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Using Creativity Approach in Mining: Integrating OTSM-TRIZ and AHP by assessing resource maturity level for new Solutions

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Abstract: Mining problems are increasingly complex, involving technical, economic, and human variables due to ongoing process, machine, and technology improvements. Effective maintenance for this new generation remains a challenge. Innovative maintenance methods and tools are crucial for identifying failures and proposing solutions that align with companies' needs, ensuring feasible real-world implementation. This article introduces a method inspired by the Theory of Inventive Problem Solving (OTSM-TRIZ) and Resource Analysis to understand implementation risks. A step-by-step procedure structures the problem context through elicitation, classification, and evaluation. The Analytic Hierarchy Process (AHP) reinforces decision-making analysis. A case study demonstrates the method's application through four stages: i) forming working groups to gather information across company levels; ii) using a Network of Problems (NoP) to identify issues and potential solutions; iii) applying Resource Analysis to understand implementation challenges; and iv) employing AHP to compare NoP solutions and determine the most suitable one. This methodology fosters idea creation, addresses risks, and facilitates decision-making, leading to robust and effective mining project proposals

Keywords—OTSM-TRIZ, AHP: Theory inventive problem solving

I. INTRODUCTION: EXPERT KNOWLEDGE IN MINING AND TRIZ APPROACH TO UNDERSTAN COMPLEXITY OF PROJECTS.

From an industry perspective, mining solutions mostly focus on increasing reliability for processes or equipment [1-2]. At the same time, mining solutions aim to support human resources activities to improve worker labor conditions, considering the extreme conditions and locations of mining companies. In this context, the creation of projects in mining must involve different aspects such as operations, human resources, environment, labor space, and others [3]. Indeed, requirements for mining solutions have increased considerably in recent years [4], making the barriers for companies larger every day when new solutions need to be implemented. When a new idea or solution needs to be implemented, it is important to consider a broad view of potential impacts. As a consequence of mining projects, the idea or solution requires implementation by reducing risk, taking into consideration a set of requirements at different organizational levels [5]. In this line, TRIZ and OTSM-TRIZ could provide strong support to the processes of knowledge acquisition and the decision actions carried out by industries. To reduce risk for solutions and their implementation, mining companies commonly use expert opinion and knowledge to reduce the potential risk of solution development[6]. However, sometimes expert knowledge is not enough to cover all potential scenarios. Therefore, thinking tools or analytical tools are always required to stimulate the thinking process to identify the main parameters that can impact the implementation of a new solution [7].

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The Theory of Inventive Problem Solving (TRIZ) has gained popularity in the mining field because it helps engineers decrease the amount of trial-and-error when a problem situation requires creativity and invention to be solved [8]. Indeed, the application of TRIZ as a creative tool for mining projects has been useful to understand its usefulness at different organizational levels [9]. TRIZ-based knowledge has different kinds of tools and approaches toward solution creation in specific context scenarios. Resource analysis, as part of a TRIZ-based toolkit, can be defined as a technique for directing creativity. This kind of resource analysis is directly applicable to every type of problem situation [10]. However, when TRIZ is applied to complex problems involving project planning, human resources, and complex relational systems, some limitations emerge. Consequently, Khomenko (2007)[11] proposed an evolution of TRIZ based on the Russian acronym for "General Theory of

Powerful Thinking," developed to extend the efficient application of Classical TRIZ to a variety of non-engineering fields. Over the years, it has also been further developed to deal with problematic complex interdisciplinary situations [11-12]. Besides providing formalized models of Classical TRIZ, OTSM introduces new instruments for organizing complex problems according to a hierarchical structure to identify the most critical issues [5]. In the context of OTSM-TRIZ application, the Network of Problems (NoP) is the first stage of problem situation analysis. Generally, NoP aims to create a more holistic scenario analysis, which can be useful to understand partial solutions. At the same time, NoP aims to understand the main problems that can emerge from new partial solutions. With this view, NoP aims to create a more realistic scenario about main problems by taking into consideration real company requirements, which is useful for project success[11].

