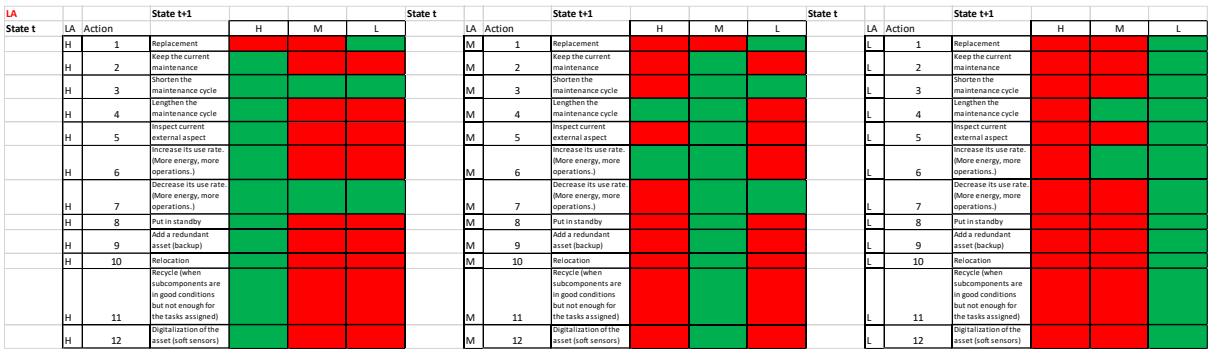
According to these definitions, at reference time **t,** the asset can assume one of the states L, M or H for each dimension. All combinations of these labels are possible. In total, there are 27 possible states.

The list of actions used in the Tool is the following:

1. Replacement
2. Keep the current maintenance
3. Advance maintenance. This means shortening the current maintenance cycle
4. Delay Maintenance. This means delaying the current maintenance cycle
5. Inspect current external aspect. Qualify the external aspect of the asset
6. Increase its use rate (More energy, more operations). The increase or decrease of use depends on network conditions. However, this can mean that this asset is too overloaded or not
7. Decrease its use rate (Less energy, fewer operations)
8. Put on standby. This is not a typical action, but it could an option in some cases.
9. Add a redundant asset (backup). This is not a typical action, but it could exist
10. Relocation. Change location. This is done often to subject aging assets to reduce stress in order to prolong their lifetime.
11. Recycle (when subcomponents are in good condition but not good enough for the tasks assigned) Dismounting the asset and reusing it
12. Digitalization of the asset (soft sensors) Addition of sensors for measuring some observable characteristic is not very often
13. Revitalization A large-scale maintenance operation in an attempt to prolong the lifetime of the asset.

The Goal defined is to reach level L in all the dimensions but other subgoals near this are permitted.

The transitions allowed are defined for all the dimensions and all the states. An example of this type of definition for the life assessment dimension is given by Figure 4.



LA			State t+1				State t				State t+1				State t			State t+1			
State t	LA	Action		H	M	L		LA	Action		H	M	L			LA	Action		H	M	L
	H	1	Replacement					M	1	Replacement						L	1	Replacement			
	H	2	Keep the current maintenance					M	2	Keep the current maintenance						L	2	Keep the current maintenance			
	H	3	Shorten the maintenance cycle					M	3	Shorten the maintenance cycle						L	3	Shorten the maintenance cycle			
	H	4	Lengthen the maintenance cycle					M	4	Lengthen the maintenance cycle						L	4	Lengthen the maintenance cycle			
	H	5	Inspect current external aspect					M	5	Inspect current external aspect						L	5	Inspect current external aspect			
	H	6	Increase its use rate. (More energy, more operations.)					M	6	Increase its use rate. (More energy, more operations.)						L	6	Increase its use rate. (More energy, more operations.)			
	H	7	Decrease its use rate. (More energy, more operations.)					M	7	Decrease its use rate. (More energy, more operations.)						L	7	Decrease its use rate. (More energy, more operations.)			
	H	8	Put in standby					M	8	Put in standby						L	8	Put in standby			
	H	9	Add a redundant asset (backup)					M	9	Add a redundant asset (backup)						L	9	Add a redundant asset (backup)			
	H	10	Relocation					M	10	Relocation						L	10	Relocation			
	H	11	Recycle (when subcomponents are in good conditions but not enough for the tasks assigned)					M	11	Recycle (when subcomponents are in good conditions but not enough for the tasks assigned)						L	11	Recycle (when subcomponents are in good conditions but not enough for the tasks assigned)			
	H	12	Digitalization of the asset (soft sensors)					M	12	Digitalization of the asset (soft sensors)						L	12	Digitalization of the asset (soft sensors)			

FIGURE 4. EXAMPLE OF TRANSITIONS BETWEEN STATES IN T AND T+1

The green color is used for permitted transition from a State in t to another state in t+1. Red is used for forbidden transitions.

Detailed information about the transitions used can be found in the excel file called: "Q_learning_approach" which is part of the software that are delivered with this Tool.

Finally, the rewards were defined using values between -1000 for hard penalization and 1000 for the maximum reward given. The values can also be found in the file called: "Q_learning_approach".

After training, the Q.matrix is used in Tool 5.3 for suggestion of actions according to the condition of the assets.

An example of Q- matrix is shown in Figure 5.

Q_TABLE				Replacement	Keep the current maintenance	Shorten the maintenance cycle	Lengthen the maintenance cycle	Inspect current external aspect	Increase its use rate. (More energy, more operations.)	Decrease its use rate. (More energy, more operations.)	Put in standby	Add a redundant asset (backup)	Relocation	Recycle (when subcomponents are in good conditions but not enough for the tasks assigned)	Digitalization of the asset (soft sensors)
States	LA	MS	EI	1	2	3	4	5	6	7	8	9	10	11	12
	H	H	H	2022,44	-6,78	59,42	-13,90	5,95	-29,47	33,83	-4,19	9,38	-7,76	-25,18	-14,21
	H	H	M	1700,15	-41,89	129,18	-51,94	-19,98	-33,04	84,14	-20,11	-4,46	-32,29	-38,32	-49,44
	H	H	L	1691,11	-16,76	35,43	-15,80	-29,82	-20,86	4,93	-12,46	-35,44	-16,84	-23,53	-17,71
	H	M	H	2017,14	-19,09	76,75	-29,04	-5,67	-28,45	29,66	-7,90	-26,71	-12,69	-28,71	-12,97
	H	M	M	1704,32	-27,24	49,03	-5,12	-39,53	-32,87	138,93	-39,73	-33,37	-14,19	4,53	-27,13
	H	M	L	1662,99	-19,48	-16,32	-9,15	-43,86	-40,31	27,08	-20,19	-43,96	-46,38	-36,23	-39,30
	H	L	H	1997,37	-2,31	95,25	-27,03	-1,16	-27,56	66,52	-35,78	-6,43	-10,76	-3,54	-15,49
	H	L	M	1657,99	-26,85	105,69	-23,33	-16,92	-58,75	34,48	-29,43	-35,87	-14,69	-16,77	-37,53
	H	L	L	1652,69	-9,03	46,98	-41,88	-33,37	-20,12	116,50	-25,83	-20,86	-11,06	-8,86	-12,38
	M	H	H	1920,39	66,00	44,24	33,60	153,28	21,16	139,14	118,13	91,65	89,49	132,48	80,21
	M	H	M	114,40	108,30	205,77	68,74	78,21	35,41	104,62	1855,06	82,66	160,42	99,34	62,87
	M	H	L	61,69	122,59	83,64	-6,28	97,81	42,07	98,69	151,44	21,80	113,48	57,72	1797,71
	M	M	H	121,93	106,07	38,33	69,54	1508,75	19,57	86,52	110,32	110,76	107,03	68,26	62,13
	M	M	M	129,41	27,23	158,49	36,50	163,55	41,85	73,27	55,67	51,66	123,70	165,32	1766,68
	M	M	L	110,15	132,74	105,91	32,39	126,17	49,43	66,89	88,78	65,85	1844,16	48,38	104,91
	M	L	H	142,01	50,85	1854,95	42,31	72,10	25,14	138,05	174,48	40,87	151,71	44,76	77,80
	M	L	M	25,39	92,00	132,51	31,68	77,58	81,43	2018,74	50,90	105,15	138,98	134,63	84,46
	M	L	L	115,25	2402,36	192,30	67,17	90,47	59,33	113,10	136,29	147,11	254,11	125,76	175,25
	L	H	H	182,78	1444,76	80,06	9,06	63,68	46,10	93,57	91,12	75,52	66,54	111,14	93,24
	L	H	M	46,86	1784,08	57,23	70,71	76,76	17,26	149,10	55,09	60,81	102,87	45,85	84,27
	L	H	L	135,98	1849,74	13,51	29,29	47,90	19,91	127,49	30,51	74,50	68,74	56,05	67,87
	L	M	H	109,58	1761,86	48,66	60,10	61,22	1,19	79,98	88,98	71,69	57,00	119,61	138,28
	L	M	M	9,70	1784,38	56,24	65,33	61,11	72,95	208,80	58,71	99,18	66,15	104,54	41,47
	L	M	L	60,75	1879,63	67,72	35,24	110,57	32,39	83,87	56,02	148,72	76,64	107,00	113,00
	L	L	H	129,13	1801,79	117,81	29,59	122,41	37,77	53,04	69,08	115,02	63,64	110,36	83,26
	L	L	M	41,57	1721,02	43,64	41,95	47,28	10,84	147,24	86,18	45,14	41,81	148,67	34,45
	L	L	L	62,75	2179,64	118,30	16,80	120,10	13,21	159,97	130,26	58,97	126,67	55,80	92,54

FIGURE 5. EXAMPLE OF Q-MATRIX RESULTING FROM THE LEARNING PROCESS

3. The primary interface of the Tool

This section describes the main interface of Tool 5.3 presented to the user when it is started, see Figure 6. This interface contains the two main options of analysis of this Tool. If the user is only interested in the actions suggested for the current conditions of the assets (*reference scenario*), the button "*Run Action Tools*" has to be clicked. After that, an auxiliary window, see Figure 7, is presented to introduce the path to the file where the reference scenario is located.

If the user wants to run the option "*Run Action Tools*"(9) with **multiple future scenarios**, files for futures scenarios must first be created. After that, the actions suggested are generated following the same procedure described for the *reference scenario*. In the interface shown in Figure 6, a configuration file name is required as input that can be selected and loaded using the button "*Load File*"(1). This file contains the configuration of the data indicators from the Tool related to deliverable D5.3. The Montecarlo procedure also needs another configuration file that is included within the source. This file contains the main parameters for the generation of the future scenarios. The present version of the Tool uses the file named "ConfigurationFile.csv," and the user can modify it in order to adjust the way future scenarios are obtained. In the interface shown in Figure 6, the user can select the Scenario number to be generated 5, 10, 15, 20, 25, and 30 years after the reference scenario and the type of assets to include in the analysis. By default, all the assets are considered. The process for generating future scenarios is described in the next section.

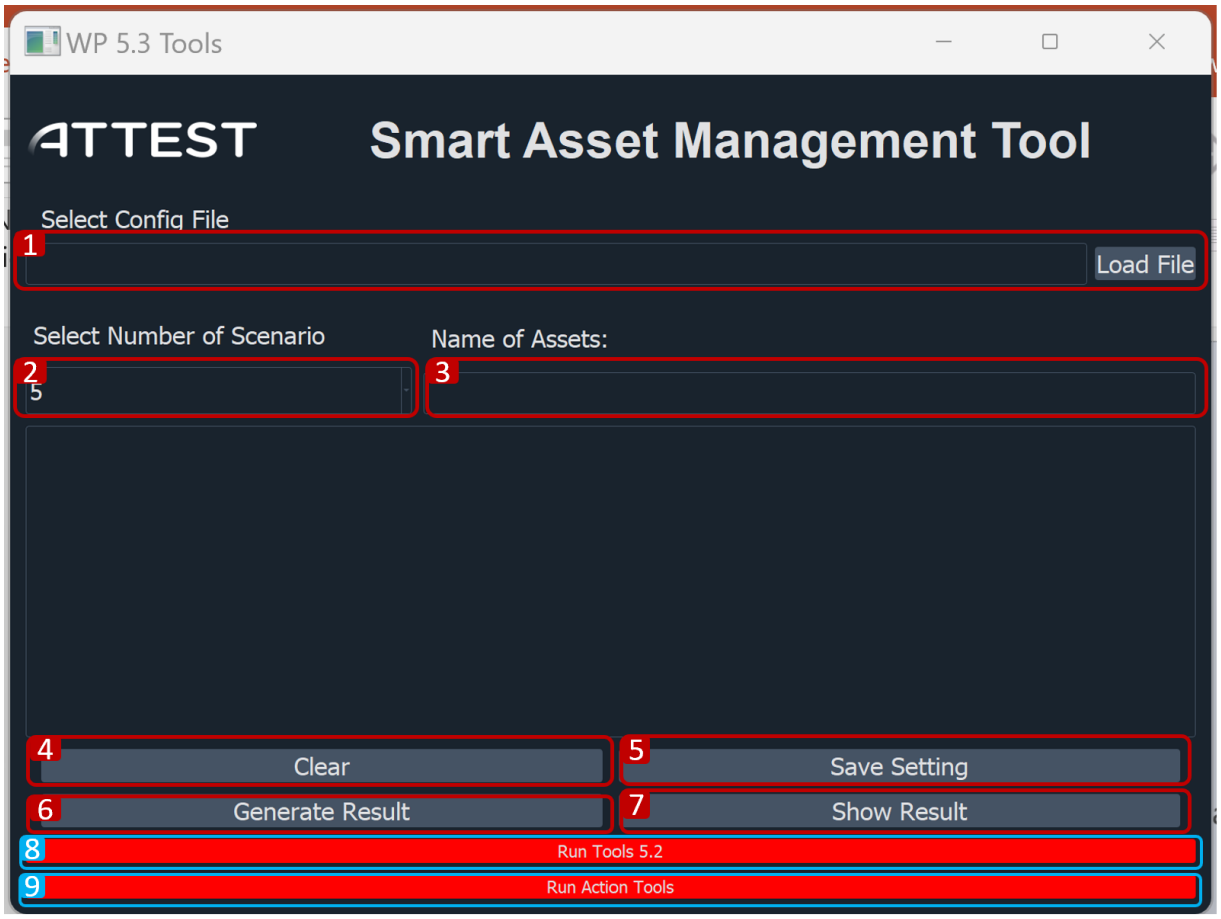


FIGURE 6. MAIN WINDOW OF TOOL 5.3

The bottom part of Figure 6 presents the actions that the user can take after the previous information has been filled out. There are four buttons available:

- Clear - This option clears the selection done
- Save Setting - This option saves the selection done
- Generate results - This starts the process that generates the results with the configuration selected.
- Show results - This starts the local server and shows the corresponding dashboards.

