REFERENCE FRAMEWORK FOR SELECTING CRITICALITY ANALYSIS TECHNIQUES IN INDUSTRIAL ENVIRONMENTS. A CASE STUDY IN THE MINING INDUSTRY

Pablo Viveros Adolfo-Crespo, Luis Barberá-Martinez, Vicente González-Prida, Fredy Kristjanpoller-Rodriguez

Universidad de Sevilla. Escuela Superior de Ingeniería. Dpto. de Organización y Gestión de Empresas I. Avda. Camino de los Descubrimientos, s/n. Isla de la Cartuja, 41092.

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ABSTRACT:
This paper discusses the performance of production processes and maintenance policies in industrial environments from an analytical point of view. Particularly, the paper analyzes those mechanisms for assets hierarchy that allow discretizing that equipment considered critical, i.e. equipment with a high impact in case of failure, whether in production, costs, human and/or environmental safety. Therefore, a great amount of resources should be assigned. For this purpose, firstly it is made a review of the main techniques used in the ranking of existing industrial assets in the literature. After that, a methodology is proposed in order to simplify the optimal selection of criticality analysis techniques, whose implementation is more appropriate for a particular industrial environment and based on a set of variables. This methodology uses decision trees together with dichotomous type questions. Finally, the proposed methodology is applied to a real case related to a production plant of sulfuric acid, located in Chile. The methodology implementation has been useful to identify the most critical plant equipment in order to make appropriate decisions.

Key Words: mining, maintenance optimization, criticality analysis, efficiency and effectiveness in maintenance

RESUMEN:
Este artículo aborda el desempeño de los procesos productivos y políticas de mantenimiento en el entorno industrial desde un punto de vista analítico. Concretamente, el artículo analiza los mecanismos de jerarquización de activos que permiten discretizar los equipos considerados como críticos, es decir, aquellos equipos que tendrían un alto impacto en el caso de fallo, ya sea en producción, en costes, en seguridad humana y/o en seguridad ambiental, y que por tanto se les debe asignar una mayor cantidad de recursos. Con este propósito, en primer lugar se hace una revisión sobre las principales técnicas utilizadas en la jerarquización de activos industriales existentes en la literatura. Posteriormente, se propone una metodología que facilita la selección óptima de aquella técnica de análisis de criticidad cuya aplicación resulta más adecuada para un entorno industrial concreto y sobre la base de un conjunto de variables. Esta metodología utiliza conjuntamente árboles de decisión y preguntas de tipo dicotómico. Finalmente, la metodología propuesta es aplicada a un caso real en una planta de producción de ácido sulfúrico, ubicada en Chile, cuya aplicación ha permitido identificar el equipo más crítico de la planta con objeto de tomar las decisiones más apropiadas.

Palabras Claves: industria minera, optimización del mantenimiento, análisis de criticidad, eficiencia y eficacia en mantenimiento.

1. INTRODUCTION AND BACKGROUND

The occurrence of events associated to failures in any industrial plant may lead to significant increases in overall costs, which not only consider direct costs in the production process, but also indirect costs. In that sense and according to Crespo (2007), those criteria of importance for evaluating and ranking events associated with failures, will depend on the organization. Normally, the most used are: Safety, Environment, Production, Costs, Failure Frequency and Mean Time To Repair [1].

The purpose of any ranking tool is to standardize and simplify the process of identifying critical equipment. In the literature, there are different techniques to hierarchy assets by criticality. Molenaers et al. [2] applied the optimization of critical spare parts, prioritizing those who pose the greatest total costs. R. Pascual [3] describes some graphical tools for prioritization of assets, as the diagram Jack-Knife and Cost Scatter Diagram, which considers system level costs associated to equipment failure. Later, other elements are incorporated such as the presence of stockpiles between equipment, SEID (System Efficiency Influence Diagram). On the other hand, there are tools whose analysis is mainly numeric, as in the case of AHP [4] [5] [6] [7] and SMART [8], which assign weights to the analysis criteria according to comparisons between elements from different points of view. Deepening in numerical techniques, there are ones with multi-attribute utility such as Karydas D. and J. Gifun [9] as well as discarding techniques (or outranking techniques), as ELECTRE [10] and PROMETHEE [11] addressed by JP Brans and B. Roy, respectively. These have the property that they involve no comparisons in their utility functions, simplifying the calculation, as difference to MAUT (Multi-Attribute Utility Theory methods).

