# AN INNOVATIVE ANALYTICAL NETWORK PROCESS MODEL FOR EVALUATION AND MANAGEMENT OF MAINTENANCE PROJECTS IN ENGINEERING PLANT FIELD

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**ABSTRACT**
The proposed paper presents: the description and the analysis of an Analytic Network Process Model for the evaluation and the management of maintenance projects in engineering plant field.
The study was made in Ansaldo Energia (AEN), Italian company active in the energy sector, one of the world's major power plant producers.
The test cases are three power plants belonging to three important Service customers. Three service contracts that respectively represent, from an HSE (Health Safety Environment) point of view, the "as was", the "as is" and the "to be" are presented and discussed aiming to demonstrate that HSE could be improved in a systematic way. These three examples are characterized by an increase in HSE preventive activities more than the simple actions required to be compliant with HSE laws and rules. The complex of the HSE measures, known in Ansaldo as "HSE package", are generally proposed in service contracts with the aim of improving the overall Customer Satisfaction that, recently, is strictly connected with HSE. Due to a rising general awareness of HSE, many general contractors are facing the complex trade-off among HSE performances improvement and other project KPI (Key Performance Indicator) related to cost saving, making this business even harder than expected. Finally this paper tries to answer these research questions: Is the HSE project with more preventive actions effectively the best project to be implemented by Ansaldo? How much does an improvement of Customer Satisfaction and HSE cost to the company in terms of time and effort?

**KEY WORDS**
Analytic Network Process; Health Safety and Environmental; Power Plant.

## 1. Introduction

Analytical Network Process (ANP) is a methodology developed by the American researcher Thomas L. Saaty and theorized in several books from 1996 [1 - 5].

ANP is a new theory that extends the Analytical Hierarchy Process (AHP) [6], the simplest method for ranking decision alternatives and selecting the best one when the decision maker has multiple criteria. It makes possible to deal with complex decision problems, hardly represented using a hierarchical scheme as including all kinds of dependence, interaction and feedback.
The transition from a linear hierarchical structure, unable to reflect the complexity of real problems, to a more dynamic structuring, able to better reflect the complex interactions related to the various components of a system, is the evolution from AHP Process to ANP Process (Figure 1).

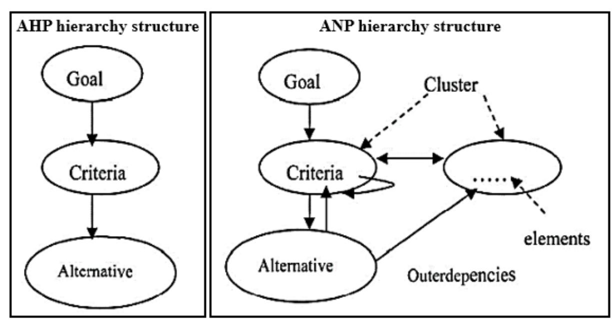


Figure 1. AHP and ANP hierarchy structure of a decision problems [7].

In ANP Process, every decision problem is structured as a network of elements arranged in groups according to multiple influence relations. This configuration allows to achieve a structure able to incorporate interdependent and feedback relations, in every group of elements and/or between the different groups of elements. Considering the existence of feedback, in fact, not only the alternatives can depend on criteria, such as in a hierarchy, but also the criteria can depend on alternatives and on other criteria considered. ANP is emerging as instrument particularly effective in the evaluation of complex systems, thanks to its dynamic approach and to its ability to model the various relations between the components of a problem.
In the study presented in this paper, the ANP method is used in an innovative way. Its use is extended from a decision-making method to an evaluation and

management method of maintenance projects for a company in the engineering plant field [8, 9].

## 2. ANP Model construction theory

The main steps that lead to the creation of an ANP Model are:

1. Decision problem structuring

Each complex decision problem is decomposed into elementary parts, called "nodes", then grouped into homogenous group, called "cluster" of elements, in order to create a network (or networks) characterized by dependencies, interactions and feedbacks between these elements.

In particular, it is necessary to identify:

- The "goal", that is the objective to be achieved with the evaluation;
- The clusters of criteria, that guide to the general objective;
- The clusters of alternatives, which represent the possible solutions of the decision problem;
- The elements, or nodes, that define each specific cluster.

Then, it is necessary to identify the relationships between the different elements of the network created. There are two possible ways to structure the decision-making model:

- The simple network, which consists of a network of relationships developed between clusters of criteria, specific elements and alternatives of choice;
- The complex network, which presupposes the existence of a control hierarchy that gives origin to subnets organized according to the structure "simple", in which groups, elements and alternatives are.

The model presented later is structured in a simple network.

2. Pair-wise comparison matrices

After the construction of the model, the evaluation is done through the pair-wise comparison method. The comparison process follows a trend to "network", in which, imposing alternatively every element of the network as "parent", a preference judgment is expressed through the implementation of multiple pair-wise comparisons between all elements that were attached to it ("son"). During the course of the different pair-wise comparisons, a binary preference relation is established between two elements, compared with respect to the parent node.

The judgments used to make comparisons are not purely subjective, but often they derive from experts of the sector. The analysis presented was carried out with the help of the AEN HSE sector internal personnel.