Once the scenarios have been generated, the user must click the button "*Run Tools 5.2*" and after this is done, the user must click the button "*Run Action Tools*" and the suggested actions will be generated for this future scenario. When all the future scenarios have been generated and their corresponding actions issued, the user must click on the button "*generate results*" in order to integrate all the actions suggested for each asset and each future scenario in a unique suggestion of action to take that will result from a strategy of majority vote of the options available for the asset in each considered future scenario.

To generate and display the results over one scenario using the Tool displayed in Figure 7, the next steps have to be followed:

1. Click the "*Load File (1)*" button and select the .csv file that contains the asset indicators generated from tool 5.2.
2. Click the "*Generate Result (4)*" button to make the .html document that shows the actions suggested by the Tool for each asset.
3. Click the "*Show Result (5)*" button to open the .html file on the browser.

The same process, but for many scenarios, can be done by selecting a folder with all the .csv instead of only one file in step 1.

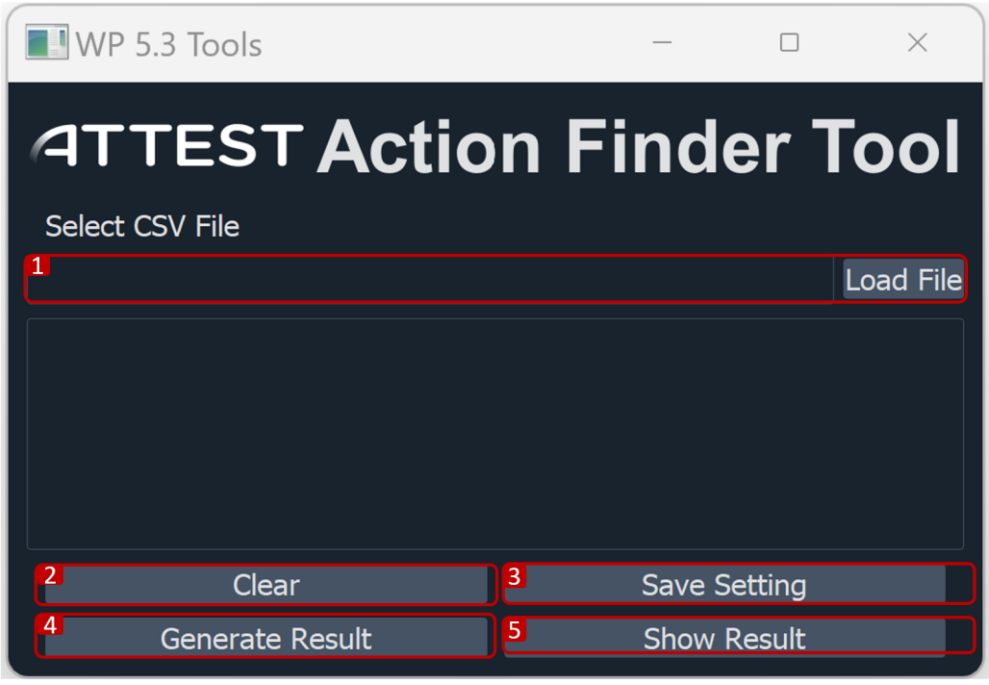


FIGURE 7. AUXILIARY WINDOW OF TOOL 5.3

4. Generation of future scenarios

Future scenarios are built using the ***reference scenario*** as the basis of their creation. The ***Reference scenario*** is the most updated real information available for the variables that describe the dimensions of the assets. The variables and dimensions are defined and described in detail in deliverable D5.1 of the ATTEST project.

The generation of future scenarios uses the values of some variables used in the reference scenario for obtaining new values expected in the future according to a predefined law of change. The file "ConfigurationFile.csv" includes a set of names of variables that can be estimated in the future. Each variable includes an interval of possible values and a law of change expected. A Montecarlo method [2] is used for the final obtention of the values of these variables.

ConfigurationFile: This file contains 3 columns Varibles, Function and Factor.

- Varibles: This columns include asset of name of variables that can be estimated in the future.
- Function: this column contains a law of change expected method for example this menthod can be linear, exponentioinal or incremental.
- Factor: This column contains the values by which a variable value is changing. For Example, A Cost_failure is changing linearly by factor 1.1.

	A	B	C
1	variables	function	factor
2	cost_failur	linear	1.1
3	cost_failur	linear	1.06
4	customers	linear	1.3
5	external_c	linear	1.15
6	H1_ Cost_	linear	1.1
7	H1_ Trans	linear	1.2
8	H1_age_y	increment	5
9	H1_Client	linear	1.03
10	H1_fail_pr	exponenti	-0.04
11	H2_ Cost_	linear	1.06
12	H2_ Custo	linear	1.3
13	H2_critica	linear	1.05
14	H2_ENS_ir	linear	1.04

The future scenarios are created with a separation of five years, six being the maximum number of future scenarios that can be generated.

The data generation for a future scenario is saved on a "*.csv" file, and it has a similar format to that used as an input for tool 5.2 described in the deliverable D5.3. The file's name is the same as the one used for the reference scenario, but adding at the end of the name the qualification "_5", "_10", and so on, indicating the number of years passed after the reference scenario. Figure 8 shows an example of data generated from the reference scenario.

	A	B	C
1	name	cost_failure	value_lost_load
2	1KV13/1	15174	7535612.25
3	1KV13/2	15174	7535612.25
4	1KV13/3	15174	27579461.45
5	1KV13/4	15174	27579461.45
6	1KV17/1	34083	3181593.1
7	1KV17/10	34083	27579461.45
8	1KV17/11	34083	27579461.45
9	1KV17/12	34083	27579461.45
10	1KV17/2	34083	3181593.1
11	1KV17/3	34083	3181593.1
12	1KV17/4	34083	3181593.1
13	1KV17/4	34083	3181593.1
14	1KV17/5	34083	3181593.1
15	1KV17/6	34083	7535612.25

Ref scenario

	A	B	C	D
1	name	H1_ Cost of failure [€	H3_ Value of Lost Load (VOLL)	
2	1KV13/1	16084.44	7610968.373	
3	1KV13/2	16084.44	7610968.373	
4	1KV13/3	16084.44	27855256.06	
5	1KV13/4	16084.44	27855256.06	
6	1KV17/1	36127.98	3213409.031	
7	1KV17/10	36127.98	27855256.06	
8	1KV17/11	36127.98	27855256.06	
9	1KV17/12	36127.98	27855256.06	
10	1KV17/2	36127.98	3213409.031	
11	1KV17/3	36127.98	3213409.031	
12	1KV17/4	36127.98	3213409.031	
13	1KV17/4	36127.98	3213409.031	
14	1KV17/5	36127.98	3213409.031	
15	1KV17/6	36127.98	7610968.373	

Future scenario

FIGURE 8. EXAMPLE OF DATA USED FOR THE REFERENCE SCENARIO AND A 5-YEAR FUTURE SCENARIO

Once each new future scenario and its corresponding "*.csv" file is generated, Tool 5.2 is run in order to obtain the condition indicators for each dimension under which the assets are considered. For example, it is possible to obtain the condition indicators for the reference scenario and the next 5 and 10 years after the reference scenario, as shown in Figure 9. Also, all the functionality described in the deliverable D5.3 for Tool 5.2 is available here for any future scenario, as shown in Figure 10.

Ref scenario

NAME	ECONOMIC IMPACT	LIFE ASSESSMENT	MAINTENANCE STRATGY	TOTAL_INDICATOR
1KV3/10	1.0	0.895	1.0	0.965
1KV3/4	1.0	0.874	1.0	0.958
1KV3/2	1.0	0.86	1.0	0.953
1KV17/10	0.899	0.971	0.798	0.889
1KV3/1	1.0	0.991	0.6	0.864
1KV17/12	0.899	0.89	0.798	0.862
1KV3/17	1.0	0.946	0.6	0.849
1KV17/9	0.899	0.833	0.798	0.843
1KV3/8	1.0	0.905		

Future scenario 5 year

NAME	ECONOMIC IMPACT	LIFE ASSESSMENT	MAINTENANCE STRATGY	TOTAL_INDICATOR
1KV3/10	0.988	0.886	0.989	0.955
1KV3/4	0.992	0.871	0.994	0.952
1KV3/2	0.996	0.851	0.988	0.945
1KV17/10	0.885	0.967	0.794	0.882
1KV3/1	0.984	0.985	0.608	0.859
1KV17/12	0.882	0.887	0.79	0.853
1KV3/17	0.987	0.935	0.595	0.839
			0.789	0.836

NAME	ECONOMIC IMPACT	LIFE ASSESSMENT	MAINTENANCE STRATGY	TOTAL_INDICATOR
1KV3/10	0.99	0.891	0.977	0.953
1KV3/2	0.988	0.881	0.979	0.949
1KV3/4	0.986	0.868	0.973	0.942
1KV17/10	0.89	0.979	0.784	0.884
1KV3/1	0.992	0.968	0.598	0.852
1KV3/17	0.99	0.941	0.613	0.848
1KV17/12	0.881	0.874	0.784	0.846
1KV17/9	0.888	0.825	0.79	0.834

Future scenario 10 year

FIGURE 9. EXAMPLES OF CONDITION INDICATORS FOR DIFFERENT SCENARIOS

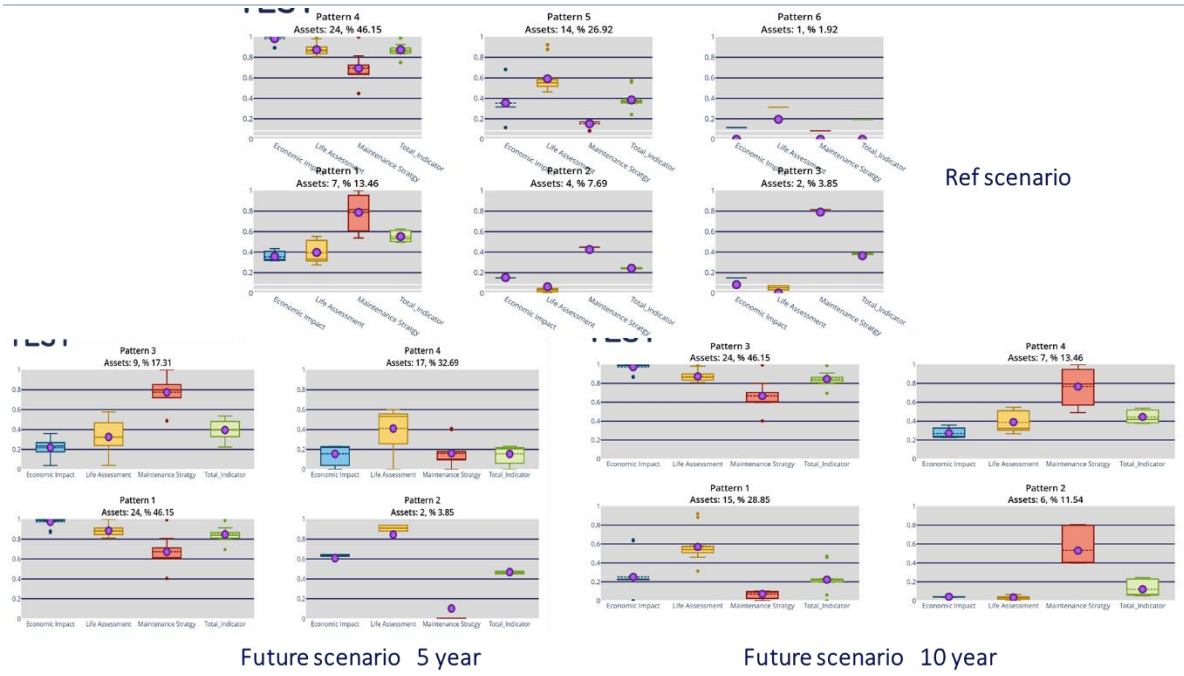


FIGURE 10. EXAMPLES OF RESULTS OBTAINED ACCORDING TO THE FUNCTIONALITY OF TOOL 5.2

5. Results of the Tool

The main idea behind Tool 5.3 is to contribute to the answer to this question: *What are the best decisions that have to be taken now to keep the value of the current assets(Total Indictor obtained from tool 5.2)?*

At this point, Tool 5.3 receives the results from tool 5.2 (values of condition indicators) and for each asset it proposes the best action to take according to the catalog of actions available.

