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# Developing an Optimization Model for Determining the Preventive Maintenance Period for Critical Machineries Using FMEA and ANP

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***Abstract*— given the importance of maintenance in the industry and the emergence of various kinds of maintenance techniques and approaches, it is crucial to have a model and general framework to use existing maintenance techniques. The aim of the present study is to develop a general framework for preventive maintenance of sensitive equipment in manufacturing enterprises with continuous processes such as refineries and petrochemical companies.**

**The proposed model detects factors affecting the maintenance approach using the ANP technique. A practical approach is developed through detecting the failure causes of sensitive equipment and classifying them using FMEA technique. The resulting model is tested on sensitive (unique) equipment in a petrochemical complex. According to the results, the reliability of maintenance plans was significantly increased from 56% to 87%.**

***Index Terms*— Fault detection, Impact analysis, Network analysis, Sensitive equipment's, Preventive maintenance.**

## I. INTRODUCTION

Maintenance engineering is of the main undeniable components of industrial and semi-industrial societies [1]. A system for maintenance techniques is a requirement for stable operation of equipment and continuous production. Accepting the famous philosophy of prevention before cure, there is no doubt about the necessity of establishing preventive maintenance approaches in various industries. However, the traditional preventive maintenance emphasizes on blindfolded inspections and shapes out the empirical knowledge of repairmen and thus not meets the growing industries[2]. Preventive maintenance is a set of activities at predetermined intervals done based on certain criteria and aims to reduce the fault probability and increase performance [3]. Excessive preventive maintenance will impose exorbitant costs to the organization while scant maintenance will increase unforeseen faults.

Recently, several studies have been published on the use of various techniques in maintenance engineering. Some researchers have used cause and effect diagram to detect and eliminate the fault causes of equipment [4]. However, some scholars have used risk-based maintenance system [5]. Undoubtedly, any maintenance model will be effective when the influential components of the model are identified and a plan is intended for improvement of the model. Sensitive machines are those with particular importance in the production cycle. Depending on importance, any failure will affect the amount and quality of products preventing an organization from achieving its goals [6]. Thus, it is critical to design a model to provide a general framework for the maintenance of sensitive equipment's so that all factors affecting the maintenance of equipment's are detected.

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## II. BACKGROUND

According to the literature, the initial developments in maintenance occurred before World War II. In those days, industries were not mechanized, thus the faults and sudden stops did not cause a serious problem for those in charge of production. In this era, the Breakdown Maintenance System (BMS) was common [7]. Evolution was significantly changed in the second period during the Second World War. The war pressures increased demand for various products while manpower supply was significantly reduced leading to mechanization and automation. Preventive maintenance, productive maintenance and total productive maintenance (TPM) have been developed in this period [7]. Developments in the third period began in the 1970s leading to new achievements in the field of maintenance:

1- Condition-based maintenance (CBM)

2- Application of failure analysis techniques

3-Intellectual development in organizations and move towards mass participation [7]

In summary, the following points are visible:

The first period: repair after failure

The second period: increased life of equipment + increased operation period= reduced costs

The third period: increase operation period+ higher reliability + increased security = more savings in costs, high quality products, protection of the environment [7]. Figure 1 summarizes the maintenance expectations.

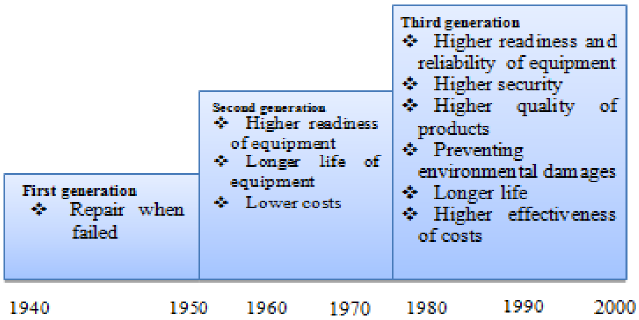



**Figure 1**: The growing maintenance expectations[7]

Esmaeilian et al [8] used FMEA to develop a new model to reduce risk priority number (RPN) and improve overall equipment effectiveness (OEE) using a heuristic mathematical model. They employed their findings in a textile factory. Kumar Sharma et al [9] examined the system failure methodology and maintenance decisions using Root Cause Analysis (RCA), Failure Mode and Effect Analysis (FMEA) and Fuzzy Method (FM) to help reliability analysts in maintenance planning. Factor contributing to the lack of reliability of the system were analyzed using RCA and FMEA and the findings were used in a paper factory.