The numerical judgments are based on "The Fundamental Scale of Saaty", a scale of values from 1 to 9 [Table 1].

There are many situations in which the elements are equal in the evaluation.

The comparison must be made not to determine how much one is larger than the other, but in which fraction is larger than the other. In other words, there may be comparisons in which you want to estimate verbally the values including, for example, between 1 and 2, as 1.1, 1.2, 1.3, etc. There is no problem in expressing the comparisons directly numerically: the Direct method is the input method used in the development of the model presented later. The verbal scale can be changed to make these distinctions in order to highlight also minimal differences.

Table 1. Scale for pair-wise comparison [10]

| **Preferences expressed in numeric variables** | **Preferences expressed in linguistic variables** |
|---|---|
| 1 | Equal importance |
| 3 | Moderate importance |
| 5 | Strong importance |
| 7 | Very strong importance |
| 9 | Extreme importance |
| 2, 4, 6, 8 | Intermediate values between adjacent scale values |

The numerical values established create square pair-wise comparison matrices at each level of the network.

Following the compilation of the matrices, it is possible to determine for each the priorities of the respective components. This is done through the extraction, from each matrix, of the main eigenvector that is, in numerical terms, the synthesis of the preference judgments expressed.

3. Super Matrix creation

The approach of Super Matrix allows ANP to incorporate and manage dependencies and feedback in the decision-making system.

There are three Super Matrices used in ANP Model:

- Unweighted Super Matrix;
- Weighted Super Matrix;
- Limit Super Matrix.

The Unweighted Super Matrix consists of the priority vectors obtained by pair-wise comparison. This super matrix represents the influence flows identified in the network. The values in the unweighted super matrix don't take into account the different weights assigned to the clusters; for this reason, it is necessary a second super matrix , the Weighted Super Matrix, obtained by multiplying the values of unweighted super matrix per the matrix obtained at the level of the comparison between the clusters.

Multiplying the weighted super matrix per itself a number of times tending to infinity, the result is the Limit Super Matrix. Its columns contain the vector of the priority of the elements analyzed.

In a simple network, the ranking of alternatives priority is obtained directly in the limit super matrix.

## 3. ANP Model in the engineering plant field

As mentioned above, in the study presented in this paper, the ANP technique is used in an innovative way, as an evaluation and management method of maintenance projects for a Company, Ansaldo Energia in this case, in the engineering plant field.
The goal is to determine the best HSE project referred to three power plants.
For reasons of secrecy, the three projects object of study, will be generically called Project A, Project B and Project C. They are three maintenance projects of three different Ansaldo customers related to three Italian power plants.
The Project A represents the "as was", the old management. It is lacking in a system for the availability of information and this is reflected in the fact that any work was not carried out in order to identify and register additional actions to the legal obligations made in the HSE area. The amount of these assets is obviously small compared to the assets found in the other two projects. Of these ones, a summary document, speaking about all HSE actions carried out, was made.
The Project B represents the "as is", the transition phase from the old to the new HSE management, and the Project C the "as to be", the new management, more focused and attentive in safety and environment aspects.
The following analysis wants to verify that the new management, the "Project C type", is actually better, through a global assessment that takes into account not only the HSE aspect.
The best HSE project for Ansaldo, taking into account 4 criteria:

- Customer Satisfaction (CS);
- Importance of HSE for Ansaldo Group and its brand;
- Costs;
- Time.

This is another innovative aspect introduced by the analysis presented. The use of the ANP, born in economic field for the evaluation of alternatives on the basis of correlated criteria, is carried out not only in a different field but also on the basis of criteria hardly correlated in order to make an analysis that has as its aim their correlation to find a result that takes into account each of them equally and simultaneously.
It is not guaranteed that the best HSE project for the customer is the best project for Ansaldo. Other 3 criteria, in fact, influence the choice of the project.
Improving the customer satisfaction may mean higher costs and more time for the Company. We must find the meeting point between CS and the other criteria.
Similarly, improving the HSE aspect may mean an improvement of CS but also an increase of costs and time. This increase, however, may be necessary for the Company in order to avoid accidents, dangerous to employees' health and to environment safety, which could be much more onerous. Since the question is: what is the maximum increase of costs and time that could protect the Company for the future without exceeding?
On the contrary, decreasing costs and time may mean a decrease of CS and HSE aspects, but on the other hand also an improvement in economics terms.
Based on the four criteria weights assigned by Ansaldo internal engineering, the study presented evaluates the optimum HSE project.
A priori, it cannot be said certainly whether the best one will be the project with a higher number of additional activities to legal obligations.

## 4. The test case ANP Model

The development in operational terms of ANP models is supported by SuperDecisions software [11].
The program was written by the ANP Team, working for the Creative Decisions Foundation. It sponsors education, research and software development in advanced methods of analytic decision-making; its goal is "to Change the Way We Measure Things" [12].
The model implemented is shown in the figure below (Figure 2).