Each asset in the study selected has values for the condition indicators of the dimensions under it. The numerical values of these indicators are converted into three labels corresponding to low (L), medium (M), or high (H) values. The thresholds used for this conversion are the following:

- L for values in the interval [0, 0.25)
- M for values in the interval [0.25, 0.5)
- H for values in the interval [0.5, 1]

The thresholds and number of labels can be easily modified in the “class ActionFinder” in the code “ActionFinderModule.py” inside the “src/” folder.

Once the condition indicators are converted into labels, the code of a row of the Q-matrix is obtained. The maximum value in this row indicates the action to suggest looking at the head of this column for the name of the action. Figure 11 shows an example of results from Tool 5.3:

Ref scenario

name	LA	EI	MS	action
1KV13/1	L	L	L	Keep the current maintenance
1KV13/2	L	L	L	Keep the current maintenance
1KV13/3	H	M	L	Replacement
1KV13/4	H	M	L	Replacement
1KV17/1	L	L	L	Keep the current maintenance
1KV17/10	H	H	H	Replacement
1KV17/11	H	H	L	Replacement
1KV17/12	H	H	H	Replacement
1KV17/2	L	L	H	Keep the current maintenance
1KV17/3	L	L	H	Keep the current maintenance
1KV17/4	L	L	L	Keep the current maintenance
1KV17/4	L	L	L	Keep the current maintenance
1KV17/5	L	L	L	Keep the current maintenance
1KV17/6	L	L	H	Keep the current maintenance
1KV17/7	L	L	H	Keep the current maintenance
1KV17/8	L	L	H	Keep the current maintenance
1KV17/9	H	H	H	Replacement
1KV22/1	M	L	L	Keep the current maintenance
1KV22/10	M	L	L	Keep the current maintenance
1KV22/11	M	L	L	Keep the current maintenance
1KV22/12	L	L	L	Keep the current maintenance
1KV22/13	M	L	L	Keep the current maintenance

FIGURE 11. EXAMPLE OF RESULTS FROM TOOL 5.3

Figure 11 is the result of Tool 5.3 for the analysis of only the reference scenario. However, when the analysis is extended to future scenarios, a similar list is obtained for each scenario analyzed. The final list of recommendations is built, integrating all the results into a unique list. This is done by a criterion based on the strategy of a majority vote. This means that the action selected will be the one that appears more often as recommended for an asset in the different scenarios. If required, a qualified vote weight can be assigned to each scenario by the user.

6. INSTALLATION

The software is developed as a portable tool. It only has to be unzipped within the desired folder. The files contained in the zip file are:

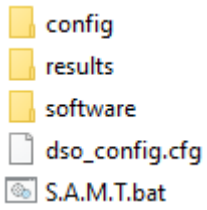


FIGURE 12 MAIN FILES OF THE TOOL

- config: folder with the "ConfigurationFile.csv" and the "Q_learning_approach.xlsx."
- Results: folder with the results obtained from the Tool, such as the future scenarios and the HTML files with the actions suggested by the Tool.
- Software: folder with all the code and binaries needed to execute the Tool.
- dso_config.cfg: configuration obtained by the Tool 5.2 needed to run the S.A.M.T. software.
- S.A.M.T.bat: script to open the Smart Asset Management Tool.

6.1. Software – Hardware requirements

- This software has been developed for a system with these minimum requirements:
  - OS: Windows 10 - 64bit.
  - Screen resolution. 1920 x 1080.
  - Python 3.8
  - RAM: 4GB
  - Hard Drive Space Required: 3 GB

7. CASE-STUDIES

To illustrate the type of results obtained, several real cases were analyzed through this Tool. This section continues with results generated in tolls 5.2.

7.1. HEP – ASSETS

Transformers

- Number of assets: 40 transformers
- Number of future SCENARIO: 3 (15 years, Each SCENARIO of 5 years)
- Results:
  - 4 patterns identified.
  - Identifier 19 has highest value of total_indicator which makes it fall into critical condition and requires immediate attention.

Reference SCENARIO

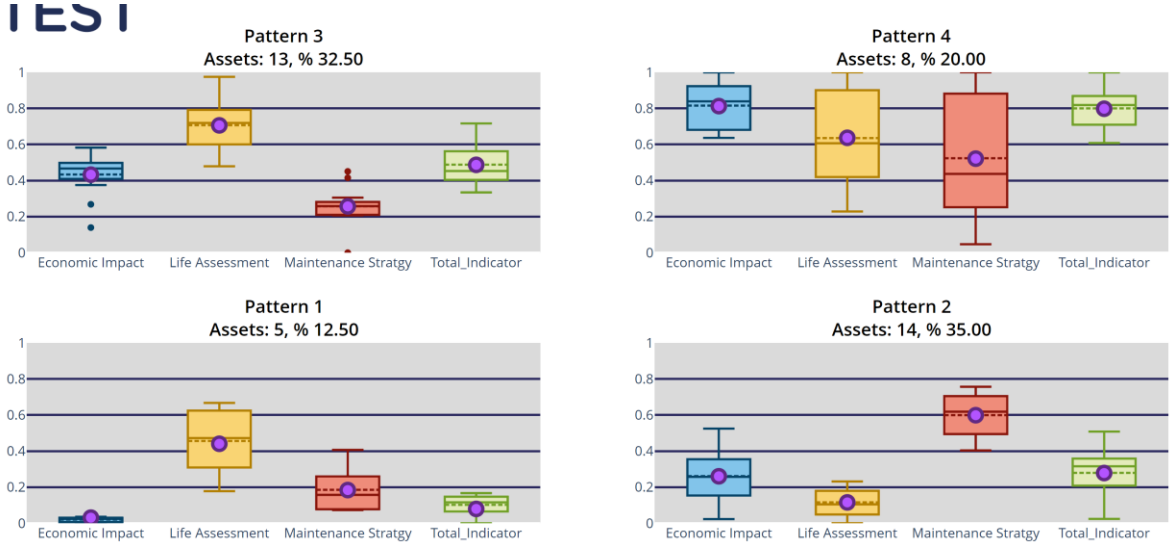


FIGURE 13 RESULTS: HEP TRANSFORMERS

NAME	ECONOMIC IMPACT	LIFE ASSESSMENT	MAINTENANCE STRATGY	TOTAL_INDICATOR
19	0.68	0.651	0.534	0.622
39	0.664	0.192	0.868	0.575
44	0.588	0.251	0.84	0.56
12	0.506	0.645	0.507	0.553
48	0.486	0.386	0.75	0.541
28	0.737	0.539	0.28	0.518
72	0.42	0.588	0.507	0.505

NAME	EI	LA	MS	ACTION
2	L	L	L	Keep the current maintenance
5	M	L	L	Keep the current maintenance
8	L	L	M	Keep the current maintenance
11	L	M	L	Keep the current maintenance
13	L	L	L	Keep the current maintenance
14	L	L	L	Keep the current maintenance
15	L	L	M	Keep the current maintenance
19	M	M	M	Digitalization of the asset (soft sensors)
21	L	L	L	Keep the current maintenance
24	L	L	L	Keep the current maintenance

FIGURE 14 RECOMMENDED ACTION FOR REF SCENARIO

Future SCENARIO I (5 years)

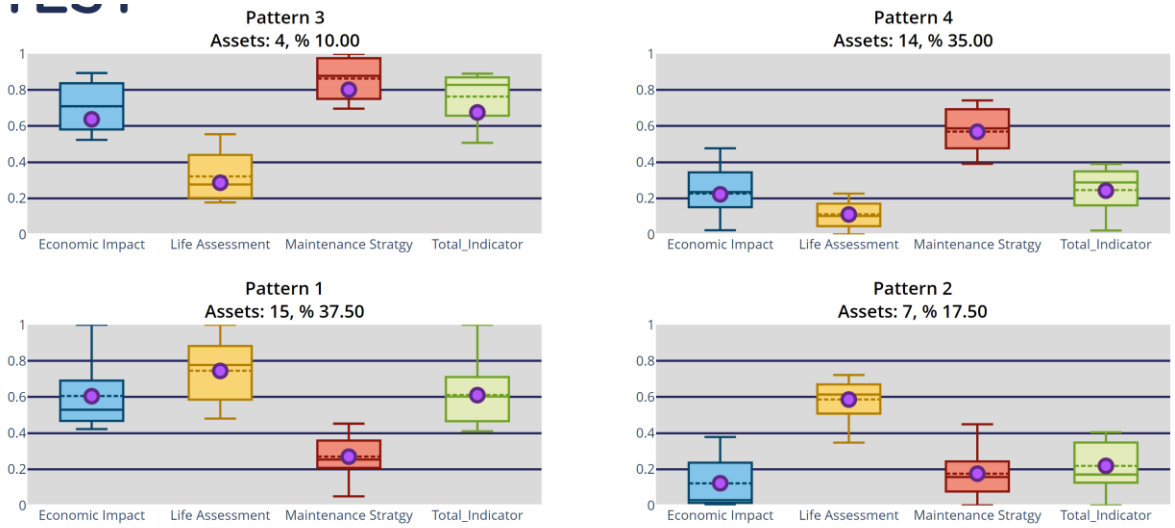


FIGURE 15 RESULTS: HEP TRANSFORMERS (FUTURE SCENARIO I)

NAME	ECONOMIC IMPACT	LIFE ASSESSMENT	MAINTENANCE STRATGY	TOTAL_INDICATOR
19	0.675	0.649	0.53	0.618
39	0.658	0.191	0.869	0.573
44	0.581	0.249	0.839	0.556
12	0.503	0.643	0.508	0.551
48	0.484	0.385	0.748	0.539
28	0.731	0.537	0.281	0.516
72	0.417	0.588	0.508	0.504

NAME	EI	LA	MS	ACTION
2	L	L	L	Keep the current maintenance
5	M	L	L	Keep the current maintenance
8	L	L	M	Keep the current maintenance
11	L	M	L	Keep the current maintenance
13	L	L	L	Keep the current maintenance
14	L	L	L	Keep the current maintenance
15	L	L	M	Keep the current maintenance
19	M	M	M	Digitalization of the asset (soft sensors)
21	L	L	L	Keep the current maintenance
24	L	L	L	Keep the current maintenance

FIGURE 16 RECOMMENDED ACTION FOR FUTURE SCENARIO I

Future SCENARIO II (10 years)

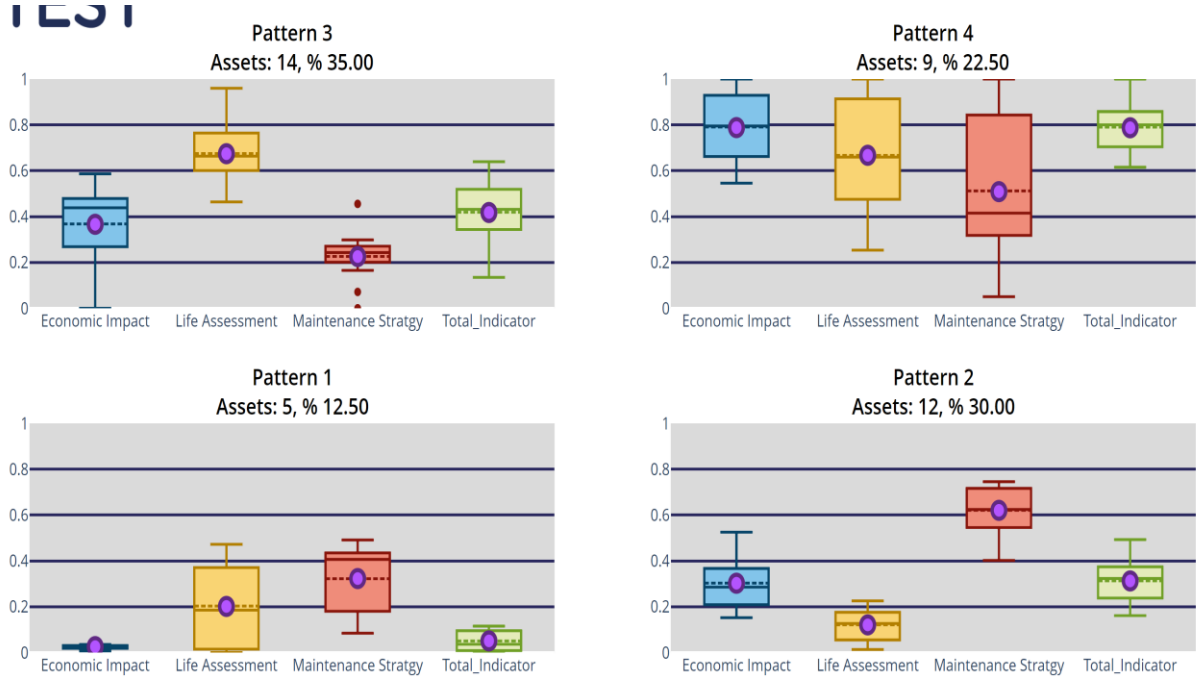


FIGURE 17 RESULTS: HEP TRANSFORMERS(FUTURE SCENARIO II)