Jalali Naini et al [10] studied condition-based maintenance for two-component systems considering reliability and costs. They investigated maintenance policies for two-component systems. Aldrgam and Dafio [11] conducted a study entitled "optimal joint policies of operation and maintenance to maximize the effectiveness of the system" in a refinery unit.

According to Silva et al [12], the maintenance model and policies are the best options to reduce the maintenance costs and to optimize key performance indicators (KPI), failure rate, reliability and mean time between the failures, mean time to repair maintenance time and access to equipment. They employed the results in Tonova Factory in Portugal.

Wireman [13] suggested the stepwise implementation of activities to ensure that all maintenance management tasks are performed. He believes that prior to implementation of CMMS, a basic preventive maintenance plan must exist. According to Wireman's model, an appropriate issuance system is required before carrying out maintenance regarding the reliability and predictive plans. Moreover, engagement of operators has utmost important in TPM.

Although Wireman's model is a good model, it does not consider the participation and satisfaction of maintenance service provides and clients. Industrial development in recent decades is such that a large part of the national capital is allocated to this issue. Undoubtedly, it is necessary to preserve this investment. In this regard, all leaders try to preserve the properties using a correct approach. Obviously, maintenance of equipment is not only a tactic, but is a culture. Thus, establishment of a culture of maintenance for industrial manufacturing processes is of utmost importance [13].

The common trend in some companies is that they try to implement the maintenance approaches of other similar organization through benchmarking without identifying the maintenance components as well as acceptable criteria in their own organization. In some industries, the maintenance approach has been very obsolete, because the factors influencing it have not been identified. The aim of the present study is to identify the important factors influencing the optimal maintenance to develop a plan for the maintenance of sensitive machines. The critical point in the maintenance approaches is that any maintenance approach will be successful when it is able to identify and promote their own acceptable criteria. The proposed model tries to include both human factors and maintenance techniques in a general framework.

## III. THE PROPOSED MODEL

The purpose of this model is to use FMEA, RCA, and RCM techniques to obtain a general framework for developing maintenance policies considering the effect of maintenance service providers and clients. Figure 2 shows the proposed model for the optimal maintenance strategy.

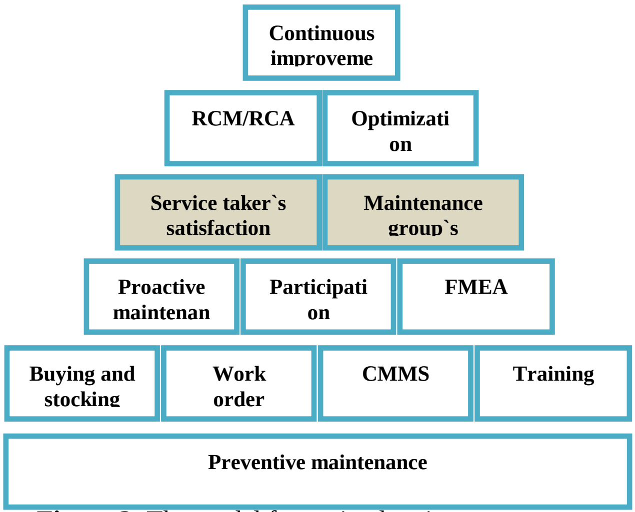



**Figure 2**: The model for optimal maintenance strategy

As it has been presented in Figure 2, FMEA technique is used to analyze the failures in the third level. FMEA allows the users to realize the weaknesses and develop the initial maintenance plan. It is worth mentioning that the following inputs are used to develop a maintenance plan:

1- FMEA
2- Manuals and documents
3- Experts' opinions
4- The outputs of predictive maintenance

At the fourth level, the maintenance plan should satisfy both service providers and clients, because optimization and continuous improvement will fail undoubtedly without cooperation of both groups. At the fifth level, RCM and RCA techniques are optimized to detect and evaluate the potential failures of specified equipment's depending of the needs of maintenance approach. According to the model, optimization and continuous improvement will be achieved when both service providers and clients are engaged in the maintenance plan.