In industrial practice, semi-quantitative approaches are often used as criticality matrices based on weighted factors and risk analysis tables, or rather generic tools are used from the point of view of decision making, such as, is the case of The Hierarchical Analysis Process (AHP), which must necessarily be contextualized and adapted to each case, consequently do not necessarily provide homogeneous and comparable results between processes or physical facilities. In the scientific literature exclusively for asset management, only the Birnbaum Index [12] has been found that allows the evaluation of the impact of equipment under a vision of epistemic risk, allowing direct analysis, but focused on specific processes. This method compares the elements with each other, depending on the uncertainty of ability they have and the propagation of this uncertainty, with the aim of ordering them by level. However, this index depends highly on the quality of historical data, does not directly consider the effect of the logical configuration of the system and is difficult to apply in systems composed of a considerable amount of elements. On the other hand, Wang et al. [13] is based on the Birnbaum index and propose a complementary evaluation technique from a probabilistic approach dependent on a simulation. Also, from a qualitative point of view, there are techniques such as RAS (Risk Across Sectors) [14] or FMECA [15], where RPN (Risk Priority Number) can also be integrated. Finally, there are also mathematical programming techniques mono-objective [16] [17] and multi-objective [18].

The problem of assets hierarchy has been analyzed even at a standard level. The ISO / DIS 14224 [19] standard classifies failure modes according to the interruption degree they cause in the fulfilling of the element production function and, also, by type of failure mode (mechanical, instrumental, electrical, etc.). It also sets certain parameters to prioritize assets associated with: redundancies, failure consequences, equipment availability, failure rate, maintainability, among others. However, until 2014, the main proposed model was the British Standard PAS 55, precisely oriented to asset management. This standard aims to improve and ensure the sustainable use of assets throughout their lifecycle, providing guidelines to ensure the maintenance planning processes [20]. It also refers to the need to align maintenance with strategic organizational goals of the company from the point of view of assets design, operation, maintenance and dismantling [21]. Today, the PASS 55 standard has become a basic reference for the new ISO 55000 standard, published in 2014 by the International Organization for Standardization (ISO), which was developed with the support of multiple institutions and countries. Its function is to specify the requirements for establishing, implementing, maintaining and improving a management system for asset management [22]. This norm was designed in order to align and integrate the organization asset management with those system related requirements, covering points from the organization and top management context till the continuous improvement, all which under a format standard based on the Deming cycle.

Hierarchy techniques allow obtaining the criticality degree of an asset for a given industrial context. Each degree considers several variables: reliability, maintainability, unavailability, number of equipment, system configuration, operating conditions, failure consequences and combinations of these variables. That is why there are many techniques for assets hierarchy; each of them has advantages and disadvantages depending on the operation context [3].
According to the introduction and contextualization presented, this paper presents a methodology that provides support for asset management, improving the strategic, tactic and operational decision-making. The proposed methodology

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allows identifying the criticality analysis technique most appropriate based on existing operational context, establishing how it should be used and applied. Then, a brief of problem description is developed. Next, a methodology is presented which helps to identify the most suitable hierarchy technique in order to determine the assets criticality based on their operational context. Finally, the proposed methodology is validated through its application to a real case in the mining industry.

2. PROBLEM APPROACH

In any industrial environment, it is necessary to identify those processes, areas, equipment and components that generate a greater impact on the occurrence of failure [23] i.e. those components potentially critical. The impact is the degree to which the occurrence of failure in one element can affect to the process continuity [24]. This is discussed in the literature from different approaches: failure rate, impact on production, impact on people safety, impact on environment, as a function based on the total or partial process interruption, among others [25-26], or as a quantitative analysis integrating the concept of risk [27]. This paper presents a methodology in order to identify the asset ranking technique that best suited to a particular operation context based on a set of criteria and variables, which determine also how to apply the hierarchy technique (e.g., the information level required among others). The objective is to determine the equipment / failure modes criticality degree in an industrial plant, identifying critical agents for which resources should be allocated to minimize the occurrence of failures, mitigating its effects, eliminating or controlling failure modes, renewing certain equipment or generate new maintenance policies, etc. while improving asset management and minimizing the overall costs.