NAME	ECONOMIC IMPACT	LIFE ASSESSMENT	MAINTENANCE STRATGY	TOTAL_INDICATOR
19	0.688	0.655	0.529	0.624
39	0.669	0.208	0.863	0.58
44	0.596	0.256	0.827	0.56
12	0.509	0.643	0.5	0.551
48	0.489	0.39	0.746	0.541
28	0.737	0.538	0.277	0.517
72	0.424	0.59	0.502	0.505
5	0.536	0.451	0.478	0.489
42	0.414	0.631	0.378	0.474

NAME	EI	LA	MS	ACTION
2	L	L	L	Keep the current maintenance
5	M	L	L	Keep the current maintenance
8	L	L	M	Keep the current maintenance
11	L	M	L	Keep the current maintenance
13	L	L	L	Keep the current maintenance
14	L	L	L	Keep the current maintenance
15	L	L	M	Keep the current maintenance
19	M	M	M	Digitalization of the asset (soft sensors)
21	L	L	L	Keep the current maintenance
24	L	L	L	Keep the current maintenance

FIGURE 18 RECOMMENDED ACTION FOR FUTURE SCENARIO II

Future SCENARIO III (15 years)

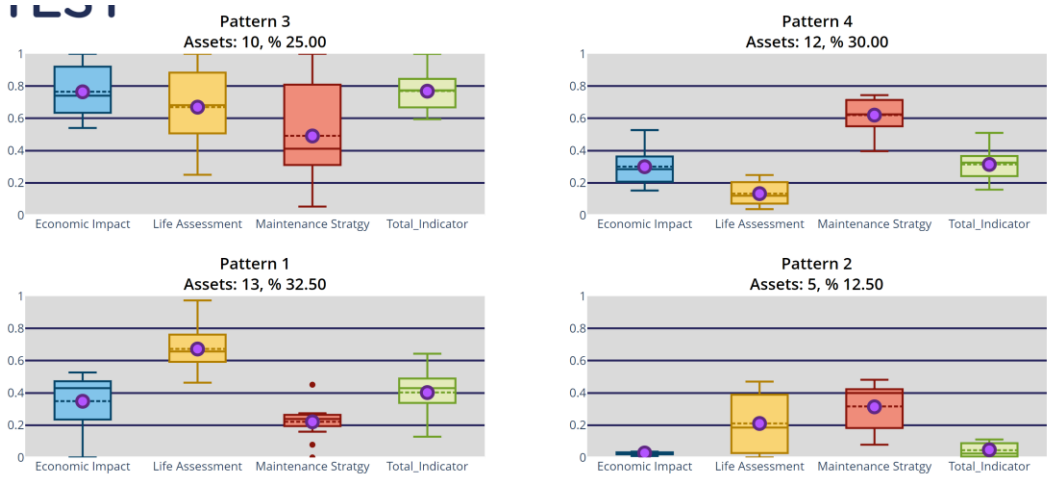


FIGURE 19 HEP TRANSFORMERS(FUTURE SCENARIO III)

NAME	ECONOMIC IMPACT	LIFE ASSESSMENT	MAINTENANCE STRATGY	TOTAL_INDICATOR
19	0.681	0.653	0.535	0.623
39	0.663	0.206	0.867	0.579
44	0.586	0.257	0.832	0.559
12	0.509	0.656	0.501	0.555
48	0.484	0.385	0.748	0.539
28	0.736	0.543	0.279	0.52
72	0.419	0.586	0.502	0.503
5	0.528	0.45	0.48	0.486
42	0.41	0.64	0.377	0.476

NAME	EI	LA	MS	ACTION
2	L	L	L	Keep the current maintenance
5	M	L	L	Keep the current maintenance
8	L	L	M	Keep the current maintenance
11	L	M	L	Keep the current maintenance
13	L	L	L	Keep the current maintenance
14	L	L	L	Keep the current maintenance
15	L	L	M	Keep the current maintenance
19	M	M	M	Digitalization of the asset (soft sensors)
21	L	L	L	Keep the current maintenance
24	L	L	L	Keep the current maintenance

FIGURE 20 RECOMMENDED ACTION FOR FUTURE SCENARIO III

Distribution Lines

- Number of assets: 52 lines
- Results:
  - 6 patterns identified in ref SCENARIO and 4 patterns identified in future SCENARIOs.
  - Identifier 1KV3/10 has highest value of total_indicator which makes it fall into critical condition and requires immediate attention.

Reference SCENARIO

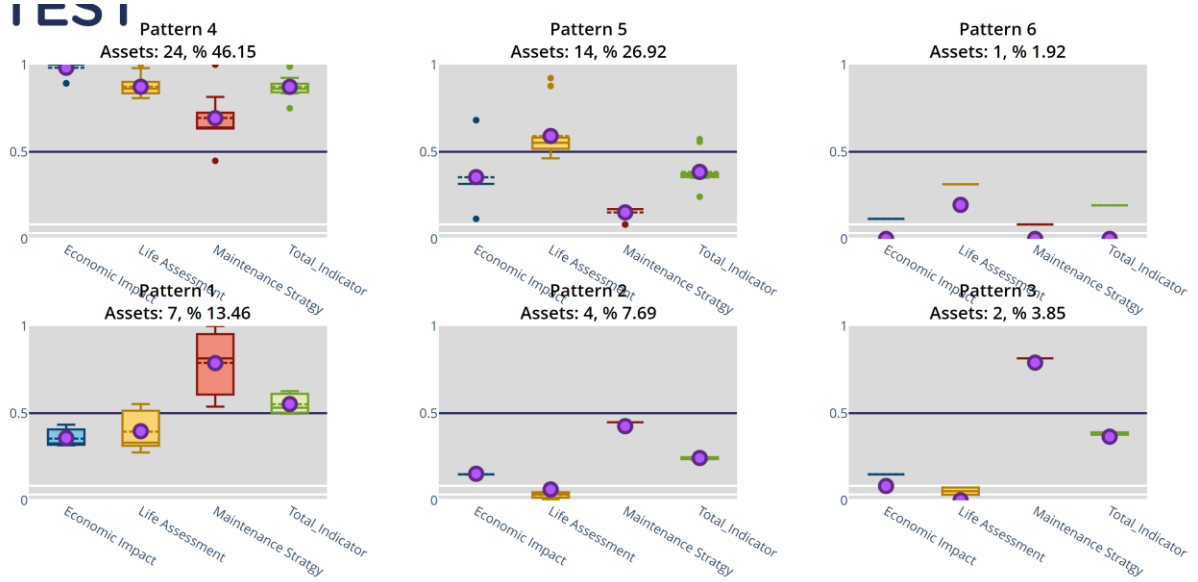


FIGURE 21 RESULTS: HEP LINE

NAME	ECONOMIC IMPACT	LIFE ASSESSMENT	MAINTENANCE STRATGY	TOTAL_INDICATOR
1KV3/10	1.0	0.895	1.0	0.965
1KV3/4	1.0	0.874	1.0	0.958
1KV3/2	1.0	0.86	1.0	0.953
1KV17/10	0.899	0.971	0.798	0.889
1KV3/1	1.0	0.991	0.6	0.864
1KV17/12	0.899	0.89	0.798	0.862
1KV3/17	1.0	0.946	0.6	0.849
1KV17/9	0.899	0.833	0.798	0.843
1KV3/8	1.0	0.905	0.6	0.835

NAME	EI	LA	MS	ACTION
1KV13/1	L	L	L	Keep the current maintenance
1KV13/2	L	L	L	Keep the current maintenance
1KV13/3	M	H	L	Replacement
1KV13/4	M	H	L	Replacement
1KV17/1	L	L	L	Keep the current maintenance
1KV17/10	H	H	H	Replacement
1KV17/11	H	H	L	Replacement
1KV17/12	H	H	H	Replacement
1KV17/2	L	L	H	Keep the current maintenance
1KV17/3	L	L	H	Keep the current maintenance

FIGURE 22 RECOMMENDED ACTION FOR REF SCENARIO

Future SCENARIO I (5 years)

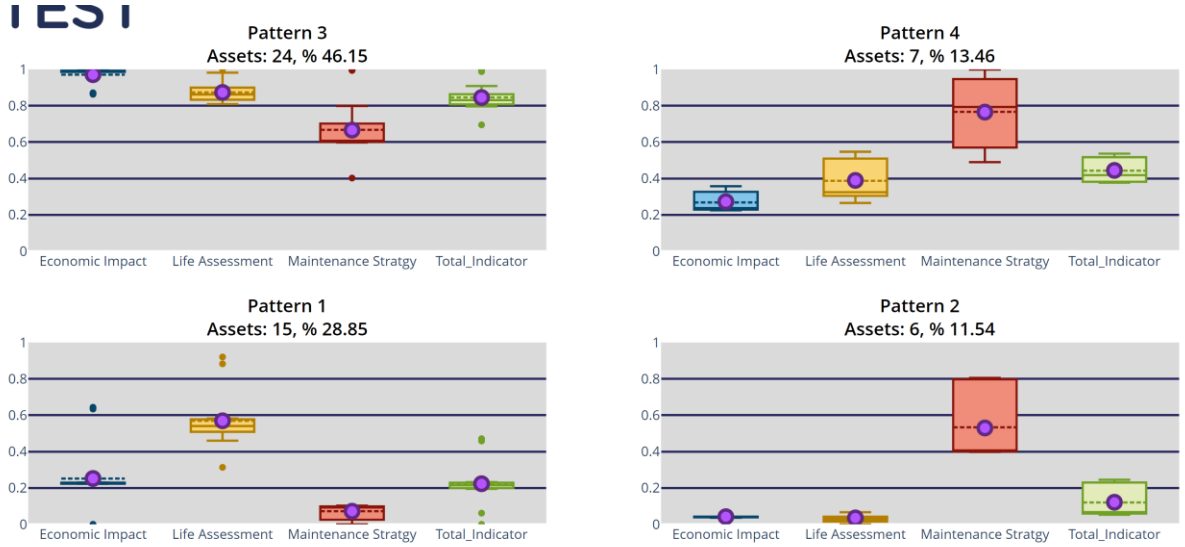


FIGURE 23 HEP LINE (FUTURE SCENARIO I)

NAME	ECONOMIC IMPACT	LIFE ASSESSMENT	MAINTENANCE STRATGY	TOTAL_INDICATOR
1KV3/10	0.988	0.886	0.989	0.955
1KV3/4	0.992	0.871	0.994	0.952
1KV3/2	0.996	0.851	0.988	0.945
1KV17/10	0.885	0.967	0.794	0.882
1KV3/1	0.984	0.985	0.608	0.859
1KV17/12	0.882	0.887	0.79	0.853
1KV3/17	0.987	0.935	0.595	0.839

NAME	EI	LA	MS	ACTION
1KV13/1	L	L	L	Keep the current maintenance
1KV13/2	L	L	L	Keep the current maintenance
1KV13/3	M	H	L	Replacement
1KV13/4	M	H	L	Replacement
1KV17/1	L	L	L	Keep the current maintenance
1KV17/10	H	H	H	Replacement
1KV17/11	H	H	L	Replacement
1KV17/12	H	H	H	Replacement
1KV17/2	L	L	H	Keep the current maintenance
1KV17/3	L	L	H	Keep the current maintenance
1KV17/4	L	L	L	Keep the current maintenance

FIGURE 24 RECOMMENDED ACTION FOR FUTURE SCENARIO I

Future SCENARIO II (10 years)