## IV. INPUT INTERACTIONS

First, the failure indicators various equipment's are obtained using FMEA analysis. Then, the key maintenance indicators are identified and classified using the cause and effect diagram and ANP analysis. The overall process is shown in Figure 3.

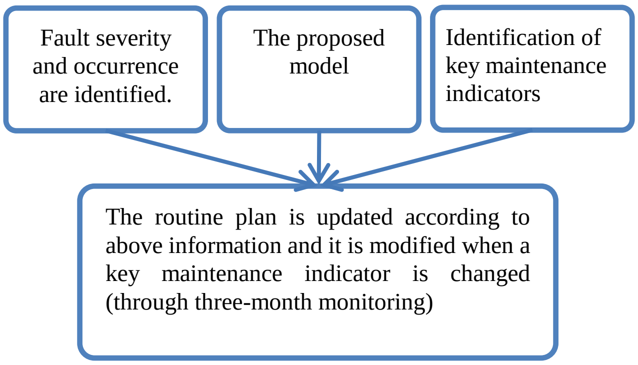



**Figure 3**: Overall View

Factors affecting the optimal maintenance approach, criteria, sub-criteria and their relevance to the proposed model are shown in Table 1. The table shows the relationship between the main criteria, sub-criteria and factors influencing the maintenance and their relevance to the proposed model.

**Table 1**: Main indicators and the relevant criteria

| SYMBOL | THE MAIN CRITERION | SYMBOL IN ANP | SUB-CRITERION | RELATIONSHIP MAIN MODEL |
|---|---|---|---|---|
| C1 | COST | S11 | SPARE PARTS QUALITY | BUYING AND STOCKING,PARTICIPATION,PROVENTIVE MAINTENANCE,PROACTIVE MAIN TENANCE, |
| | | S12 | PERSONEL | |
| | | S13 | MTBF | |
| | | S14 | MTTR | |
| C2 | RISK | S21 | SEVERITY | FMEA ،RCM ،RCA |
| | | S22 | OCCURVENCE | |
| C3 | SATISFACTION | S31 | INTERNAL CUSTOMERS | MAINTENANCE GROUP`S SATISFACTION SERVICE TAKER`S SATISFACTION |
| | | S32 | EXTERNAL CUSTOMERS | |
| C4 | ADD VALUE | S41 | HSE | CONTINUOUS IMPROVEMENT, OPTIMIZATION |
| | | S42 | EFFICIENCY | |
| | | S43 | PRODUOCT QUALITY | |

The classification for main criteria and sub-criteria was agreed by 25 maintenance experts. The weight value of criteria and sub-criteria is determined using ANP technique. The network analysis method was first proposed by Saaty and Takizawa in 1986.

## V. THE PRIORITY OF MODEL COMPONENTS BY ANP TECHNIQUE

ANP technique was presented after analytic hierarchy process. In many cases, the independent elements in the hierarchal structure may interact with each other. The lower-level components may have an impact on higher-level components. There is a feedback relationship in the process. The resulting structure is similar to a network system. The network structure of ANP not only identifies dependencies between different elements, but also calculates the relative weight of each component. Figure 4 shows the overall structure of AHP and ANP techniques.