3. PROPOSED METHODOLOGY

The proposed methodology has been built from simple questions that refer to characteristics of the operational context, the availability of information and the skills and training of the technicians. The methodology has two main sets of questions. The first one consists on questions that aim to diagnose the existing scenario. The second set includes a decision tree potentially applicable to different techniques depending on the requirements. After that, both sets of information are collated, identifying a particular technique in case of accordance between the two sets, or setting suggestions for improvements or choices related to other ranking technique in case of discrepancy.

Previously, all existing ranking techniques in the literature have been analyzed, considering a set of common criteria to allow comparison and suitability measurement for each case. The information related to variables assigned to each technique, together with the information available in the company, will identify the most suitable technique. Next, the variables considered to analyze each hierarchy techniques are briefly described:

a) Type of technique (Mono-criterion / Multi-criterion, Numeric / Graphic, Quantitative / Qualitative / Mixed).
b) Involved variables (Quantitative variables, qualitative variables, KPIs).
    - Quantitative variables (Failure rate, Repair rate, MTBF (Mean time between failures), MTTR (Mean time to repair), UT (Uptime), DT (Downtime), Costs, Number of events).
    - Qualitative variables (Maintenance policies, Redundancies, Mitigation measures, Buffers size, Failure frequency (low, medium, high), Failure severity (low, medium, high), Failure detection (low, medium, high), Other impacts (environment, production, occupational safety and health).
    - KPI (Reliability, Availability, Efficiency, Effectiveness, Processing times, Demanding times, ROA).
c) Calculation complexity (low, medium, high). It depends on quantity, quality, difficulty of getting information, specialized software requirements, and knowledge needed.
d) Type of results. It refers to the level of detail of the results generated by the tool (e.g. possibility of performing a sensitivity analysis).
e) Additional observations. Any additional observation to the items described above for each technique as well as their advantages and disadvantages.
f)

Based on the literature review of criticality techniques, a total of twelve tools have been analyzed. Below, table 1 shows an example of the technical assessment made by a Pareto Analysis.

PARETO ANÁLYSIS	
Type	✓ Mono-criterion ✓ Graphic.

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PARETO ANÁLYSIS	
	✓ Quantitative.
Variables	**Quantitative Variables.** ✓ Costs. ✓ Time out of service. ✓ Number of events ✓ Processing Times (KPI). ✓ Demanding total Time (KPI).
Calculation complexity	**Low**. ✓ Only weighting variables with respect to the total. ✓ There are no requirements for specialized software. ✓ Information must be obtained.
Level of detail in results	✓ As it is a graphical tool, sensitivity analysis presents less difficulty than in other techniques.

Observations	
Advantages	✓ Easy result comprehension and interpretation.
Disadvantages	✓ It works with one criterion at a time. ✓ It does not work with qualitative variables..

Table 1. Pareto Analysis technique assessment.

Once performed the assessment for each technique, the design of the proposed methodology is mainly based on the existing particular operational context in the company. Based on this, the methodology is able to propose the ranking technique best suited to the circumstances and the way it should be used, allowing those critical assets to be unequivocally discretized. In order to facilitate the application thereof, the proposed methodology is represented graphically by a decision tree (Figure 1).

The first part of the methodology consists on a set of preliminary questions that allow preliminarily narrowing the spectrum of asset prioritization techniques which may be applicable for the particular operational context, based on three perspectives (Table 2, Appendix): Database records, information management and staff competencies. This proposal is an adaptation and complement to the one proposed by Marshall Institute - MES [28]. The MES questionnaire aims to fully diagnose a maintenance unit, having 5 five perspectives (Management resources, information management, Preventive maintenance techniques, Planning and executing and Maintenance support). On the other hand, the methodological proposal seeks to raise information with focus on priorization and criticality respectively. Then, the complement exists specifically in this aspect, given the depth of the questioning and the focus on the discrimination of the tool to use.

After applying the methodology, decisions should be made based on the answers given in the questionnaire (Table 2, Appendix). The first three sections refer to the operational context of the company, while the fourth section considers the requirements needed by the company with respect to all possible techniques to implement. All criteria that make up the first three blocks of questions are answered using the following scale of responses [21]:

1. Never: The issue is not presented. There is no information nor skills.
2. Almost never - Bad: The appearance occurs rarely, very little information
3. Generally - Good: acceptable results are appreciated, the aspect is shortly worked.
4. Always - Excellent: There is wide information and relevant competence.