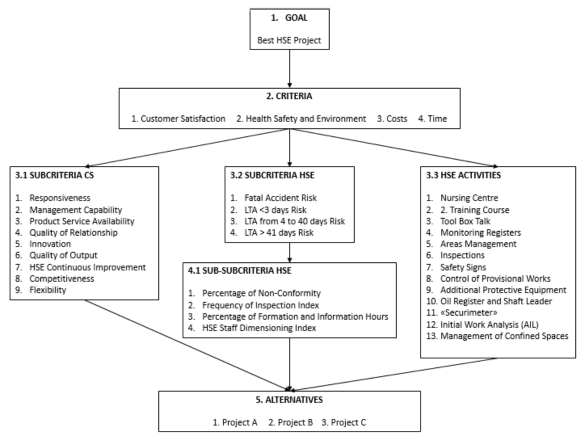

Figure 2. ANP Model Implementation

The analysis goal is to find what is the best HSE project for Ansaldo Group in terms of Customer Satisfaction, Health Safety and Environment, costs and time.
The four criteria are not directly related to the alternatives cluster. Otherwise, an extremely simplified analysis would be obtained, in which it would be only necessary to assign an importance order of the criteria and to make a comparison of the projects considering CS, HSE, costs and time aspects globally.
A global analysis is obviously unreliable. To make a detailed analysis it has been necessary to add sub-criteria, so that each project is compared not globally but on the basis of individual factors for each criteria.
Last cluster is obviously made up of the alternatives, the three HSE Projects.
Following, there is a description of the sub-criteria clusters.

1. Sub-Criteria CS

The sub-criteria used in Customer Satisfaction area are the 9 macro-factors that subdivide, in 9 groups, the questions of the CS survey questionnaires that Ansaldo Group sends to its customers in order to verify their satisfaction and to discuss the progress of works.

The 9 macro-factors are:

- Responsiveness: promptness of Ansaldo to answer various items regarding commercial, management and technical issues.
- Management Capability: capability of AEN personnel about contract management (resources, timing, documentation, internal and external interfaces);
- Product/Service Support: availability, reliability and maintenance of AEN products;
- Quality of Relationship: quality, reliability and experience of AEN personnel and capability of communication to the customer;
- Innovation: AEN technological innovation level, capability of conforming to the market and continuous upgrading of its own processes;
- Quality of Output: quality for product/service supplied under ever aspect (technical documentation, planning, report and security, inspection and maintenance activity);
- HSE Continuous Improvement: the assessment of AEN management about its attention to security and environmental impact;
- Competitiveness: assessment of product competitiveness about quality, reliability and costs;
- Flexibility: flexibility for contract management depending on customer needs.

These 9 sub-criteria allow to simplify the assignment of weights to each sub-criteria. It will be based on an order of importance, shown in Table 2, obtained from the last annual audit between the Business Unit (New Unit and Service) directors and the Customer Satisfaction Manager. One of the topics of this annual audit is the analysis and evaluation of the customers' assessment about the previous year. Based on it, the macro-factors ranking that best represents the customer is evaluated. This is made possible thanks to the structure of the questionnaires that, even if they have different questions on the basis of their different aims (the evaluation of a contract, the evaluation of a maintenance inspection, the global evaluation of the relationship with AEN and its personnel, etc.), are all divided into 9 macro-factors and ask the customer to express an order of importance for them.

The value associated with a single macro-factor in Table 2 is not a pure mean of all values associated with it in the rankings of the various questionnaires of the previous year. The associated value in the table is the most frequent value associated with the macro-factor (a.k.a. modal value).

In this way, an abnormal relative ranking cannot affect the result from the most frequent ranking chosen by customer, thus ensuring a better coherence of the results.

The 9 sub-criteria allow to simplify not only the assignment of weights to the level of sub-criteria, but also the comparison of the three projects for each sub-criteria to the level of alternatives.

Table 2. Macro Factor groups importance 2015

| **MACRO FACTOR GROUPS** | **RANKING**<br>1 = Minimum relative<br>9 = Maximum relative importance |
|---|---|
| 1. Responsiveness | 6 |
| 2. Management Capability | 5 |
| 3. Product/Service Support | 3 |
| 4. Quality of Relationship | 7 |
| 5. Innovation | 3 |
| 6. Quality of Output | 7 |
| 7. HSE Continuous Improvement | 9 |
| 8. Competitiveness | 4 |
| 9. Flexibility | 6 |

It will be based on the averages of rates for every macro-factor group of questions, shown in Table 3, obtained from the questionnaire, sent to the three customers, about the evaluation of the last maintenance inspection carried out by Ansaldo Energia in the three power plants.

Table 3. Macro-Factor groups average

| **MACRO FACTOR GROUPS** | **A** | **B** | **C** |
|---|---|---|---|
| 1. Responsiveness | 6.3 | 9.2 | 9.0 |
| 2. Management Capability | 6.3 | 9.3 | 8.4 |
| 3. Product/Service Support | 6.3 | 9.0 | 9.0 |
| 4. Quality of Relationship | 6.6 | 9.2 | 8.5 |
| 5. Innovation | 7.0 | 9.0 | 8.0 |
| 6. Quality of Output | 5.9 | 8.9 | 8.2 |
| 7. HSE Continuous Improvement | 6.6 | 7.7 | 8.1 |
| 8. Competitiveness | 6.8 | 9.3 | 6.6 |
| 9. Flexibility | 5.1 | 9.7 | 8.3 |

For reasons of secrecy required by the company, it is not possible to show the entire CS Survey.