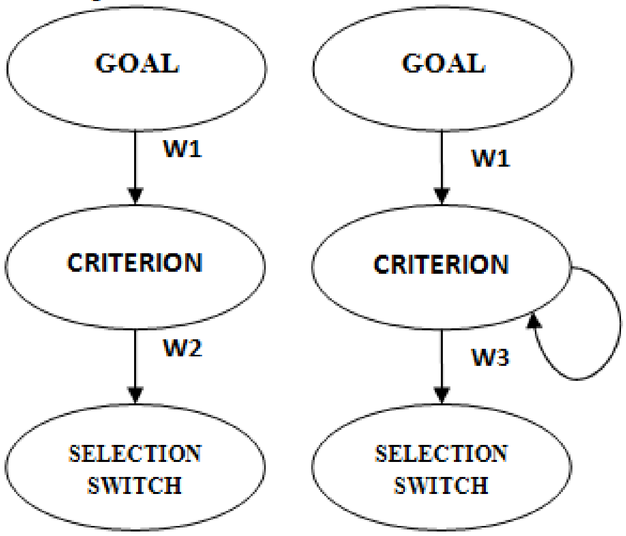



**Figure 4**: The overall structure of AHP and ANP [30, 31]

Figure 5 shows very simple structures of the hierarchical and network analysis processes. The figure on the right hand shows the relationship between the criteria by a loop. The weights calculated for each cluster and intra-cluster relationships form a super matrix. The resulting super matrix is called unweight super matrix. First, the super matrix is normalized by linear methods so that the sum of each column in the new super matrix is equal to one. The resulting super matrix is called weighted super matrix. Calculating the limit super matrix, the net weight of criteria and options is calculated. Higher weight indicates higher priority. As a result, the best variables can be selected. Higher priority will be given to criteria with higher weight. Best results are achieved when the opinions of all experts are used. Network analysis process is mainly used to select multiple variables.
The geometric mean of maintenance experts' opinions was used to determine the priority of main criteria. The eigenvectors are shown in Table 2.

**Table 2**: The priority eigenvector of main criteria

| SPECILLY VECTOR | GEOMETRIC MEAN | ADD VALUE | SATISFACTION | RISK | COST | |
|---|---|---|---|---|---|---|
| 0.23 | 0.997 | 1.734 | 0.212 | 2.69 | 1 | COST |
| 0.126 | 0.546 | 0.482 | 0.497 | 1 | 0.372 | RISK |
| 0.402 | 1.744 | 0.971 | 1 | 2.014 | 4.728 | SATISFACTION |
| 0.243 | 1.054 | 1 | 1.029 | 2.077 | 0.577 | ADD VALUE |

In this table, the importance of each criteria compared to the other criteria has been identified.
Figure 5 shows the interrelations between the criteria.

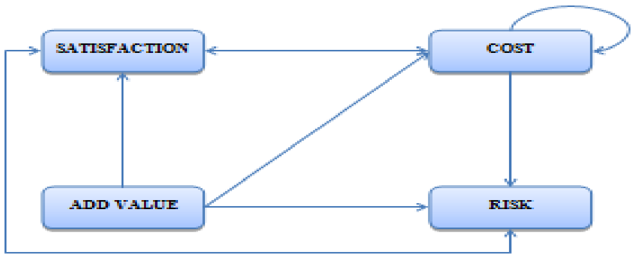



**Figure 5**: The interrelations of main criteria

After determining the priority of sub-criteria, weighted and limit super matrices are calculated as respectively shown in Tables 3 and 4. Once the un-weighted super matrix is formed, it is converted into weighted super matrix (normal) using the normalization techniques so that the sum of all elements of each column is equal to one.