For the analysis of the preliminary part (diagnosis), acceptability limits have been applied on responses to the application of certain techniques for the ranking of assets. Thus, if the score of an answer is less than or equal to the set limits, the technique is invalidated by failure or deficiencies in the company for its successful implementation (Table 3).

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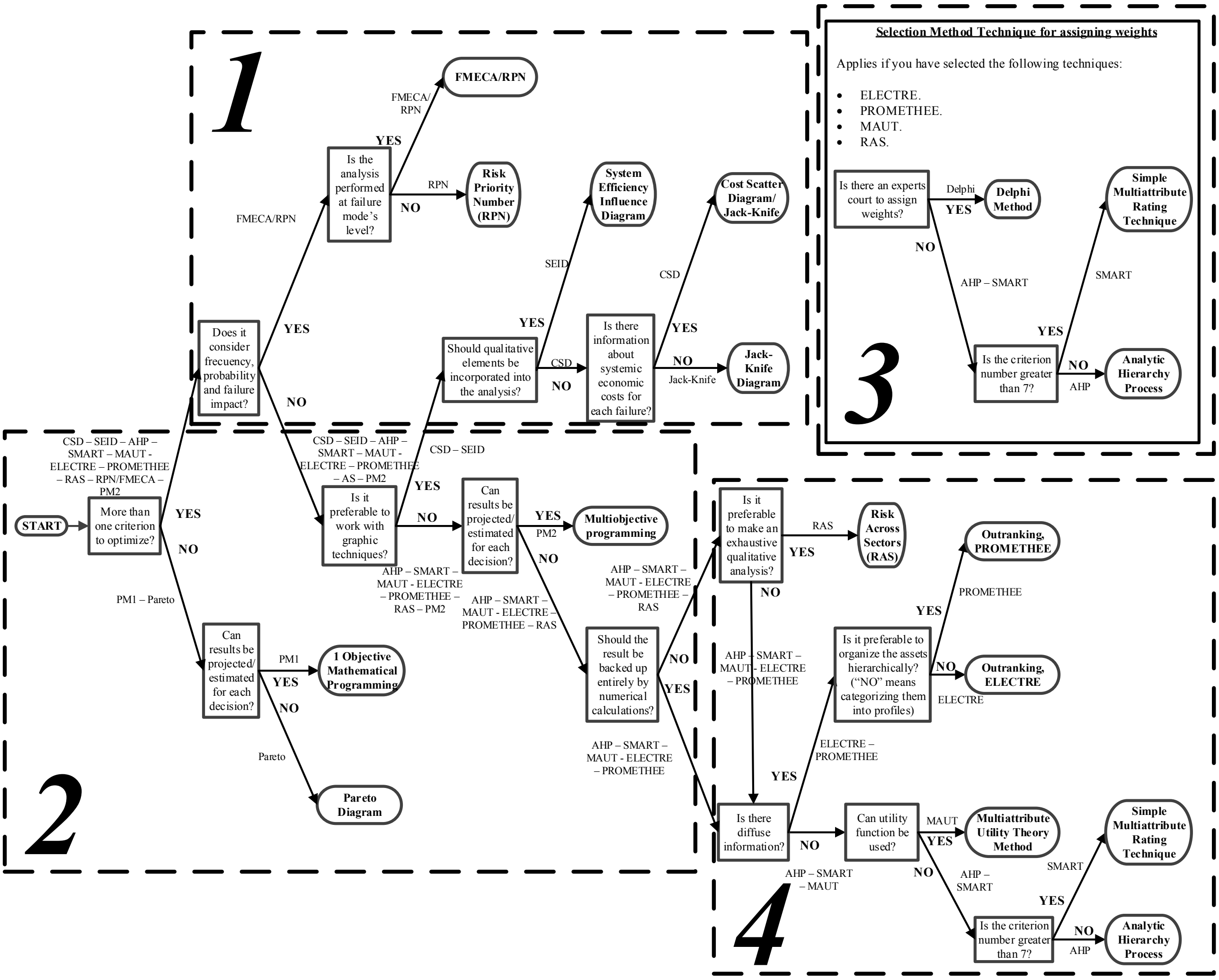

Fig. 1. Decision tree on ranking techniques.