Then, the 9 sub-criteria allow to perform an analysis on the basis of reliable and tangible data.

2. Sub-Criteria HSE

The sub-criteria used in HSE area are the occurrence risks of an accident. A breakdown of the risks is carried out on the basis of the amount of prognosis days that the accident can cause. A prognosis shorter than 3 days does not require complaint. Between 3 and 40 days, the complaint must be done according to legal obligations. An accident with prognosis of more than 41 days shall initiate an investigation by Judicial Police Force office and then it open a criminal proceeding.

Based on what has been said, the HSE sub-criteria are:

- Fatal Accident Risk;
- Risk of accident with prognosis more than 41 days (Lost Time Accident > 41 days);
- Risk of accident with prognosis from 4 to 40 days;
- Risk of accident with prognosis up to 3 days.

The model mentions “risk of accidents” and not “number of accidents”, because it is of interest to know what is the project with the highest occurrence probability of an event. A project with a small number of preventive activities may not be characterized by a fatal accident but this does not mean it is a safety project.

It is not easy to evaluate directly the occurrence risk of an event, so an additional block of “sub” sub-criteria containing the main evaluable factors that affect the risks is created:

- Percentage of Non-Conformity detected, based on the number of inspection carried out;
- Frequency of Inspections Index;
- Percentage of Formation and Information Hours;
- HSE Staff Dimensioning Index.

This makes it easier to compare the projects. This rate, in fact, is available from interviews with the HSE personnel and from the final reports of the majors present in the HSE Office.

2.1 Sub-Criteria Costs and Time – HSE Activities

The sub-criteria cluster, in terms of cost and time, is the set of HSE activities carried out in addition to legal obligations.

From a careful analysis of the final reports, the sub-criteria identified are:

- *Nursing Centre*;
- *Training Courses*;
- *Tool Box Talk*;
- *Monitoring Registers*;
- *Areas Management*;
- *Inspections*;
- *Safety Signs*;
- *Control of Provisional Works*;
- *Additional Protective Equipment*;
- *Oil Register and Shaft Leader*;
- “*Securimeter*” (interviews with workers and bonus point assigned);
- *Initial Work Analysis* (AIL);
- *Management of Confined Spaces*.

The weight to each sub-criteria is assigned on the basis of a meeting with the Prevention and Protection Office of Ansaldo. The comparison of the projects determines the presence or absence of an activity and, if present, in what amounts.

## 5. Process of Data Synthesis

After finishing the construction of the model, it is possible to assess and to upload the data into the ANP Software using the *Direct method*.

An evaluation questionnaire has been realized in order to obtain the preference relations and the importance degree between the various nodes and clusters of ANP model safety side. This questionnaire has been proposed to the HSE staff and in particular has been compiled by the AEN Prevention and Protection Service Manager (PPSM).

In the survey, it is required to assign a rating of importance from 1 to 9 to the various elements constituting the model, following “The Fundamental Scale of Saaty” (Table 1).

Concerning the data about Customer Satisfaction, relying on CS surveys as explained in previous section (Table 2).

As first requirement, the evaluation survey needed to assign a rating of general importance to determine which aspect was more important from a global point of view:

- Customer Satisfaction: 7;
- Health, Safety and Environment: 9;
- Costs: 3;
- Time: 5.

This valuation, once again, underlines the importance of Health Safety and Environment aspects in a maintenance project. Drawing attention to HSE activities, in fact, it has not to be considered a cost but an investment that could protect the company, also in a legal way, from and in case of accident.

The second question, proposed in the survey, goes into the detail of HSE criteria:

- Fatal Risk: 9;
- LTA < 3 days Risk: 5;
- LTA from 3 to 40 day Risk: 7;
- LTA > 41 days: 8.

This degree of valuation is the consequence of what has been previously said.

The next step is to determine and valuate the indexes that could influence the category of risk:

- Percentage of Non-Conformity: 1;
- Frequency of Inspection Index: 9;
- Percentage of Formation and Information Hours: 7;
- HSE Staff Dimensioning Index: 9.

The *Non-Conformity* is a deviation from the adopted standards or failure to comply with legal requirements, regulations, practices, procedures, operational instructions, or with the framework of the management system adopted. According to statistics, one fatal event happens every 750.000 non-conformities and so this aspect has not an important influence on fatal accidents risk.

Concerning the *Frequency of Inspection Index*, more inspections are synonymous with better prevention and thus they have a positive impact on the non-occurrence of an accident, fatal or not. In fact, at the moment in which a lack is detected, it decreases the probability that this failure may trigger an event, and also the severity of the accident. Therefore, the number of inspections has the maximum importance in the prevention and in the protection from an accident.

The same approach is followed with the *HSE Staff Dimensioning Index*. The greater the number of HSE personnel, the greater of the number of inspections carried out.

Also the *Formation and Information Hours* play an important role in order to obtain a high level of safety. Workers properly trained and informed, in fact, perform their activities in a safer and more reliable way, avoiding unnecessary risks.