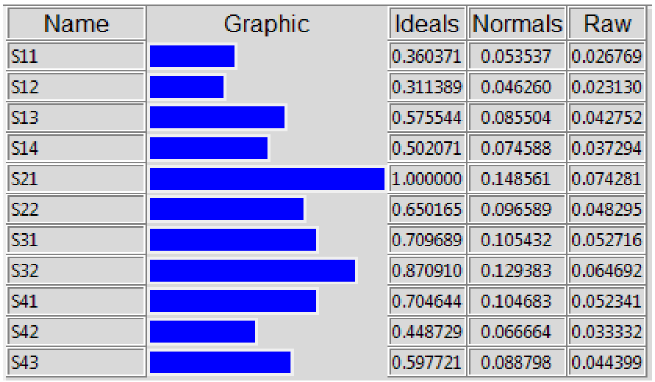
**Table 3:** The weighted super matrix

| 3Alternatives | | | | | | | | | | | 2Criteria | | | | 1Goal | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S43 | S42 | S41 | S32 | S31 | S22 | S21 | S14 | S13 | S12 | S11 | C4 | C3 | C2 | C1 | Goal | | |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | Goal | 1Goal |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.13 | 0.13 | 0.13 | 0.12 | 0.23 | C1 | 2Criteria |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.12 | 0.12 | 0.12 | 0.13 | 0.13 | C2 | |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.12 | 0.11 | 0.12 | 0.12 | 0.4 | C3 | |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.12 | 0.13 | 0.13 | 0.13 | 0.24 | C4 | |
| 0.100 | 0.102 | 0.101 | 0.100 | 0.102 | 0.102 | 0.102 | 0.101 | 0.101 | 0.102 | 0.091 | 0 | 0 | 0 | 0.1 | 0 | S11 | 3Alternatives |
| 0.089 | 0.090 | 0.091 | 0.092 | 0.090 | 0.092 | 0.093 | 0.091 | 0.093 | 0.082 | 0.091 | 0 | 0 | 0 | 0.09 | 0 | S12 | |
| 0.097 | 0.097 | 0.097 | 0.098 | 0.097 | 0.098 | 0.098 | 0.098 | 0.088 | 0.098 | 0.098 | 0 | 0 | 0 | 0.16 | 0 | S13 | |
| 0.095 | 0.096 | 0.095 | 0.096 | 0.097 | 0.095 | 0.095 | 0.086 | 0.095 | 0.095 | 0.095 | 0 | 0 | 0 | 0.14 | 0 | S14 | |
| 0.092 | 0.091 | 0.092 | 0.092 | 0.092 | 0.094 | 0.083 | 0.091 | 0.094 | 0.092 | 0.094 | 0 | 0 | 0.3 | 0 | 0 | S21 | |
| 0.101 | 0.099 | 0.100 | 0.100 | 0.100 | 0.090 | 0.100 | 0.102 | 0.100 | 0.100 | 0.100 | 0 | 0 | 0.2 | 0 | 0 | S22 | |
| 0.084 | 0.083 | 0.081 | 0.082 | 0.074 | 0.081 | 0.081 | 0.082 | 0.081 | 0.081 | 0.083 | 0 | 0.22 | 0 | 0 | 0 | S31 | |
| 0.077 | 0.076 | 0.076 | 0.068 | 0.076 | 0.076 | 0.074 | 0.076 | 0.076 | 0.076 | 0.075 | 0 | 0.28 | 0 | 0 | 0 | S32 | |
| 0.092 | 0.092 | 0.082 | 0.089 | 0.090 | 0.090 | 0.091 | 0.091 | 0.091 | 0.091 | 0.091 | 0.2 | 0 | 0 | 0 | 0 | S41 | |
| 0.090 | 0.081 | 0.091 | 0.090 | 0.090 | 0.088 | 0.090 | 0.090 | 0.090 | 0.090 | 0.089 | 0.13 | 0 | 0 | 0 | 0 | S42 | |
| 0.084 | 0.093 | 0.094 | 0.091 | 0.093 | 0.093 | 0.093 | 0.094 | 0.091 | 0.092 | 0.093 | 0.17 | 0 | 0 | 0 | 0 | S43 | |