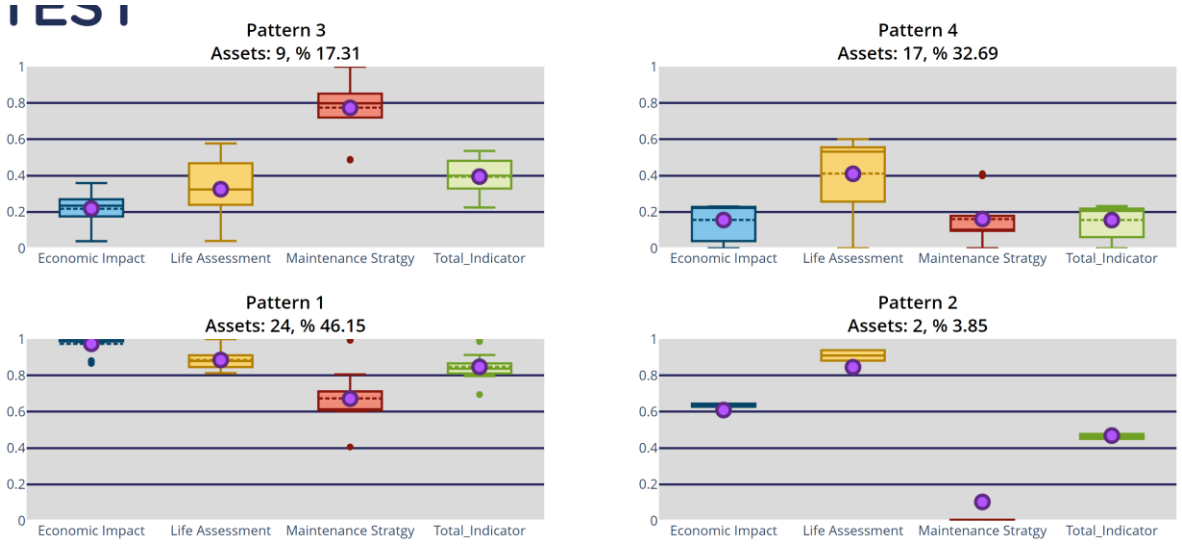


FIGURE 25 HEP LINE(FUTURE SCENARIO II)

NAME	ECONOMIC IMPACT	LIFE ASSESSMENT	MAINTENANCE STRATGY	TOTAL_INDICATOR
1KV3/10	0.99	0.891	0.977	0.953
1KV3/2	0.988	0.881	0.979	0.949
1KV3/4	0.986	0.868	0.973	0.942
1KV17/10	0.89	0.979	0.784	0.884
1KV3/1	0.992	0.968	0.598	0.852
1KV3/17	0.99	0.941	0.613	0.848
1KV17/12	0.881	0.874	0.784	0.846
1KV17/9	0.888	0.825	0.79	0.834
1KV3/8	0.988	0.914	0.597	0.833

NAME	EI	LA	MS	ACTION
1KV13/1	L	L	L	Keep the current maintenance
1KV13/2	L	L	L	Keep the current maintenance
1KV13/3	M	H	L	Replacement
1KV13/4	M	H	L	Replacement
1KV17/1	L	L	L	Keep the current maintenance
1KV17/10	H	H	H	Replacement
1KV17/11	H	H	L	Replacement
1KV17/12	H	H	H	Replacement
1KV17/2	L	L	H	Keep the current maintenance
1KV17/3	L	L	H	Keep the current maintenance
1KV17/4	L	L	L	Keep the current maintenance

FIGURE 26 RECOMMENDED ACTION FOR FUTURE SCENARIO II

Future SCENARIO III (15 years)

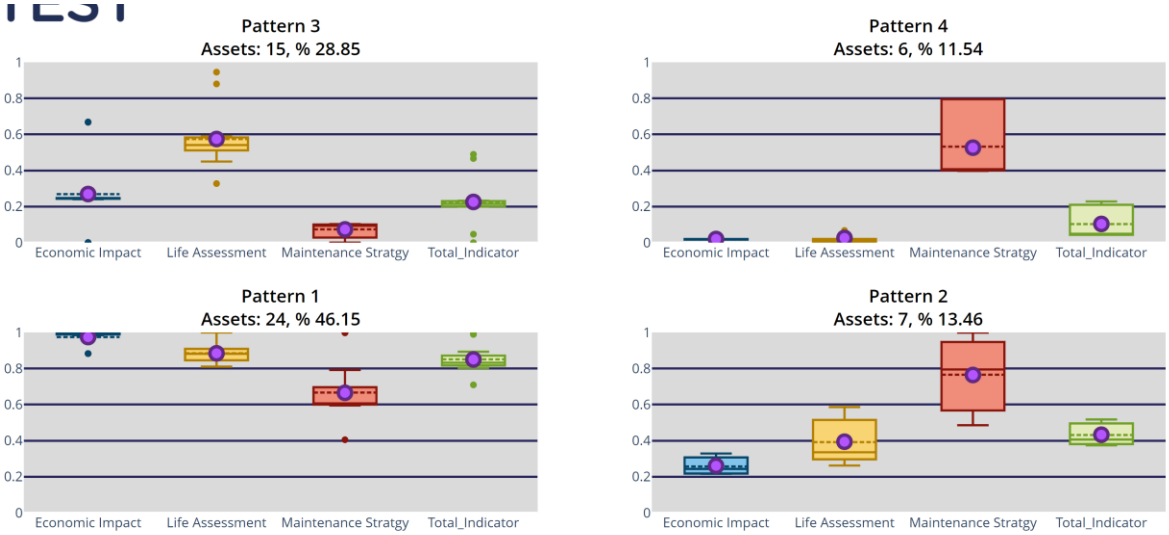


FIGURE 27 HEP LINE(FUTURE SCENARIO III)

NAME	ECONOMIC IMPACT	LIFE ASSESSMENT	MAINTENANCE STRATGY	TOTAL_INDICATOR
1KV3/10	1.086	0.892	0.996	0.991
1KV3/4	1.091	0.864	0.998	0.984
1KV3/2	1.082	0.867	0.996	0.982
1KV17/10	0.989	0.936	0.787	0.904
1KV17/12	0.989	0.893	0.79	0.891
1KV3/1	1.088	0.979	0.604	0.89
1KV3/17	1.092	0.953	0.603	0.883

NAME	EI	LA	MS	ACTION
1KV13/1	L	L	L	Keep the current maintenance
1KV13/2	L	L	L	Keep the current maintenance
1KV13/3	M	H	L	Replacement
1KV13/4	M	H	L	Replacement
1KV17/1	L	L	L	Keep the current maintenance
1KV17/10	H	H	H	Replacement
1KV17/11	H	H	L	Replacement
1KV17/12	H	H	H	Replacement
1KV17/2	L	L	H	Keep the current maintenance
1KV17/3	L	L	H	Keep the current maintenance
1KV17/4	L	L	L	Keep the current maintenance

FIGURE 28 RECOMMENDED ACTION FOR FUTURE SCENARIO III

7.2. HOPS – ASSETS

Transmission Lines

- Number of assets: 10 transmission lines.
- Results:
  - 3 patterns identified.
  - Identifier SUBST26 has highest value of total_indicator which makes it fall into critical condition and requires immediate attention.

Reference SCENARIO

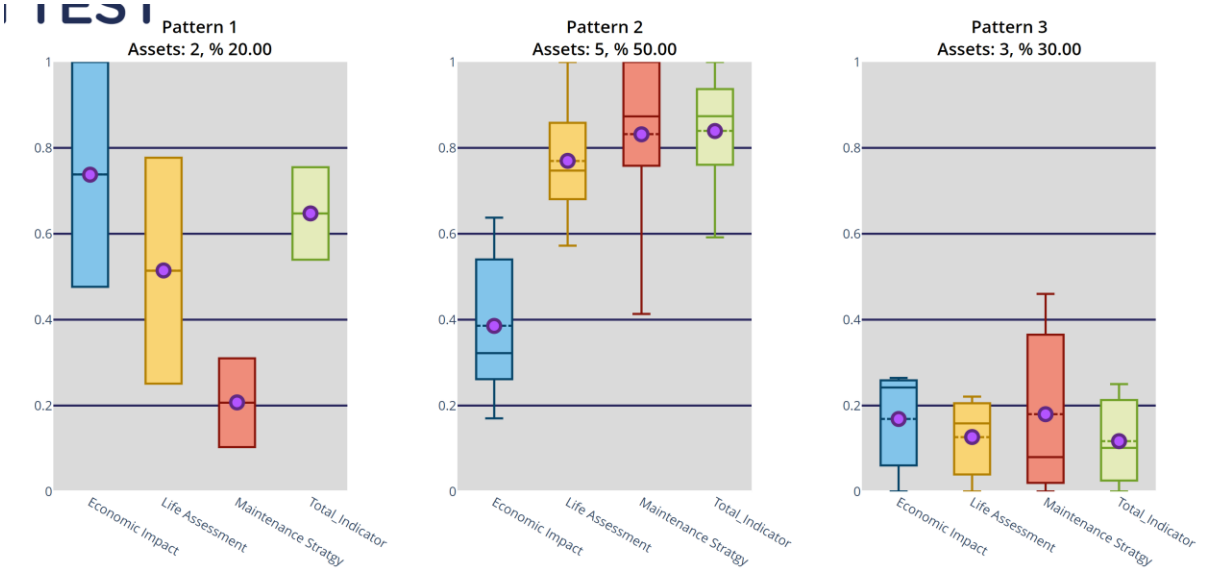


FIGURE 29 RESULTS: HOPS TRANSMISSION LINE

NAME	ECONOMIC IMPACT	LIFE ASSESSMENT	MAINTENANCE STRATGY	TOTAL_INDICATOR
SUBST26-SUBST55	0.487	0.63	0.6	0.572
SUBST05-SUBST01	0.388	0.702	0.524	0.538
SUBST42-SUBST05	0.246	0.717	0.6	0.521
SUBST01-SUBST55	0.223	0.749	0.524	0.498
SUBST36-SUBST01	0.764	0.47	0.186	0.473
SUBST29-SUBST01	0.13	0.843	0.248	0.407
SUBST34-SUBST29	0.364	0.732	0.062	0.386
SUBST19-SUBST01	0.185	0.345	0.276	0.269
SUBST35-SUBST36	0.202	0.424	0.0	0.209
SUBST34-SUBST35	0.0	0.455	0.048	0.168

NAME	EI	LA	MS	ACTION
SUBST34-SUBST29	L	M	L	Keep the current maintenance
SUBST29-SUBST01	L	H	L	Replacement
SUBST19-SUBST01	L	L	L	Keep the current maintenance
SUBST36-SUBST01	H	L	L	Keep the current maintenance
SUBST35-SUBST36	L	L	L	Keep the current maintenance
SUBST34-SUBST35	L	L	L	Keep the current maintenance
SUBST05-SUBST01	L	M	M	Relocation
SUBST42-SUBST05	L	M	M	Relocation

FIGURE 30 RECOMMENDED ACTION FOR REF SCENARIO

Future SCENARIO I (5 years)

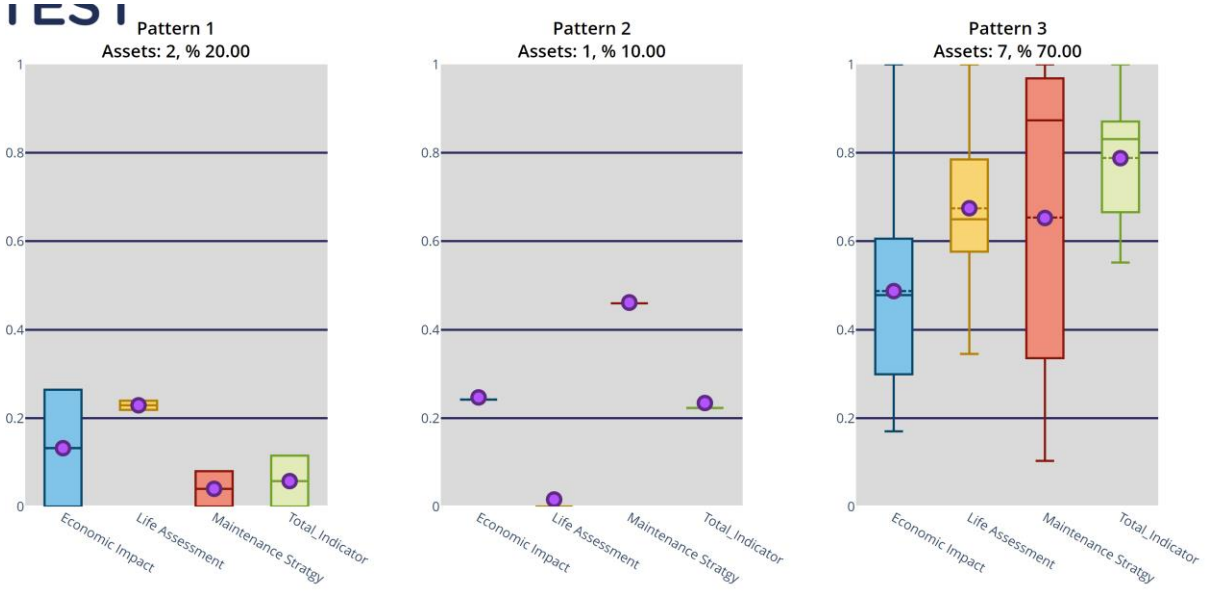


FIGURE 31 HOP LINE(FUTURE SCENARIO I)