The evaluations of the HSE activities impact on costs and time are:

- Nursing Centre: 1 for costs, 7 for time;
- Training Courses: 6 for costs, 5 for time;
- Tool Box Talk: 2 for costs, 6 for time;
- Monitoring Registers: 2 for costs, 6 for time;
- Areas Management: 5 for costs, 8 for time;
- Inspections: 2 for costs 2 for time;
- Safety Signs: 8 for costs, 8 for time;
- Control of Provisional Works: 2 for costs, 4 for time;
- Additional Protective Equipment: 7 for costs, 9 for time;
- Oil Register and Shaft Leader: 8 for costs, 9 for time;
- "Securimeter": 5 for costs, 6 for time;
- Initial Work Analysis (AIL): 5 for costs, 4 for time;
- Management of Confined Spaces: 5 for costs, 4 for time.

It is necessary to consider that in these cases the valuation method is inverse: 9 is the mark that certificates the minimum impact, 1 is the value that indicates the maximum impact. For the purpose of this analysis, in fact, it is necessary to assign greater weight to activities that have minor costs and time.

Following some analyses and motivations of the main ratings given by experts.

The *Nursing Centre* has a great impact in term of costs because it requires the permanent presence of a qualified person. Differently concerning the time, it influences but not significantly, because making a proper prevention, you can avoid serious injuries and so the presidium does not take over.

The *Training Courses* have, instead, little impact since they are mainly legal requirements and so common to all three projects.

*Tool Box Talk* is important and it needs a dimensioned structure. In some cases, it requires more than one people, and this obviously implies an impact at an economic point of view. It however has a lower impact than the nursing supervision. Concerning the time, Tool Box Talk affects about half an hour each, so if you consider 2 tool box talks per day you calculate 1 hour per day for 45 days, it accounts for around 0.8% of the total time of the major inspection. So, little incidence.

As the Tool Box Talk, also the *Monitoring Registers* are tasks of the HSE Office, as well as all activities that insists on the safety personnel. Such activity may requires a single officer but if it will be better structured it may ensure a higher safety level with the consequence is additional costs. Tool Box Talk, Monitoring Registers, Inspections and Control of Provisional Works, which will be seen later, are all activities that are under the responsibility of the HSE Office and then it will be given an equal weight, in term of costs, to all these ones. Regarding the time, Monitoring Registers have a quite small impact, while Control of Provisional Works and Inspections, in particular, have a higher impact.

*Additional Protective Equipment* individually have a relatively high cost, but there are usually one for working tools containers and so they weight little on full costs. Concerning the time, they are ready to use, so minimum impact in term of time.

The activity of *Oil Register and Shaft Leader* has a low impact in term of cost and time because it requires no additional human resources.

The *Management of Confined Space* requires training, specific equipment, and everything that involves the possible recovery of a worker in an emergency. All these aspects involve costs and time.

Once attributed the values to the nodes that constitute the clusters, it is necessary to assign the single value of the three projects in relation to these nodes.

Concerning the data about Customer Satisfaction, relying on CS surveys as explained in previous section [Table 3].

Regarding the HSE indexes, the values are calculated directly:

- *Percentage of Non-Conformity*:

$$\frac{n° \; Non \; Conformity}{n° \; Inspections} \tag{1}$$

This formula has been designed in order to create a more realistic solution to represent the lack of attention in HSE aspects. A large number of Non-Conformities, in fact, could not depend only on the lack of HSE attention and care but also, obviously, on the number of inspections carried out to identify them. The identification of non-conformity is very important since every non-conformity found is a potential risk eliminated.

Dividing the number of non-conformities by the number of inspections, thus, the relation between number of inspection, that is a positive aspect, and number of non-conformity is eliminated.

In order to give more weight to the project with a minor number of Non-Conformity Percentage, in the software the inverse value of the index just calculated is reported, and so how many inspections found a non-conformity.
The results of the data collected are that the Project A has approximately three non-conformity per inspection, while the other two projects have better results.

- *Frequency of Inspection Index*:

$$\frac{n° \, Inspections}{total \; days \; worked} \tag{2}$$

In this case, the number of inspections and the total days worked during the major inspection are related in order to obtain the frequency. The only number of inspections, in fact, is not so representative of the HSE quality.
In Project A there is only one safety person for an activity that involves an average of 80-90 people, compared with 2 settled employees in Project B and 5 in Project C.

- *Percentage of Formation and Information Hours*:

$$\frac{total \; hours \; of \; formation \; and \; information}{total \; hours \; worked} \tag{3}$$

As regards the Project A major inspection, it has been conducted an initial induction of 1 hour to all workers involved, and so approximately 80 formation and information hours.
In the Project B, it has been realized an initial induction of 1,5 hours to all workers involved and also 6 tool box talk of 2 hours each. Therefore, a total value of 132 hours of formation and information is obtained.
In the Project C, HSE staff has done 276 hours of formation and information.

- *HSE Staff Dimensioning Index*:

$$\frac{n° \, HSE \; personnel}{total \; workers} \tag{4}$$

Also in this case the number of HSE personnel on the total number of the workers during the major inspection activities has been weighted, in order to consider the size of the project itself. The results obtained are shown in Table 4.
The last values that the ANP model needed indicate what safety activities were presents during the three major inspections.
As in the case of costs and time explained just above, also in this evaluation an inverse rating scale is used: 9 is the mark that certifies the absence or the minimum presence of the activities in the project considered, 1 is the value that indicates the maximum presence.