**Table 4**: The limit super matrix

| 3Alternatives | | | | | | | | | | | 2Criteria | | | | 1Goal | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S43 | S42 | S41 | S32 | S31 | S22 | S21 | S14 | S13 | S12 | S11 | C4 | C3 | C2 | C1 | Goal | | |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | Goal | 1Goal |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.13 | 0.13 | 0.13 | 0.12 | 0.23 | C1 | 2Criteria |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.12 | 0.12 | 0.12 | 0.13 | 0.13 | C2 | |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.12 | 0.11 | 0.12 | 0.12 | 0.4 | C3 | |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.12 | 0.13 | 0.13 | 0.13 | 0.24 | C4 | |
| 0.100 | 0.102 | 0.101 | 0.100 | 0.102 | 0.102 | 0.102 | 0.101 | 0.101 | 0.102 | 0.091 | 0 | 0 | 0 | 0.1 | 0 | S11 | 3Alternatives |
| 0.089 | 0.090 | 0.091 | 0.092 | 0.090 | 0.092 | 0.093 | 0.091 | 0.093 | 0.082 | 0.091 | 0 | 0 | 0 | 0.09 | 0 | S12 | |
| 0.097 | 0.097 | 0.097 | 0.098 | 0.097 | 0.098 | 0.098 | 0.098 | 0.088 | 0.098 | 0.098 | 0 | 0 | 0 | 0.16 | 0 | S13 | |
| 0.095 | 0.096 | 0.095 | 0.096 | 0.097 | 0.095 | 0.095 | 0.086 | 0.095 | 0.095 | 0.095 | 0 | 0 | 0 | 0.14 | 0 | S14 | |
| 0.092 | 0.091 | 0.092 | 0.092 | 0.092 | 0.094 | 0.083 | 0.091 | 0.094 | 0.092 | 0.094 | 0 | 0 | 0.3 | 0 | 0 | S21 | |
| 0.101 | 0.099 | 0.100 | 0.100 | 0.100 | 0.090 | 0.100 | 0.102 | 0.100 | 0.100 | 0.100 | 0 | 0 | 0.2 | 0 | 0 | S22 | |
| 0.084 | 0.083 | 0.081 | 0.082 | 0.074 | 0.081 | 0.081 | 0.082 | 0.081 | 0.081 | 0.083 | 0 | 0.22 | 0 | 0 | 0 | S31 | |
| 0.077 | 0.076 | 0.076 | 0.068 | 0.076 | 0.076 | 0.074 | 0.076 | 0.076 | 0.076 | 0.075 | 0 | 0.28 | 0 | 0 | 0 | S32 | |
| 0.092 | 0.092 | 0.082 | 0.089 | 0.090 | 0.090 | 0.091 | 0.091 | 0.091 | 0.091 | 0.091 | 0.2 | 0 | 0 | 0 | 0 | S41 | |
| 0.090 | 0.081 | 0.091 | 0.090 | 0.090 | 0.088 | 0.090 | 0.090 | 0.090 | 0.090 | 0.089 | 0.13 | 0 | 0 | 0 | 0 | S42 | |
| 0.084 | 0.093 | 0.094 | 0.091 | 0.093 | 0.093 | 0.093 | 0.094 | 0.091 | 0.092 | 0.093 | 0.17 | 0 | 0 | 0 | 0 | S43 | |

The limit super matrix is obtained by exponentiation of all weighted elements. This operation is repeated until the elements of limit super matrix converge to a constant value. Figure 6 shows the final priority of the main criteria derived from the limit super matrix using the Super Decision Software.



| Name | Graphic | Ideals | Normals | Raw |
|---|---|---|---|---|
| S11 | | 0.360371 | 0.053537 | 0.026769 |
| S12 | | 0.311389 | 0.046260 | 0.023130 |
| S13 | | 0.575544 | 0.085504 | 0.042752 |
| S14 | | 0.502071 | 0.074588 | 0.037294 |
| S21 | | 1.000000 | 0.148561 | 0.074281 |
| S22 | | 0.650165 | 0.096589 | 0.048295 |
| S31 | | 0.709689 | 0.105432 | 0.052716 |
| S32 | | 0.870910 | 0.129383 | 0.064692 |
| S41 | | 0.704644 | 0.104683 | 0.052341 |
| S42 | | 0.448729 | 0.066664 | 0.033332 |
| S43 | | 0.597721 | 0.088798 | 0.044399 |

**Figure 6**: The priority of the main criteria by ANP technique (Super Decision outputs)

The index S21 with a normal weight of 0.148 is the most important factor among all indicators. Second priority is given to S32 with a normal weight of 0.129. The parameters S41 and S31 with a same weight are of great importance. On the other hand, S12 is less important than other factors.
The cost of maintenance personnel <satisfaction of the executive groups and HSE <satisfaction of clients < the failure severity
As seen, the weight value of failure severity is of great importance. The second priority is given to clients' satisfaction. Thus, the implementation of maintenance policies will be impossible without the cooperation of the service providers and clients.

## VI. THE PARAMETERS FOR POTENTIAL CAUSE OF FAILURE

Using FMEA standard scales, the team members match their experiences with a range of possible scores (from one to ten) of severity, occurrence and detection and allocate a particular number to the potential cause of failure. These numbers indicate the riskiness of the failure causes considering a specified parameter. Table 5 to 7 show severity, occurrence and detection, respectively.