The first block of preliminary questions, called "I. Database Records", serves to clearly discern the existence and, where appropriate, the level of detail that is collected as well as all that information and data related to the management of maintenance records. The second block "II. Information management" is used to discretize the existing information by type, both qualitatively and quantitatively, as well as the existence of measuring KPIs. The third block "III. Staff Competencies" serves to identify and measure the level of education and training of the personnel. Finally, the forth block "IV. Decision Tree" serves to clearly identify the requirements, needs and factors that determine the choice of the technique to implement.

		Question No.	PARETO	CSD	SEID	AHP	SMART	MAUT	ELEC.	PROM.	RAS	FMECA	PM Mono-Objetive	PM Multi-Objetive
II	Quantitative Inf.	No. 1	2	2	2									
		No. 2	2	2										
		No. 3	1	1	1									
		Total	3	3	3	3	3	3	3	3	3	3	3	3
	Qualitative Inf.	No. 4												
		No. 5												
		No. 6												

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		No. 7												
		Total			8	4	4	4	4	4	4	4		
	KPI	No. 8												
		No. 9												
		Total			2	2	2	2	2	2	2	2		
III		No. 1												
		No. 2	3	3	3	3	3	3	3	3	3		3	3
		No. 3	1	3	3	2		2	2	2		1		
		No. 4			2									
		No. 5		2	2	2								
		No. 6						2						
		No. 7							2	2				
		No. 8									2		3	3
		No. 9										2		
		No. 10											2	2
		No. 11											2	2

Table 3: Technique discrimination detail based on diagnostic.

Section I has not been considered because this is purely introductory in order to know the characteristics of the company from a generic point of view. It is necessary to clarify that recommendations from the proposed methodology are intended to be an aid and support to the decision-making in the selection of asset ranking technique most appropriate for a particular industrial context. Nevertheless, most of ranking techniques could be adapted in the event of not fulfilling any of the information requirements. For analysis of the decision tree, it is necessary to answer all questions in Section IV. The tree is designed in order to follow a logical order from left to right.

4. CASE STUDY IN THE MINING INDUSTRY

The presented methodology has been successfully applied to a real existing case in the mining industry, particularly in a copper treatment plant located in Chile.

4.1. INDUSTRIAL CONTEXT OF THE CASE

In the case of study, the absorption group is analyzed in a sulfuric acid plant. The equipment characteristics to consider are shown in Table 4.

TYPE	CODE	FEATURES
Tower	T1	Primary drying tower
Tower	T2	Secondary drying tower
Tower	T3	Intermediate absorption tower
Tower	T4	Final absorption tower
Pump	B1	(2) Acid pumps
Pump	B2	(2) Acid pumps
Pump	B3	(3) Acid pumps
Pump	B4	(3) Acid pumps
Pump	B5	(2) Acid pumps
Exchanger	I1	(2) Acid coolers

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Exchanger	I2	(4) Acid coolers
Exchanger	I3	(2) Acid coolers
Exchanger	I4	(1) Acid product cooler
Blower	S1	(1) Blower-moving gas

Table 4: Equipment to consider in the case study.

With a total of 26 pieces of equipment, the goal is to determine the one with the highest degree of criticality, using the ranking technique more appropriate for this context.

4.2. APPLICATION OF THE PROPOSED METHODOLOGY

Once identified and characterized the different equipment involved, it is appropriate to respond to different blocks of questions that make up the first part of the methodology, with the aim of identifying the criticality analysis technique that best suits to industrial reality under study. These questions are answered with help from operation and maintenance of the plant, obtaining the results shown in Table 5 (Appendix).

Comparing the results obtained with the limits of acceptability (Table 3), it is shown that there is no discardable model. After that, the decision tree is constructed (Figure 2) based on the answers obtained, which determines the most appropriate ranking technique. For the context analyzed, it results to be the RPN (Risk Priority Number), since this case is only intended to analyze the criticality of the equipment within the plant.