Table 4. Project A, Project B and Project C indexes values

| **HSE index** | **A** | **B** | **C** |
|---|---|---|---|
| $\frac{1}{\text{Percentage of Non} - \text{Conformity}}$ | 1.1 | 4.7 | 3.3 |
| Frequency of Inspection Index | 1 | 2 | 6 |
| Percentage of Formation and Information Hours | 0.2 | 0.3 | 0.6 |
| HSE Staff Dimensioning Index | 0.01 | 0.03 | 0.06 |

This is, in fact, the continuation of the costs and time analysis. In this sense, the presence of the HSE activity in a project represents a disadvantage in term of costs and time; therefore, we need to consider better a condition where there is lack of activities compared with a situation where the HSE activities are presents.
The results obtained by the interview with HSE Staff are shown in Table 5.
The *Nursing Centre* is completely absent in the Project A major inspection; in the Project B there was a nursing presidium of the customer, thus without impact in terms of costs and time for Ansaldo, while in the Project C it was completely provided by Ansaldo Energia.

Table 5. HSE activities related to Project A, Project B and Project C

| **HSE Activity** | **A** | **B** | **C** |
|---|---|---|---|
| Nursing Centre | 9 | 9 | 1 |
| Training Course | 9 | 8 | 7 |
| Tool Box Talk | 9 | 6 | 1 |
| Monitoring Registers | 7 | 6 | 1 |
| Areas Management | 7 | 6 | 1 |
| Inspections | 9 | 8 | 5 |
| Safety Signs | 5 | 1 | 1 |
| Control of Provisional Works | 5 | 3 | 1 |
| Additional Protective Equipment | 9 | 1 | 9 |
| Oil Register | 1.25 | 1 | 1 |
| “Securimeter” | 9 | 1 | 9 |
| AIL | 9 | 9 | 1 |
| Management of Confined Spaces | 1.25 | 1 | 1 |

Concerning the *Training Courses*, as mentioned above, in the Project A the minimum hours required by law were carried out, in the Project B major inspection more-in-depth inductions were provided by Ansaldo, while during the Project C, the HSE staff focused a lot on this aspect reaching even the number of 276 formation and information hours.
As regards the *Tool Box Talk*, they were completely absent in the Project A, in the Project B they were carried out occasionally for a total of 6 meetings of 2 hours each, while in the Project C major inspection HSE staff

provided one tool box talk before each work-shift of the personnel.
Talking about *Monitoring Registers*, the personnel interviewed assigned grade 7 to the Project A for the presence of few registers, grade 6 to the Project B that has also the register of work permits and confined spaces register, while it was assigned grade 1 to the Project C for the presence of a high amount of monitoring registers such as scaffolding register, confined spaces register, register of work permits, tool box talk registers, extinguishers registers and many others.
The same considerations has been done to evaluate the presence of *Area Management* in the three projects.
As mentioned above, the number of *inspections* is directly influenced by the number of the HSE personnel present on the three plants during the maintenance activities, and so it has been assigned a mark that consider the presence of 1 HSE supervisor in the Project A, 2 HSE supervisors in the Project B and 5 HSE supervisors in the Project C.
The same could be said for the *Control of Provisional Works*.
Concerning the Safety Signs, Project C and Project B were both very conscious to this type of preventive measure, for the Project A, instead, it has been assigned only a sufficient evaluation grade.
Additional *Protectives Equipment* were used only in the Project B, while they were absent in the Project A and the Project C.
The "*Securimeter*" strategy is present only in the Project B, while the *Initial Work Analysis* only in the Project C.
Concerning the *Oil Register and Shaft Leader* and the *Management of Confined Spaces*, these activities are presents in every project, but with a different grade of attention linked to the different sizing of the HSE staff.

## 6. Validation Tests

Before carrying out the pair-wise comparison relative to the alternatives cluster, a series of model validation analysis is conducted [13], in order to verify the stability of the final preference ranking and thus the robustness of the model.

1. Extreme Value Analysis

The Extreme Values Analysis is a simple analysis that represents the first validation phase of the model. It consists of considering two alternatives, the generic projects X and Y.
The first alternative, the project X, is very bad. The second alternative, the project Y, is optimal. In a comparison phase then it is assigned minimum weight, 1, to the project X and maximum weight, 9, to the project Y for each sub-criteria.
It expects to obtain the following final evaluation, normalized to 1, of the two projects:

- Project X: 0.1;
- Project Y: 0.9.

The results obtained in the Limit Super Matrix are as expected. The Extreme Values Analysis for 2 projects is verified.

The same analysis was made to verify the validity of the model to compare simultaneously three alternatives, or three generic projects, and not just two.
The first alternative, the project X, is very bad. The second alternative, the project Y, is intermediate. The third alternative, the project Z, is optimal. In comparison phase then, the minimum weight is assigned to the project X, 1, intermediate weight to the project Y, 5, and maximum weight to the project Z, 9, for each sub-criteria.
Similarly to what was said before, it is expected to obtain the following final evaluation, normalized to 1, for the three projects:

- Project X: 0.067;
- Project Y: 0.333;
- Project Z: 0.6.

The Limit Super Matrix obtained shows results as expected. The Extreme Values Analysis for 3 projects is verified.