NAME	ECONOMIC IMPACT	LIFE ASSESSMENT	MAINTENANCE STRATGY	TOTAL_INDICATOR
SUBST26-SUBST55	0.487	0.591	0.6	0.559
SUBST05-SUBST01	0.389	0.618	0.524	0.51
SUBST42-SUBST05	0.246	0.64	0.6	0.495
SUBST01-SUBST55	0.223	0.724	0.524	0.49
SUBST36-SUBST01	0.764	0.465	0.186	0.472
SUBST29-SUBST01	0.13	0.842	0.248	0.406
SUBST34-SUBST29	0.365	0.7	0.062	0.376
SUBST19-SUBST01	0.185	0.266	0.276	0.242
SUBST35-SUBST36	0.202	0.392	0.0	0.198
SUBST34-SUBST35	0.0	0.404	0.048	0.151

NAME	EI	LA	MS	ACTION
SUBST34-SUBST29	L	M	L	Keep the current maintenance
SUBST29-SUBST01	L	H	L	Replacement
SUBST19-SUBST01	L	L	L	Keep the current maintenance
SUBST36-SUBST01	H	L	L	Keep the current maintenance
SUBST35-SUBST36	L	L	L	Keep the current maintenance
SUBST34-SUBST35	L	L	L	Keep the current maintenance
SUBST05-SUBST01	L	M	M	Relocation
SUBST42-SUBST05	L	M	M	Relocation

FIGURE 32 RECOMMENDED ACTION FOR FUTURE SCENARIO I

Future SCENARIO II (10 years)

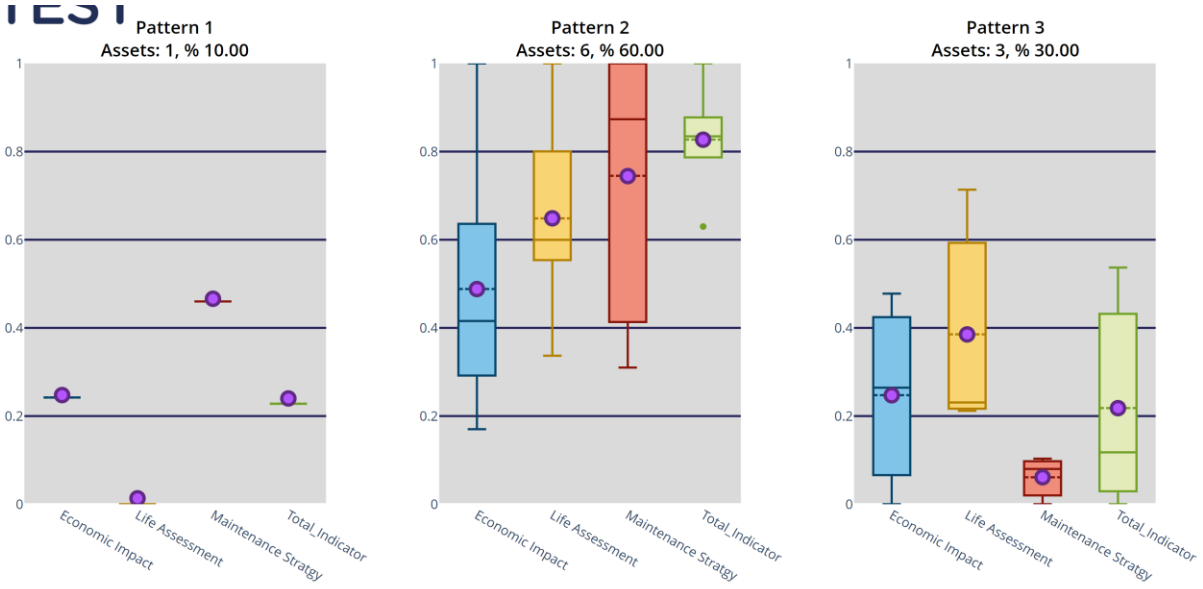


FIGURE 33 HOP LINE(FUTURE SCENARIO II)

NAME	ECONOMIC IMPACT	LIFE ASSESSMENT	MAINTENANCE STRATGY	TOTAL_INDICATOR
SUBST26-SUBST55	0.486	0.585	0.6	0.557
SUBST05-SUBST01	0.389	0.606	0.524	0.507
SUBST01-SUBST55	0.223	0.727	0.524	0.491
SUBST42-SUBST05	0.246	0.617	0.6	0.488
SUBST36-SUBST01	0.764	0.46	0.186	0.47
SUBST29-SUBST01	0.13	0.842	0.248	0.406
SUBST34-SUBST29	0.365	0.677	0.062	0.368
SUBST19-SUBST01	0.185	0.266	0.276	0.242
SUBST35-SUBST36	0.202	0.388	0.0	0.197
SUBST34-SUBST35	0.0	0.399	0.048	0.149

NAME	EI	LA	MS	ACTION
SUBST34-SUBST29	L	M	L	Keep the current maintenance
SUBST29-SUBST01	L	H	L	Replacement
SUBST19-SUBST01	L	L	L	Keep the current maintenance
SUBST36-SUBST01	H	L	L	Keep the current maintenance
SUBST35-SUBST36	L	L	L	Keep the current maintenance
SUBST34-SUBST35	L	L	L	Keep the current maintenance
SUBST05-SUBST01	L	M	M	Relocation
SUBST42-SUBST05	L	M	M	Relocation

FIGURE 34 RECOMMENDED ACTION FOR FUTURE SCENARIO II

Future SCENARIO III (15 years)

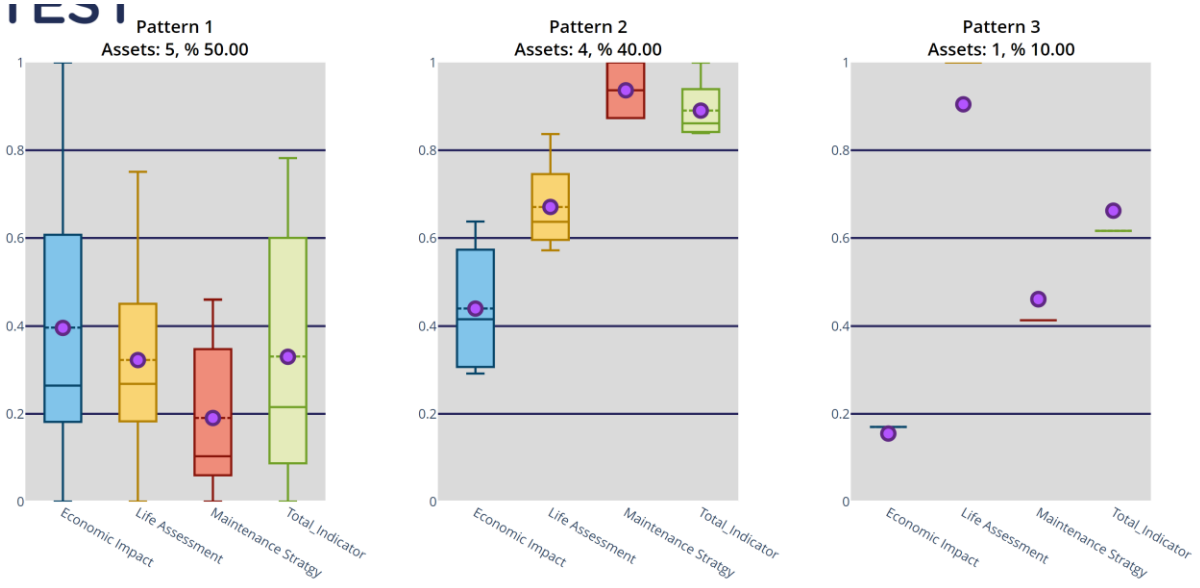


FIGURE 35 HOP LINE(FUTURE SCENARIO III)

NAME	ECONOMIC IMPACT	LIFE ASSESSMENT	MAINTENANCE STRATGY	TOTAL_INDICATOR
SUBST26-SUBST55	0.487	0.587	0.6	0.558
SUBST05-SUBST01	0.389	0.614	0.524	0.509
SUBST01-SUBST55	0.223	0.738	0.524	0.495
SUBST42-SUBST05	0.246	0.634	0.6	0.493
SUBST36-SUBST01	0.764	0.461	0.186	0.47
SUBST29-SUBST01	0.13	0.831	0.248	0.403
SUBST34-SUBST29	0.364	0.689	0.062	0.372
SUBST19-SUBST01	0.185	0.261	0.276	0.241
SUBST35-SUBST36	0.202	0.4	0.0	0.201
SUBST34-SUBST35	0.0	0.414	0.048	0.154

NAME	EI	LA	MS	ACTION
SUBST34-SUBST29	L	M	L	Keep the current maintenance
SUBST29-SUBST01	L	H	L	Replacement
SUBST19-SUBST01	L	L	L	Keep the current maintenance
SUBST36-SUBST01	H	L	L	Keep the current maintenance
SUBST35-SUBST36	L	L	L	Keep the current maintenance
SUBST34-SUBST35	L	L	L	Keep the current maintenance
SUBST05-SUBST01	L	M	M	Relocation
SUBST42-SUBST05	L	M	M	Relocation

FIGURE 36 RECOMMENDED ACTION FOR FUTURE SCENARIO III

Transformers

- Number of assets: 10 transformers
- Results:
  - 4 patterns identified.
  - All the assets are in good condition and don't require immediate attention.

Reference SCENARIO

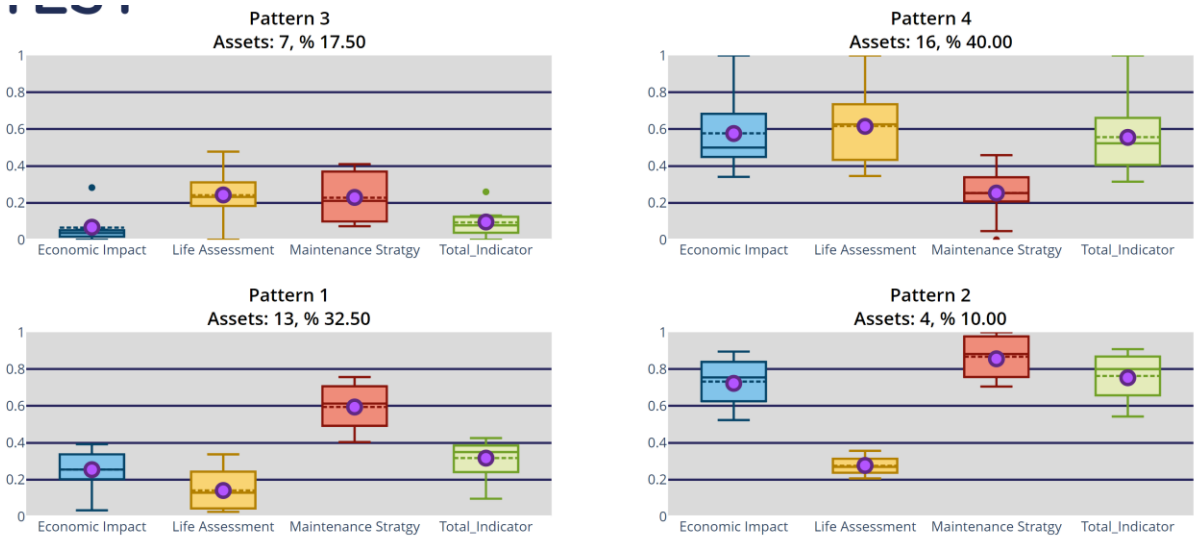


FIGURE 37 RESULTS: HOPS TRANSFORMERS

NAME	ECONOMIC IMPACT	LIFE ASSESSMENT	MAINTENANCE STRATGY	TOTAL_INDICATOR
19	0.68	0.663	0.534	0.626
39	0.664	0.225	0.868	0.586
12	0.509	0.689	0.507	0.568
44	0.587	0.226	0.84	0.551
48	0.549	0.281	0.75	0.527
28	0.736	0.53	0.28	0.515
5	0.528	0.455	0.481	0.488
42	0.413	0.614	0.381	0.469
72	0.431	0.456	0.507	0.465
2	0.449	0.412	0.439	0.433

NAME	EI	LA	MS	ACTION
2	L	L	L	Keep the current maintenance
5	M	L	L	Keep the current maintenance
8	L	L	M	Keep the current maintenance
11	L	L	L	Keep the current maintenance
13	L	L	L	Keep the current maintenance
14	L	L	L	Keep the current maintenance
15	L	L	M	Keep the current maintenance
19	M	M	M	Digitalization of the asset (soft sensors)
21	L	L	L	Keep the current maintenance

FIGURE 38 RECOMMENDED ACTION FOR REF SCENARIO

7.3. Spanish Case

Supports

- Number of assets: 380
- Results:
  - 4 patterns identified.
  - some assets are in critical condition and require immediate attention.