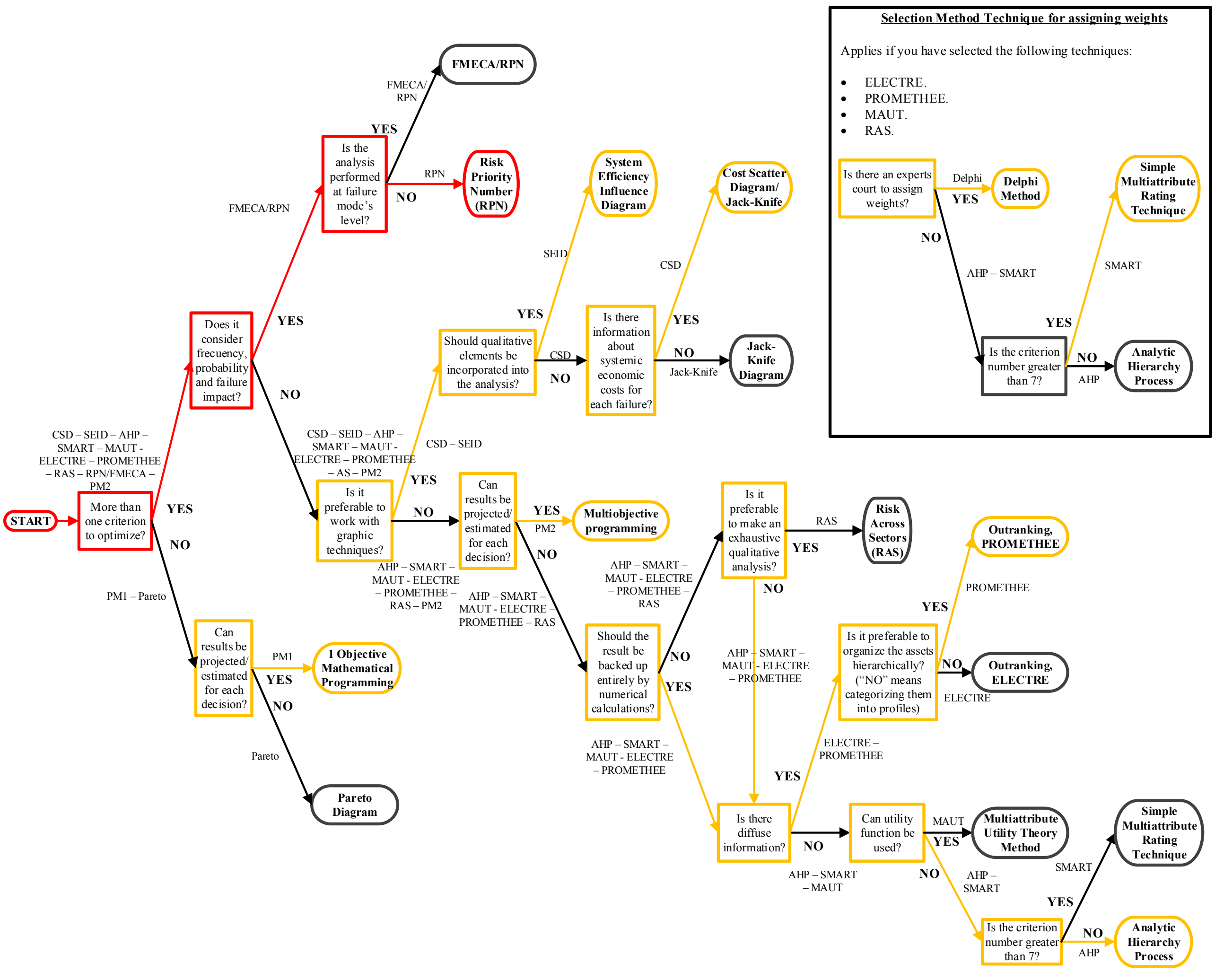

Fig. 2. Case study decision tree.

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The choice of the criticality analysis technique RPN is particularly useful in the mining environment, where the operating personnel and plant maintenance assign mainly qualitative assessments to each criterion, and where the most important is the weight given to the failure probability and its impact. Having identified the criticality analysis technique, we proceed now to generate a structured framework to the analysis, data collection, application of the technique and outcome. In order to determine the RPN, different criteria are considered such as: failure likelihood (very low, low, moderate, high, very high), failure severity (no effect, minor, serious, major, catastrophic) and failure detection (very high, high, medium, low, nil). Based on these parameters, the following criticality scale related to RPN (Table 6) is defined.

RPN	Criticality degree
[1 – 4]	Null
[5 - 8]	Low
[9 – 12]	Moderate
> 12	High

Table 6: RPN criticality scale RPN for the case study.

After collecting data from all the equipment, we proceed to calculate the risk priority for each one and, based on the established scale, the criticality degree is determined for each piece of equipment that constitutes the absorption group of the plant. Thus, a ranking that allows ranking the equipment based on their associated criticality (Table 7) is established.