2. Sensitivity Analysis

The sensitivity analysis is made to test the sensitivity of the ANP model to changes of the system parameters. Also in this case, the analysis should have trivial solutions expected.
First of all, it creates a cluster with 2 alternatives:

- The project X, average-low, to which it assigns weight 3 for each sub-criteria;
- The project Y, average-high, to which it assigns weight 7 for each sub-criteria.

It attends to obtain the following final results, normalized to 1, for the two projects:

- Project X: 0.3;
- Project Y: 0.7.

The Limit Super Matrix shows results as expected.
At this point, the Sensitivity Analysis consists in the model modification: first, amplifying the difference between the weights always allocated symmetrically (2 to project X, 8 to project Y), and then, decreasing the difference (4 to project X, 6 to project Y).
We expect symmetric solutions, normalized to 1, with respect to the middle of the fundamental scale of Saaty.
The two Limit Super Matrices show results as expected. The Extreme Values Analysis is verified in both cases.

## 7. Results

Inserting the effective comparison values, shown in Table 3, at the level of the alternatives cluster and so going to compare the three projects, the software provides, as output, the Limit Super Matrix.
Analyzing the matrix through a global view, it shows the consistency of the results obtained with the values entered in the model at the level of each cluster. The rankings

obtained for each cluster, in fact, are reasonable and foreseeable on the basis of the HSE Office interview.
In particular, observing the final part of the matrix, known as the synthesis, it allows to analyze the results obtained from a global point of view on a level of the criteria cluster (Table 6): is possible to see the results for overall criteria (goal) and for single criteria as well.

Table 6. Synthesis part of Limit Super Matrix

| | GOAL | CS | HSE | COSTS | TIME |
|---|---|---|---|---|---|
| **A** | 0.0860 | 0.1338 | 0.0441 | 0.2418 | 0.2456 |
| **B** | 0.0910 | 0.1904 | 0.0892 | 0.1359 | 0.1482 |
| **C** | 0.1192 | 0.1758 | 0.2000 | 0.1224 | 0.1061 |

As expected, in terms of HSE Project C prevails, followed by Project B and finally by Project A. On the contrary, obviously, in terms of costs and time Project A is preferable, followed by Project B and finally by Project C. In terms of Customer Satisfaction, the resulting ranking is Project B, ranked first, Project C, second, and Project A, third. This result is expected if carefully observing, in Table 3, the average of the rates assigned by the customers to the questions of the CSS questionnaires, despite the Project B Project has less HSE preventive activities than Project C project.
Although the rates given are subjective from customer to customer, the questionnaire takes place involving the CS Manager who has the task of intermediating the customer rates on the basis of Ansaldo yardstick, in order to make a "subjective" rate as an "objective" rate. Based on this, the input values and the output results of the software, can be assume coherent related to the HSE criteria.
It is useful to report the ranking results obtained in percentage terms, shown in Table 7 below.

Table 7. Percentage results of the synthesis part of Limit Super Matrix

| | GOAL | CS | HSE | COSTS | TIME |
|---|---|---|---|---|---|
| **A** | 29.04% | 26.76% | 13.22% | 48.35% | 49.13% |
| **B** | 30.72% | 38.08% | 26.77% | 27.17% | 29.64% |
| **C** | 40.24% | 35.17% | 60.01% | 24.47% | 21.23% |

The percentage results allow to have an immediate view of what distinguishes a project from another.
In terms of HSE, Project C prevails much over the projects A and B, although Project B is preferable compared to Project A. In term of CS, costs and time, the projects B and C are very similar. Analyzing the goal, the Project A and the Project B differ only of one percentage point.
In addition to the rankings, which is easily predictable, what is curious and needs to be analyzed, for the purpose of the study presented, is how the transition from a project to another impacts in terms of CS, HSE, costs and time.
So let's see how a project is worse or better than another project in function of the four criteria. In order to have a more immediate impact to understand the results, they will be expressed in percentage terms.

With the purpose of comparing and to quantifying how much a project is better than another in terms of HSE, CS, Costs and Time, an analysis of the percentage change is made with the following formula:

$$B\ respect\ A = \frac{Project\ B - Project\ A}{Project\ A} \qquad (5)$$

Figure 3 shows the results of the transition from A to C HSE management. In order to present performance more effectively, the diagram indicates with a *green arrow* the changes that characterize a positive improvement, with a *red arrow* the changes that characterize the negative consequences.

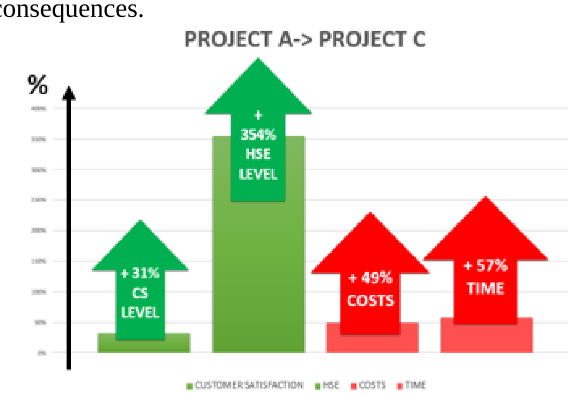


Figure 3. Consequences of the transition from Project A to Project C HSE approach

As shown in Figure 3, the evolution from Project A to Project C brings the following consequences:

- An increase of 31% of the Customer Satisfaction Level;
- An increase of 354% of the HSE Level;
- An increase of 49% of the Costs;
- An increase of 57% of the Time.