Reference SCENARIO

FIGURE 39 RESULT: SPANISH SUPPORT

NAME	ECONOMIC IMPACT	LIFE ASSESSMENT	MAINTENANCE STRATGY	TOTAL_INDICATOR
RQ9W9OJR//74-32	0.904	0.908	0.75	0.854
RQ8UCGAG//74-33-4	0.819	0.744	1.0	0.854
RQAUFPTH//74-33-2	0.819	0.744	0.875	0.813
SAM60AF0//D59-70	0.933	0.94	0.458	0.777
RQBQDFTA//74-33	0.784	0.785	0.75	0.773
RQ3K0TFG//82	0.588	0.947	0.75	0.762
RQA9HCG7//74-33-3	0.819	0.744	0.625	0.729
RQ37A8RE//74-28	0.754	0.76	0.625	0.713
RQ61SCFJ//74-30	0.664	0.686	0.75	0.7

NAME	EI	LA	MS	ACTION
RPUDB12T//74-22-4	M	L	M	Keep the current maintenance
RPUWQIFO//74-22-5-CT	L	L	L	Keep the current maintenance
RPWULH1G//74-22-3	L	L	M	Keep the current maintenance
RQ0W7MUL//74-22-2	L	L	L	Keep the current maintenance
RQ2HC35J//74-27	M	M	L	Decrease its use rate. (More energy, more operations.)
RQ2NBO45//79	L	M	L	Keep the current maintenance
RQ2O32O0//74-26	M	M	L	Decrease its use rate. (More energy, more operations.)
RQ2O34P5//74-2-1-CT	L	L	L	Keep the current maintenance

FIGURE 40 RECOMMENDED ACTION FOR REF SCENARIO

Future SCENARIO I (5 years)

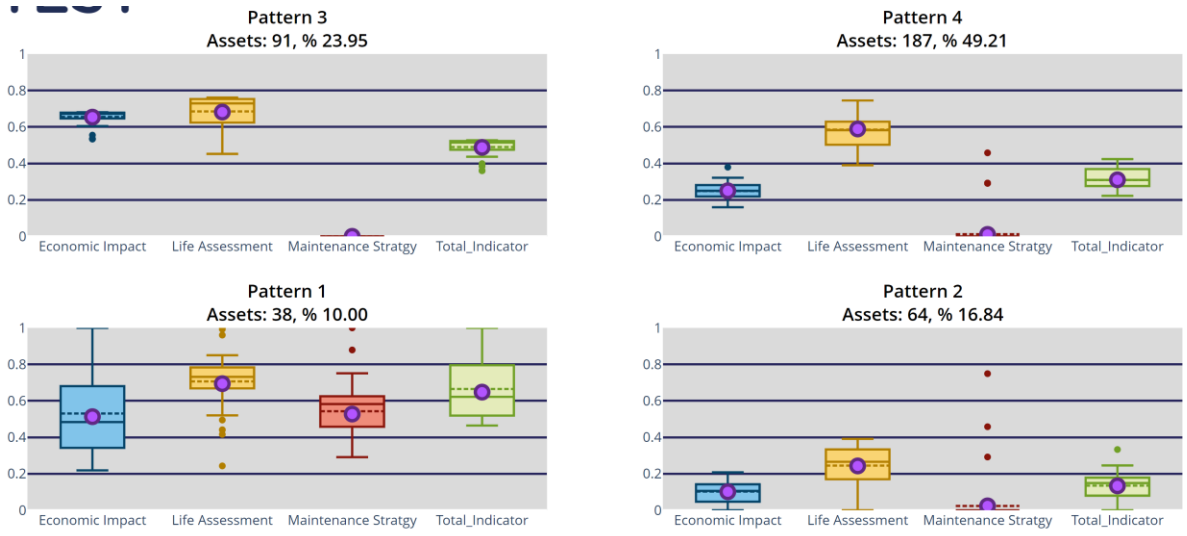


FIGURE 41 SPANISH SUPPORT(FUTURE SCENARIO I)

NAME	ECONOMIC IMPACT	LIFE ASSESSMENT	MAINTENANCE STRATGY	TOTAL_INDICATOR
RQ9W9OJR//74-32	0.904	0.908	0.75	0.854
RQ8UCGAG//74-33-4	0.819	0.742	1.0	0.854
RQAUFPTH//74-33-2	0.817	0.744	0.879	0.813
SAM60AF0//D59-70	0.933	0.938	0.459	0.777
RQBQDFTA//74-33	0.782	0.784	0.749	0.772
RQ3K0TFG//82	0.588	0.945	0.751	0.761
RQA9HCG7//74-33-3	0.818	0.741	0.625	0.728
RQ37A8RE//74-28	0.753	0.758	0.624	0.712
RQ61SCFJ//74-30	0.664	0.683	0.749	0.699

NAME	EI	LA	MS	ACTION
RPUDB12T//74-22-4	M	L	M	Keep the current maintenance
RPUWQIFO//74-22-5-CT	L	L	L	Keep the current maintenance
RPWULH1G//74-22-3	L	L	M	Keep the current maintenance
RQ0W7MUL//74-22-2	L	L	L	Keep the current maintenance
RQ2HC35J//74-27	M	M	L	Decrease its use rate. (More energy, more operations.)
RQ2NBO45//79	L	M	L	Keep the current maintenance
RQ2O32O0//74-26	M	M	L	Decrease its use rate. (More energy, more operations.)
RQ2O34P5//74-2-1-CT	L	L	L	Keep the current maintenance

FIGURE 42 RECOMMENDED ACTION FOR FUTURE SCENARIO I

Future SCENARIO II (10 years)

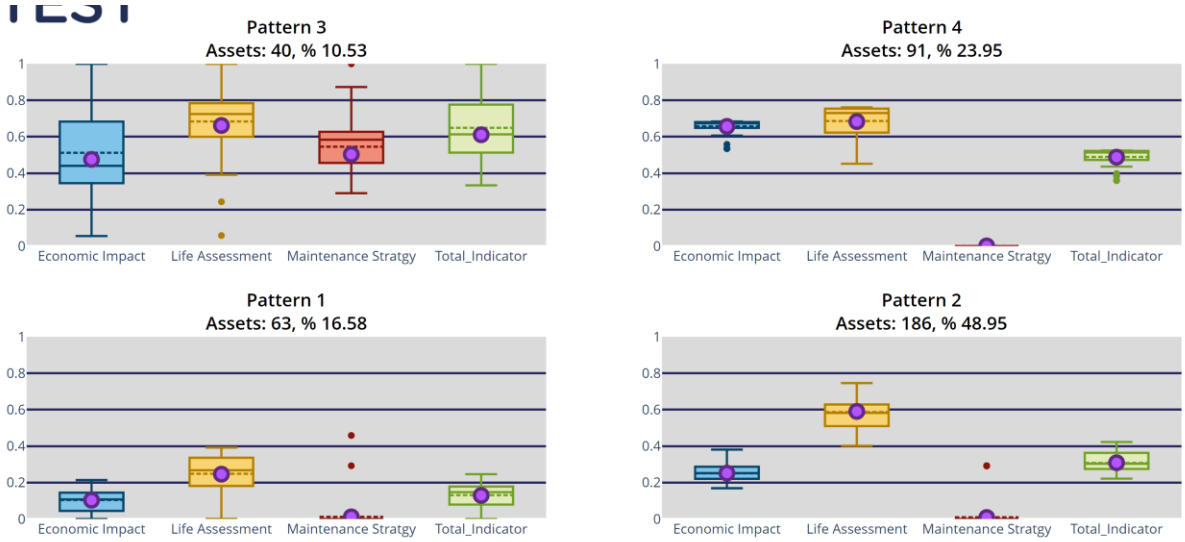


FIGURE 43 SPANISH SUPPORT(FUTURE SCENARIO II)

NAME	ECONOMIC IMPACT	LIFE ASSESSMENT	MAINTENANCE STRATGY	TOTAL_INDICATOR
RQ8UCGAG//74-33-4	0.819	0.745	0.999	0.854
RQ9W9OJR//74-32	0.903	0.905	0.751	0.853
RQAUFPTH//74-33-2	0.817	0.74	0.872	0.81
SAM60AF0//D59-70	0.93	0.937	0.457	0.775
RQBQDFTA//74-33	0.781	0.781	0.747	0.77
RQ3K0TFG//82	0.589	0.942	0.749	0.76
RQA9HCG7//74-33-3	0.82	0.74	0.624	0.728

NAME	EI	LA	MS	ACTION
RPUDB12T//74-22-4	M	L	M	Keep the current maintenance
RPUWQIFO//74-22-5-CT	L	L	L	Keep the current maintenance
RPWULH1G//74-22-3	L	L	M	Keep the current maintenance
RQ0W7MUL//74-22-2	L	M	L	Keep the current maintenance
RQ2HC35J//74-27	M	M	L	Decrease its use rate. (More energy, more operations.)
RQ2NBO45//79	L	M	L	Keep the current maintenance
RQ2O32O0//74-26	M	M	L	Decrease its use rate. (More energy, more operations.)
RQ2O34P5//74-2-1-CT	L	L	L	Keep the current maintenance

FIGURE 44 RECOMMENDED ACTION FOR FUTURE SCENARIO II

Future SCENARIO III (15 years)

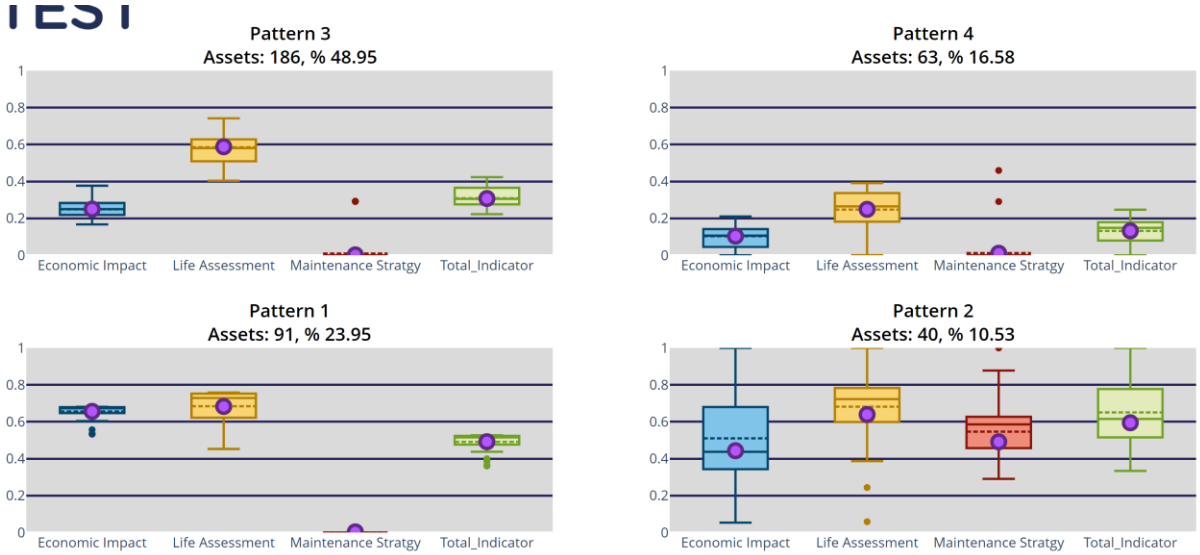


FIGURE 45 SPANISH SUPPORT(FUTURE SCENARIO III)

NAME	ECONOMIC IMPACT	LIFE ASSESSMENT	MAINTENANCE STRATGY	TOTAL_INDICATOR
RQ9W9OJR//74-32	0.901	0.908	0.746	0.852
RQ8UCGAG//74-33-4	0.818	0.742	0.997	0.852
RQAUFPTH//74-33-2	0.817	0.742	0.875	0.811
SAM60AF0//D59-70	0.932	0.938	0.456	0.775
RQBQDFTA//74-33	0.783	0.783	0.747	0.771
RQ3K0TFG//82	0.589	0.946	0.75	0.762
RQA9HCG7//74-33-3	0.817	0.742	0.623	0.727
RQ37A8RE//74-28	0.753	0.759	0.624	0.712
RQ61SCFJ//74-30	0.664	0.686	0.747	0.699

NAME	EI	LA	MS	ACTION
RPUDB12T//74-22-4	M	L	M	Keep the current maintenance
RPUWQIFO//74-22-5-CT	L	L	L	Keep the current maintenance
RPWULH1G//74-22-3	L	L	M	Keep the current maintenance
RQ0W7MUL//74-22-2	L	L	L	Keep the current maintenance
RQ2HC35J//74-27	M	M	L	Decrease its use rate. (More energy, more operations.)
RQ2NBO45//79	L	M	L	Keep the current maintenance
RQ2O32O0//74-26	M	M	L	Decrease its use rate. (More energy, more operations.)

FIGURE 46 RECOMMENDED ACTION FOR FUTURE SCENARIO III

TRANSFORMERS

- Number of assets: 92 transformers.
- Results:
  - 4 patterns identified.
  - All assets are in condition and don't require immediate attention.