Equipment	RPN	Criticality	Ranking
T1	6	Low	5
T2	6	Low	5
T3	8	Low	4
T4	8	Low	4
B1	9	Moderate	3
B2	9	Moderate	3
B3	12	Moderate	2
B4	12	Moderate	2
B5	9	Moderate	3
I1	9	Moderate	3
I2	12	Moderate	2
I3	12	Moderate	2
I4	6	Low	5
S1	15	High	1

Table 7: RPN, criticality and ranking of equipment constituting the absorption group.

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5. DISCUSSION AND RESULTS

According to the obtained values for RPN (Risk Priority Number), Table 7 shows elements with low, moderate and high criticality. This criticality analysis provides a qualitative idea that makes easier the design of a maintenance planning process. Among the elements, the most critical equipment corresponds to Equipment S1 (Blower). That means that a failure occurred in this element may cause catastrophic consequences in terms of safety (to persons, environment, and/or facilities), profitability (less production), etc. This blower is decisive for the proper functioning of the acid plant, being responsible for sucking and generating pressure in order the extracted gas of the conversion process to circulate throughout the plant. In other words, the occurrence of failure in the equipment causes a total collapse of the plant with a catastrophic impact from the point of view of both, safety and the environment, mainly because those gases that do not enter the in the acid plant, can damage the environment, generating considerable levels of environmental pollution. Therefore, online monitoring systems are implemented for the entire absorption group and, particularly, for this blower.

6. CONCLUSIONS

This paper proposes a methodology based on the review and monitoring of major criticality analysis techniques existing in the current literature, which supports decision-making and is capable of determining and recommending a ranking technique that best suit to existing operational context in a company. In order to do this, a decision tree is applied based on prior information collection according to a set of criteria. The previous collection is essential since it shows different aspects of the organization prior to implement any technique. Thus an adequate allocation of resources is ensured and, at the same time, the performance of the assets is improved. Therefore, a correct hierarchy of assets is an additional stage in the maintenance management in any industrial environment, prior to the definition of maintenance strategies and plans.

The application of the proposed methodology to a case study has allowed selecting the most suitable ranking technique depending on the operational context. In fact, through its application, it has been unequivocally determined that the most critical equipment is the so-called Blower (S1). From this information, a system for real-time monitoring is implemented in order to detect different failure modes before the occurrence of such failure. Specifically, the blower (S1) even keeps records that enable reliability predictions. With respect to the frequency of failure, it is addressed through policies of preventive maintenance and the use of early warning systems through real-time monitoring (predictive maintenance). While the consequences of failure can be lower through mitigation systems in the mining sector, they may directly affect the environment and safety of people. In particular, the blower (S1) was determined as the most critical equipment mainly because, unlike other devices, this presents environmental consequences in case of a catastrophic failure. Moreover, it should be noted that the ranking of assets is a dynamic process (time-varying) because the criticality levels for each equipment or component can be altered either by changes in the configuration of the plant, by the acquisition of new equipment (redundancy, new safety systems, etc.), by wearing and aging, or simply by the renewal of some existing equipment. In any case, the proposed methodology can be improved by incorporating new techniques assets hierarchy or by the combination of some of them, incorporating new decision nodes in the tree for an optimal planning of maintenance activities.

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APPENDIX

I. DATABASE RECORDS	*1*	*2*	*3*	*4*
1. The company has maintenance management software ERP.				
2. Each component is identified, coded and associated with a system within the whole plant.				
3. There is a records system of historical data for each event.				
4. All plant configurations are registered.				
5. The items recorded in the system can be discriminated by discipline.				

II. INFORMATION MANAGEMENT	*1*	*2*	*3*	*4*
Quantitative Information				
1. Times of equipment operation and shutdown				
2. Costs of failure, at a particular level and aggregated				
3.Number of maintenance interventions				
Qualitative Information				
4. Reservation Systems (buffers, types of interventions to each equipment, redundancies)				
5. General measures to mitigate effects of failure.				
6. Failure intrinsic properties (frequency, severity, characteristics of detection)				
7. Impacts of failure (environmental, production, occupational safety and health)				
KPI				
8. Associated to availability and efficiency				
9. Associated to costs				

III. STAFF COMPETENCIES	*1*	*2*	*3*	*4*
1. The staff is qualified to data entry /load in the ERP maintenance system.				
2. Calculation of percentages in quantitative variables.				
3. Basic use of spreadsheets (functions, graphs, etc).				
4. Simulation scenarios based on qualitative variables.				
5. Basic mathematical knowledge.				
6. Design of functions based on historical information.				
7. Estimation of acceptance levels and model variables rejection.				
8. Data projection.				
9. Generation of information together with plant personnel.				
10. Basic knowledge in operations research (mathematical programming).				
11. Scenarios simulation for each possible decision.				