**Table 5**: The failure severity

| Notes | Impact | Score |
|---|---|---|
| Any failure challenges one of the HSE requirements. | Dangerous | **10** |
| Any failure violates state laws. | Serious | **9** |
| Failure causes dysfunction so that the equipment is not usable. | Very high | **8** |
| The equipment works with reduced efficiency. | High | **7** |
| Failure causes dysfunction and damage to its subset. | Moderate | **6** |
| Failure causes dysfunction, but not influences production until shut down. | Low | **5** |
| Failure causes dysfunction due to the equipment life. | Very low | **4** |
| Failure causes negligible and temporary dysfunction. | Negligible | **3** |
| Failure to equipment and production process is negligible. | Very negligible | **2** |
| The equipment works without any failure. | Nothing | **1** |

**Table 6**: The occurrence of failures

| Notes | Impact | Score |
|---|---|---|
| More than once in a defined working period | Very high: the occurrence of failure is indispensable. | **10** |
| One fault in a defined working period | High: a large number of failures occur. | **8** |
| One fault in two working periods | Moderate: failures occur occasionally. | **6** |
| One fault in three working periods | Low: the number of failures is very low. | **4** |
| One fault in four working periods | Very low | **2** |
| One fault in five working periods | Almost never: The failure does not occur. | **1** |

**Table 7**: Fault detection

| Notes | Impact | Score |
|---|---|---|
| Production process is under control and a fault leading to breakdown is not detected. | Absolutely unknown | **10** |
| Production process is not under control and a fault leading to breakdown is not detected. | Very negligible | **8** |
| Production process is under control and a fault leading to breakdown is detected. | Negligible | **6** |
| Production process is not under control and a fault leading to breakdown is detected. | Very low | **4** |
| The fault can be detected by in-site inspection. | Low | **2** |
| The fault is visible. | Moderate | **1** |

## VII. DEFECT PRIORITY NUMBER

DPN = S x O x D (1)
DPN=DEFECT PRIORTITY NUMBER, S=Severity, O=Occurrence, D=Detection
Tip:
It's obvious that various numbers can be multiplied to obtain the same DPN. To evaluate the severity and occurrence of faults, Table 8 is used for sensitivity analysis of fault severity and occurrence.

**Table 8**: Sensitivity of faults

| 10 | 8 | 6 | 4 | 2 | 1 | S/O |
|---|---|---|---|---|---|---|
| **A** | 2 | N | N | N | N | 1 |
| **A** | 2 | 2 | 1 | 1 | N | 2 |
| **A** | 3 | 2 | 2 | 2 | N | 3 |
| **A** | 4 | 3 | 2 | 2 | N | 4 |
| **A** | 5 | 4 | 3 | 2 | N | 5 |
| **A** | A | 5 | 3 | 2 | N | 6 |
| **A** | A | 5 | 3 | 2 | N | 7 |
| **A** | A | A | 3 | 2 | 2 | 8 |
| **A** | A | A | A | A | A | 9 |
| **A** | A | A | A | A | A | 10 |

The resulting number for severity × occurrence at best and worst conditions is 1 and 100, respectively. Although 9×4= 36 and 6×6=36 both have same numerical value, but are not the same in terms of net worth. To evaluate this process, Table 8 is used as follows :
N: no action, existing maintenance approach is appropriate.

A: Out the equipment of service immediately to take corrective action.
5: prepare the conditions for corrective action at the first stop. Reduce the routine period.
4: Review the maintenance checklist and express the operating conditions of the equipment for the operator. Monitor the routine operation.
3: Express the operating conditions of the equipment for the operator. Check the operations performed by repair groups.
1, 2: Check the equipment operating conditions. Do not take action and continue to keep the same approach.

## VIII. RESULTS

The proposed model is based on equipment maintenance approach and techniques such as FMEA and RCA RCM. The model is more applicable in the oil, gas and petrochemical industries. According to the model, to implement optimization policies for maintenance and the use of RCM and RCA techniques, it is essential to gain the support of service providers and clients. The implementation of this model over a period of 12 months in a petrochemical company revealed the reliability and applicability of all maintenance works on the equipment (sensitive rotating machines) and improved quality of maintaining activities. Table 9 shows the effect of model on the reliability of maintenance activities.

**Table 9**: The effect of model on the reliability of routine maintenance activities

| | Degree of compliance with the routine | Reliability maintenance program |
|---|---|---|
| BEFOR EXECUIVE TO MODEL | 0.96 | 0.56 |
| AFTER EXECUIVE TO MODEL | 0.97 | 0.87 |

According to the results, to increase the reliability of maintainability plans, especially on sensitive equipment, FMEA, RCA and RCM techniques are appropriate when each can be used at the right time.

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