Reference SCENARIO

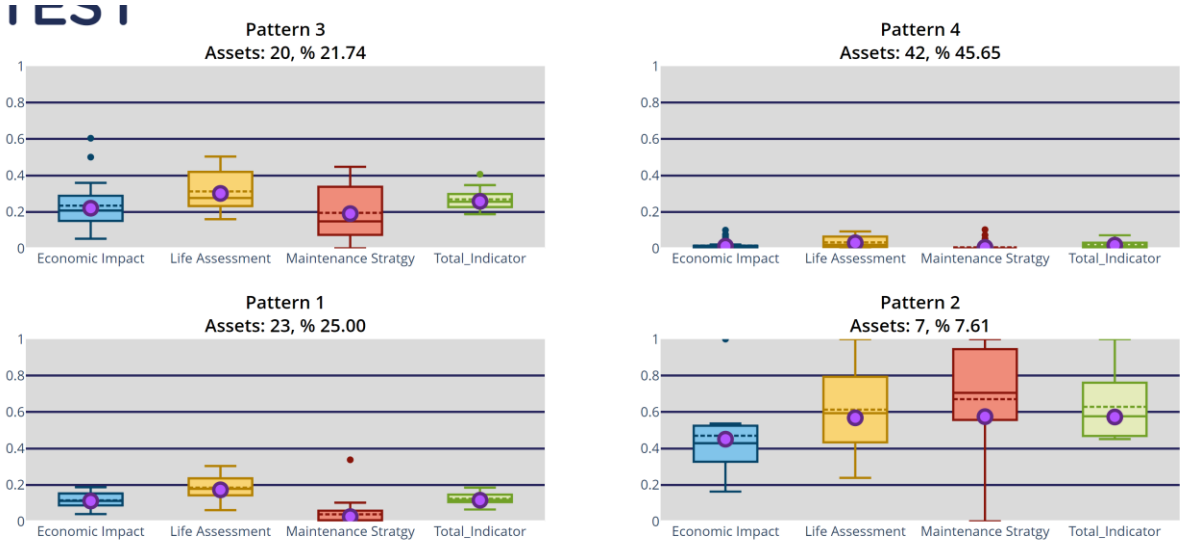


FIGURE 47 RESULT: SPANISH TRAFO

NAME	ECONOMIC IMPACT	LIFE ASSESSMENT	MAINTENANCE STRATGY	TOTAL_INDICATOR
28CDR2	0.849	0.646	0.711	0.735
28CHHS	0.456	0.601	0.74	0.599
28CQPQ	0.414	0.475	0.43	0.44
28CYL3	0.364	0.386	0.522	0.424
28PCAT	0.301	0.8	0.0	0.367
28CIA7	0.27	0.334	0.406	0.337
28CDR5	0.139	0.191	0.664	0.332
28CHQD	0.513	0.351	0.032	0.299

NAME	EI	LA	MS	ACTION
19A649	L	L	L	Keep the current maintenance
19A650	L	L	L	Keep the current maintenance
19A716	L	L	L	Keep the current maintenance
19A754	L	L	L	Keep the current maintenance
19P814	L	L	L	Keep the current maintenance
28AGM9	L	L	L	Keep the current maintenance
28AIN3	L	L	L	Keep the current maintenance
28AIQ3	L	L	L	Keep the current maintenance
28AIQ4	L	L	L	Keep the current maintenance
28ANG2	L	L	L	Keep the current maintenance

FIGURE 48 RECOMMENDED ACTION FOR REF SCENARIO

Future Scenario I (5 years)

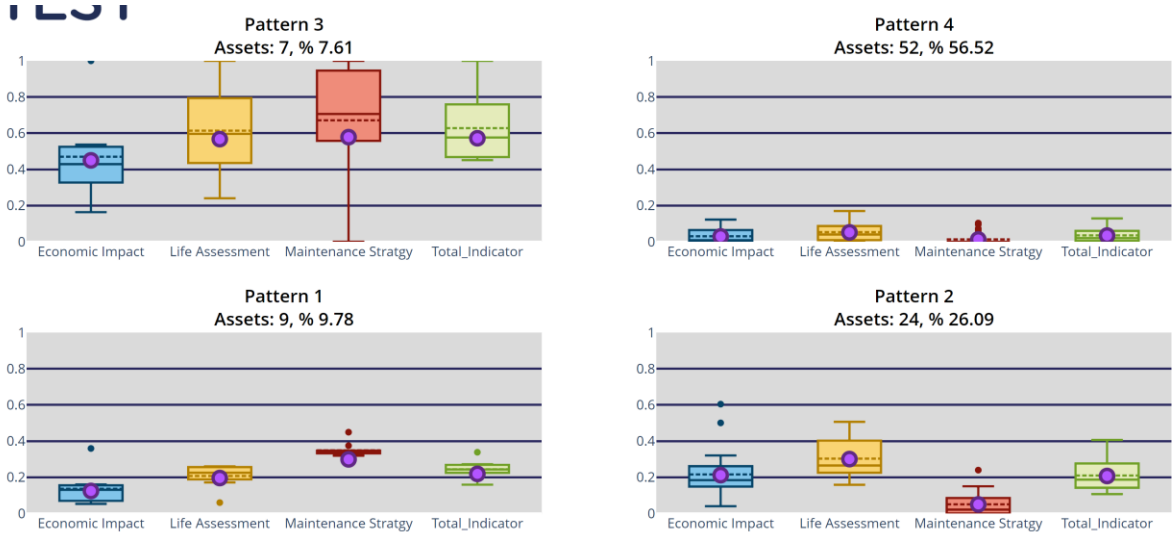


FIGURE 49 SPANISH TRAFO(FUTURE SCENARIO I)

NAME	ECONOMIC IMPACT	LIFE ASSESSMENT	MAINTENANCE STRATGY	TOTAL_INDICATOR
28CDR2	0.849	0.647	0.711	0.736
28CHHS	0.456	0.599	0.739	0.598
28CQPQ	0.414	0.477	0.43	0.441
28CYL3	0.364	0.388	0.522	0.424
28PCAT	0.301	0.8	0.0	0.367
28CIA7	0.27	0.335	0.406	0.337
28CDR5	0.139	0.192	0.664	0.332
28CHQD	0.513	0.352	0.032	0.299

NAME	EI	LA	MS	ACTION
19A649	L	L	L	Keep the current maintenance
19A650	L	L	L	Keep the current maintenance
19A716	L	L	L	Keep the current maintenance
19A754	L	L	L	Keep the current maintenance
19P814	L	L	L	Keep the current maintenance
28AGM9	L	L	L	Keep the current maintenance
28AIN3	L	L	L	Keep the current maintenance

FIGURE 50 RECOMMENDED ACTION FOR FUTURE SCENARIO I

Future SCENARIO II (10 years)

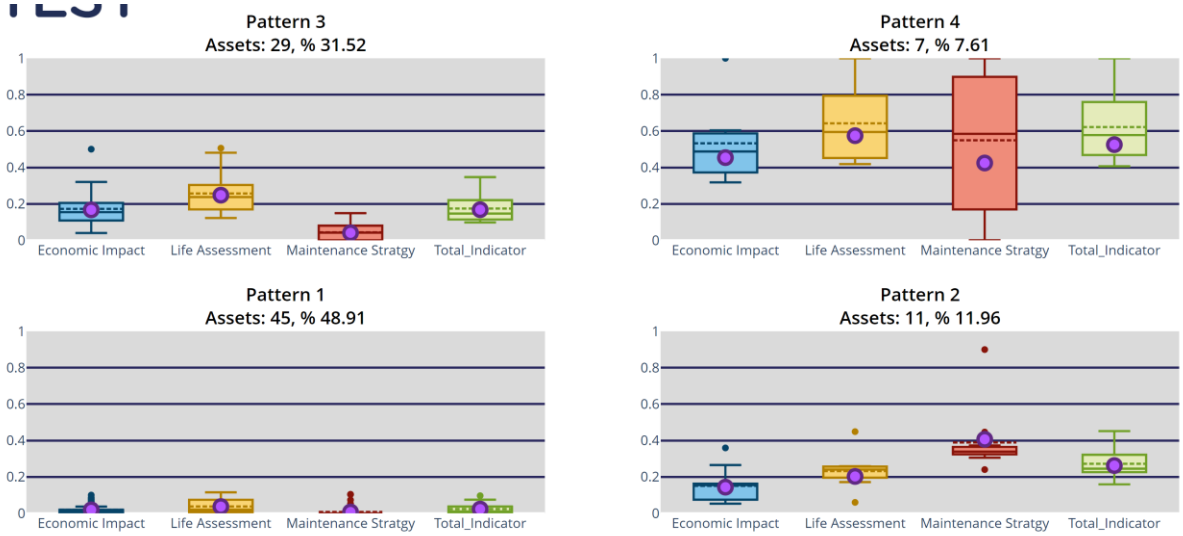


FIGURE 51 SPANISH TRAFO(FUTURE SCENARIO II)

NAME	ECONOMIC IMPACT	LIFE ASSESSMENT	MAINTENANCE STRATGY	TOTAL_INDICATOR
28CDR2	0.849	0.647	0.709	0.735
28CHHS	0.456	0.6	0.737	0.598
28CQPQ	0.414	0.476	0.431	0.44
28CYL3	0.364	0.388	0.521	0.425
28PCAT	0.301	0.8	0.0	0.367
28CIA7	0.27	0.335	0.405	0.337
28CDR5	0.139	0.192	0.663	0.332
28CHQD	0.513	0.353	0.032	0.299

NAME	EI	LA	MS	ACTION
19A649	L	L	L	Keep the current maintenance
19A650	L	L	L	Keep the current maintenance
19A716	L	L	L	Keep the current maintenance
19A754	L	L	L	Keep the current maintenance
19P814	L	L	L	Keep the current maintenance

FIGURE 52 RECOMMENDED ACTION FOR FUTURE SCENARIO II

Future SCENARIO III (15 years)

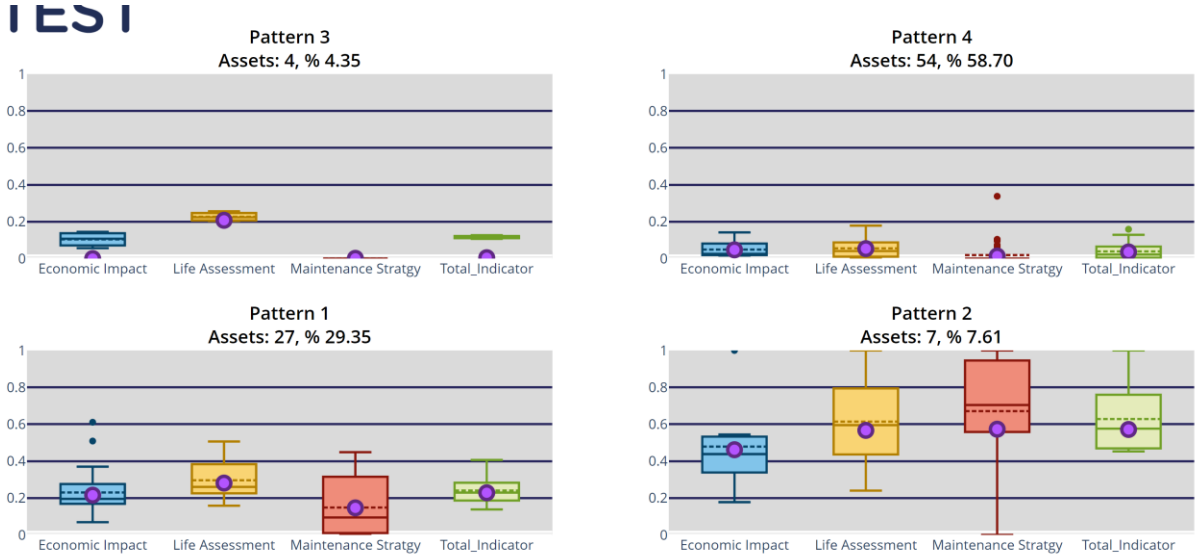


FIGURE 53 SPANISH TRAFO(FUTURE SCENARIO III)

NAME	ECONOMIC IMPACT	LIFE ASSESSMENT	MAINTENANCE STRATGY	TOTAL_INDICATOR
28CDR2	0.849	0.647	0.711	0.736
28CHHS	0.456	0.6	0.74	0.599
28CQPQ	0.414	0.476	0.431	0.44
28CYL3	0.364	0.388	0.521	0.424
28PCAT	0.301	0.8	0.0	0.367
28CIA7	0.27	0.336	0.407	0.338
28CDR5	0.139	0.192	0.666	0.333
28CHQD	0.513	0.353	0.032	0.299
28CUB0	0.272	0.405	0.09	0.256

NAME	EI	LA	MS	ACTION
19A649	L	L	L	Keep the current maintenance
19A650	L	L	L	Keep the current maintenance
19A716	L	L	L	Keep the current maintenance
19A754	L	L	L	Keep the current maintenance
19P814	L	L	L	Keep the current maintenance

FIGURE 54 RECOMMENDED ACTION FOR FUTURE SCENARIO III

8. References

[1] R. S. Sutton and A. G. Barto. Reinforcement Learning. MIT Press Second Edition, 2018

[2] A. Barbu, S. Zhu. Monte Carlo Method. Springer Verlag, ISBN-10: 9811329702, 2020