IV. DECISION TREE (Internal requirements)	*YES*	*NO*
1. Do you want to optimize more than one objective or criterion function?		
2. Can the problem be approached from perspective frequency detection probability and impact of failure?		
4. Can the analysis be performed at a failure mode?		
5. Do you want to work with graphic techniques?		
7. Should elements / qualitative variables be incorporated to the analysis?		

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IV. DECISION TREE (Internal requirements)	YES	NO
8. Is it possible to project/assume results or consequences for each decision to take?		
9. Is there information on costs associated to possible failure of each device / system?		
11. Must the result be supported entirely by numerical calculations?		
12. Do you want to perform an exhaustive qualitative analysis? (Experts' judgments; special observations; ethical / political / organizational aspects; etc.)		
13. Is there fuzzy information? (Uncertainty, variability, lack of information or criteria)		
14. Do you want to rank or categorize assets according to certain profiles?		
15. Can you use a global function which represents the total utility and functions in order to quantify the contribution of each criterion to it?		
16. Is the number of criteria higher than 7?		
17. Is a panel of expert available in order to assess numerical weights to each criterion?		

Table 2: Set of preliminary questions.

I. DATABASE RECORDS	1	2	3	4
1. The company has maintenance management software ERP.				X
2. Each component is identified, coded and associated with a system within the whole plant.				X
3. There is a records system of historical data for each event.				X
4. All plant configurations are registered.				X
5. The items recorded in the system can be discriminated by discipline.				X

II. INFORMATION MANAGEMENT	1	2	3	4
Quantitative Information				
1. Times of equipment operation and shutdown			X	
2. Costs of failure, at a particular level and aggregated			X	
3.Number of maintenance interventions			X	
Qualitative Information				
4. Reservation Systems (buffers, types of interventions to each equipment, redundancies)				X
5. General measures to mitigate effects of failure.				X
6. Failure intrinsic properties (frequency, severity, characteristics of detection)			X	
7. Impacts of failure (environmental, production, occupational safety and health)				X
KPI				
8. Associated to availability and efficiency				X
9. Associated to costs				X

III. STAFF COMPETENCIES	1	2	3	4
1. The staff is qualified to data entry /load in the ERP maintenance system.				X
2. Calculation of percentages in quantitative variables.			X	
3. Basic use of spreadsheets (functions, graphs, etc).			X	
4. Simulation scenarios based on qualitative variables.			X	
5. Basic mathematical knowledge.			X	

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6. Design of functions based on historical information.			X	
7. Estimation of acceptance levels and model variables rejection.			X	
8. Data projection.			X	
9. Generation of information together with plant personnel.				X
10. Basic knowledge in operations research (mathematical programming).				X
11. Scenarios simulation for each possible decision.			X	

IV. DECISION TREE (Internal requirements)	***YES***	***NO***
1. Do you want to optimize more than one objective or criterion function?	X	
2. Can the problem be approached from perspective frequency detection probability and impact of failure?	X	
4. Can the analysis be performed at a failure mode?		X
5. Do you want to work with graphic techniques?	X	
7. Should elements / qualitative variables be incorporated to the analysis?	X	
8. Is it possible to project/assume results or consequences for each decision to take?	X	
9. Is there information on costs associated to possible failure of each device / system?	X	
11. Must the result be supported entirely by numerical calculations?	X	
12. Do you want to perform an exhaustive qualitative analysis? (Experts' judgments; special observations; ethical / political / organizational aspects; etc.)		X
13. Is there fuzzy information? (Uncertainty, variability, lack of information or criteria)	X	
14. Do you want to rank or categorize assets according to certain profiles?	X	
15. Can you use a global function which represents the total utility and functions in order to quantify the contribution of each criterion to it?		X
16. Is the number of criteria higher than 7?		X
17. Is a panel of expert available in order to assess numerical weights to each criterion?	X	

Table 5: Questionnaire on ranking process resolved by the company

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