With similar reasoning, it can say that the transition from Project B to Project C brings:

- A decrease of 8% of the Customer Satisfaction Level;
- An increase of 124% of the HSE Level;
- An increase of 10% of the Costs;
- An increase of 28% of the Time.

Passing from Project A to Project B has the following consequences:

- An increase of 42% of the Customer Satisfaction Level;
- An increase of 102% of the HSE Level;
- An increase of 44% of the Costs;
- An increase of 40% of the Time.

The analysis shows that passing from a project characterized by the "Project A HSE philosophy" to a new project management, as Project C, leads to a potential growth of the Customer Satisfaction Level, and to a great increase, four time as much, of the HSE Level. At the same time, this evolution causes an increase of costs and times.

The same could also be said for the transition from a Project A to a Project B HSE management. In this situation, the HSE Level doubles its value, the CS Level increases more and there is always an increase in term of Cost and Time but less than the previous case.
From the comparison between Project B and Project C projects, instead, emerges that Project B is a little better in all aspects except in the HSE Level, for which the Project C is more than two times better than the other project. This aspect has the maximum impact in the choice of the best project and this justifies the supremacy of Project C also in relation to Project B project.

At this point, it is interesting to understand in the transition from a project to another, what are the effects of the variation of one percentage point of a parameter on the other aspects considered.
The dimensions of analysis focused on are:
*What is the impact in terms of HSE and CS level of any reductions of 1% of Costs and Time?*
*What is the impact of any increases of 1% of HSE and CS Level in terms of Costs and Time?*
In the paper, the analysis is carried out in order to understand how an increase of one percentage point in HSE impacts on Costs and Time. Similarly, the same analysis could be carried out to analyse the other cases.
The impact of HSE in terms of Costs and Time can be deducted through the comparison between the increase of Costs or Time, obtained in the transition from a project to another, respect the increase in terms of HSE that is consequences of this change of management.
For example, with the formula:

$$\frac{COST\ increase\ from\ A\ to\ C\ Project}{HSE\ increase\ from\ A\ to\ C\ Project} = 0.14\% \qquad (6)$$

It is deducted that in the transition from Project A to Project C HSE management, for any increase of 1% of HSE Level, an increase of 0.14 % of the Costs is obtained.
With the same criterion, every transitions can be analysed.
For the proposed examples the major conclusions could be drawn from the analysis of figures 4, 5 and 6 as discussed in the following.
Figure 4 shows the transition from the Project A to the Project C HSE management. It is clear that for any increase of 1% of HSE Level, an increase of 0.16% of the Time, of 0.14% of the Costs, and also an increase of 0.09% of the CS Level are obtained.
Figure 5 shows the consequences of the passage from the Project A to the Project B Management. In the transition, for any increase of 1% of the HSE Level, an increase of 0.38% of the Time, of 0.43% of the Costs, and also an increase of 0.42% of the CS Level are obtained.
Figure 6 represents the transition from the Project C to the Project B: for any increase of 1% of HSE Level, an increase of 0.23% of the Time, of 0.1% of the Costs and also a decrease of 0.06% of the CS Level are obtained. CS Level are obtained.


Figure 4. Transition from Project A to Project C in HSE Analysis


Figure 5 – Transition from Project A to Project B in HSE Analysis

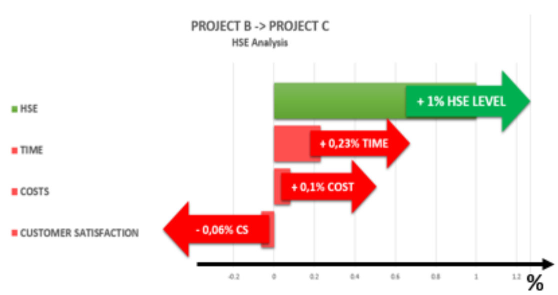


Figure 6. Transition from Project C to Project B in HSE Analysis

## 8. Conclusions

The proposed methodology was proven to be very effective in identifying the complex results/effort ratio for improving the HSE aspect of a project.
The analysis presented gives the possibility to show how the transition from a managerial approach to another will impact on the various project KPI (HSE performances, cost and elapsed time). Before the proposed approach

many of the hidden relationship among these KPI were just unknown or assessed only from a qualitative point of view.

The proposed methodology was proved to be very effective in providing a quantitative evaluation of the impact of the variation of one KPI over the others and is now regarded, inside of Ansaldo Energia, as one of the prominent methods to guide further improvement in the HSE commitment towards performance improvement.

The article presents only one side of the analysis, the impact of the HSE increase of one percentage points in terms of Costs and Time. A similar analysis can be done of course to investigate the impact of the CS increase of one percentage points in terms of Costs and Time, and vice versa the impact of the decrease of one percentage point of Costs and Time in terms of CS and HSE. Authors are applying Systems Dynamics modelling to investigate the complex interdependence among the actions required for improving the HSE and the expected results, results of such study will be published in an upcoming paper.

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