From an organizational perspective, organizations need to understand how to address solution implementation under appropriate conditions [5]. With this perspective, companies typically analyze their capabilities and resources to determine if they are suitable for achieving a new solution [13]. In many cases, companies rely on different suppliers' knowledge and background to develop parts of projects, and in some instances, for the overall project implementation. This approach seems reasonable when companies acquire a fully implemented project. However, when companies need to take responsibility for the operation and maintenance of the solution, this approach can lead to many risky situations, mainly caused by the lack of knowledge among the company's workers related to the specific solution. As a result, the final solution may appear more aligned with the specific desires of the companies rather than a practical implementation.For instance, companies need to understand how to identify drivers and barriers for project success at the implementation and operational levels [14]. In more detail, companies cannot solely rely on suppliers but also need to possess internal knowledge to properly address the overall project. Therefore, expert opinion alone is not sufficient for project success. In this context, maturity models seem useful for measuring and evaluating a company's condition to address different scenarios[15]. Additionally, it's worth noting that the availability and complexity of new technologies are increasing rapidly, making the selection process an increasingly demanding activity.

The final output of the study is an approach that combines qualitative modeling with quantitative criteria, built upon a TRIZ (Theory of Inventive Problem Solving,[16]) based procedure and supported by information retrieved from teamwork's knowledge. It is important to point out that the methodology is sufficiently flexible for application in different industrial fields, as examples from various technological domains have been developed. The "Mining process" has been chosen because of the authors' previous experiences gained from real industrial case studies. This article presents a novel methodology by proposing an approach that uses OTSM-TRIZ to stimulate solution scenarios in the maintenance field when it is necessary to understand the effectiveness of solutions in maintenance teamwork. Additionally, a novel TRIZ-resource scale is introduced based on the maturity level to understand a company's capabilities to address different partial solutions and problems emerging from real situations for implementation based on OTSM-TRIZ. Specifically, this operative approach integrates NoP analysis with a novel resource assessment based on teamwork skills to afford the project. Finally, AHP analysis is introduced to understand teamwork priorities according to the main resource parameters.

The authors used a real case study to validate the methodology approach presented in this research, which was applied in a mining company in Chile to illustrate the application and the emerged results in the field. The case study is related to using drones to monitor conveyor belts in mining, aiming to identify failures in conveyor belts to avoid more critical failures.

II. Industrial context and TRIZ-Resources based on maturity levels.

Mining is widely perceived as an old industry with mature and stable technologies [17], characterized by long life cycles [18]. Similar to other industrial fields such as glass and cement, major technological innovation discontinuities occur with very low frequencies compared to high-tech sectors. These industries are inherently less technologically dynamic in terms of lead times and market entry but more capital-intensive [18]. Nevertheless, it would be more accurate to investigate the boundary conditions that influence and drive their innovation process rather than distinguishing them solely by the stage of maturity [19]. In the mining industry, the lead time to develop and commercialize new equipment is typically in the order of 7–10 years [20], and investing in new technologies often implies high capital R&D costs. This is due to the large scale and complexity of earthmoving equipment and the need to coordinate technology acquisition with mine development plans [21]. Moreover, while there is a general demand to prioritize improving equipment productivity and reliability [21], more tailored products are needed to optimize each phase of operation, especially from the resource consumption perspective. The mining industry is one of the most energy-intensive industries in the world.

This overview suggests that more research efforts are necessary to support the mining industry in correctly adopting new technological solutions and scenarios, properly setting development priorities, and efficiently managing the mining process. The major difference between resource understanding within the fields of TRIZ and strategic management is the application of resources [22]. Resources are the basic unit of analysis [23] and can be conveniently classified under several headings [24]. The benefits of this classification become apparent with the real application of each resource to achieve optimal benefits in the solution process. Furthermore, TRIZ resources are used to solve a problem [22], extending the solution space by attempting to maximize its usefulness inside or outside the system. Resource analysis, as part of a TRIZ-based toolkit, can be defined as a technique for directing creativity, directly applicable to every type of problem situation [25]. In TRIZ terms, a resource is anything in and around the system that is not being used to its maximum potential [26]. One key finding of the TRIZ resource is that the strongest solutions are based on both unwanted and harmful elements, which are transformed into useful resources inside or outside the process.

A novel assessment is proposed based on TRIZ logic to understand the successful possibilities of an overall idea-solution proposal [27][28]. For solution quantification, it is necessary to assess the level of expertise/knowledge and resources available to address the main problem. Each parameter was conceived by maturity scenario inspired by Essman's model (2009). What is lacking behind all these powerful tools or frameworks is the exploration of new alternatives, and hence the initial problem formulation is based on algorithms that support decision-makers to follow a reasoned analysis for the extraction and prioritization of the main metrics to be considered. However, these methodologies are designed for a discrete set of experienced decision-makers; secondly, the problem formulation, which is at the basis of technology alternatives identification and hence of the measuring analysis, completely hides any technical content (i.e., the problems, the needs, the requirements of the technology) or at least roughly summarizes it through simplified performance indexes. Indeed, a basic level (1) has been defined ad-hoc, with a value that is reactive to circumstances occurring over time. An intermediate level (3) represents when the solution, practices, and their management are already internalized processes and can be diffuse and not formal. The project already has a role available and is recognized within the assessed capacities. Finally, at level (5), the maturity levels, as support for the solution development, are at a maximum. There is a formal process managing its implementation, with the aid of specialized human capital, and it becomes an intrinsic resource of the organization to execute the project properly. The logic used for resource evaluation of these TRIZ-based parameters is described below:

Parameter	General description	Level 1	L 2	Level 3	L4	Level 5
Developer knowledge/ experience (DK)	Developers know about activity-related topics and can create a real solution with their knowledge.	Poor knowledge and experience. The activity has never been developed for the analyst(s).		Some knowledge and, in certain cases, the activity has been developed.		Deep knowledge and experience. The activity has been developed frequently and regularly in practice. Unpredicted events are missed.
System information (SI)	Data compilation, images, and other information belonging to the system. Workers have access to the information for analysis.	The system suffers from a lack of information to develop the solution, and/or information access is difficult or impossible to obtain.		The system has sufficient information to be used for solution building, and/or information access may be limited.		The system includes the complete and necessary information to develop the solution or access to information is easy and rapidly obtained.
Process material and Human Resource (PrHr)	Tools, implements, and equipment are available to develop the manufacturing or building process, also includes Human resource availability as a part of the process	Tools, equipment, and implements are unavailable for use and/or difficult to obtain.		Poor equipment, only a few tools and implements are available for the manufacturing process. Obtaining the equipment requires substantial time.		Equipment and all necessary tools for manufacturing are available and in good condition and/or equipment is easy to obtain in a short time.
Product material and Resource availability (PdM)	Materials (wood, steel, plastic, aluminum, etc.) that are transformed to obtain the final product.	All the required materials are unavailable or in a poor condition. Developers need to consider high acquisition times.		Only a few materials are available, in a good condition, or have fast and easy access.		All requested materials are available and have facility of use. In other cases, materials can be obtained in a short time.
Time needed/ availabiilty (T)	The time considered in all development processes (analysis, design, manufacturing, quality assurance).	The time available for the solution development is less than that established in the planning. In other words, there is not sufficient time to develop an appropriate solution.		The time available for the solution is affordable and established in the planning.		There is a considerable amount of time for the project, far above that established in the planning. There is more time available than expected.

Fig 1: Maturity levels to evaluate risk in Project development

III. Methodological proposal to assess initial idea-solution in complex scenarios.

As discussed in previous sections, the existing techniques aims to manage different parts of ideas-generation and prioritization, however each one by separated suffer of lacks of information for an appropriated decision making process inside companies when complex situation emerge. The original contribution this paper consists in an original procedure to guide initial idea-solution organization information with OTSM-TRIZ logical, evaluation of maturity based on different levels based on TRIZ-resources logic and finally prioritization based on AHP. The four-steps approach can be considered as a sort of operative algorithm that describes all the specific action to performs in order to correctly manage idea-solution scenario.

Step 1: Initial teamwork for solution proposal: Initial teamwork have to focalize the AS-IS situation and which can be the initial idea that can be implemented inside of the company. During this step, task is to identify a potential solution that can allow to increase productivity of the line. The teamwork has to envision the benefits that can obtain if solution have desirable results. Ideally, the teamwork need to be constituted with technical knowledge about process/product and human resource involved in the process/company. The main outcome of this step is to understand qualitative ideas of throw initial solution proposal can work in real situation. In more detail,

This step described in this paper concentrates into the “identification”, need to be consistency and completeness, by a number of possible and proper alternatives are identified, strongly influence the final decision: that group of alternatives delineates the “decisional space” of the decision-maker. However, despite its strategic role, according to [29] a number of pitfalls negatively affects that “pre-analysis” or identification phase. The wrong collection and understanding of the data used to identify the technologies, as well as their incorrect analysis due to an inadequate training of the analyst are two of those main issues. Indeed, as underlined in [30]deriving promising alternatives from unclear and uncertain development directions is highly challenging.

Step 2. Network of Problems (NoP) to elicited idea-solution framework: the Network of Problems (NoP) is a problem situation analysis, which aims to understand complex scenarios. It is dedicated to forming overall understanding of problem situations to obtain a holistic framework of the problem. The NoP is a graph where nodes represent both Problems (Pb) and Partial Solutions (PS), which is the initial solution to address the main problem situation (Figure 1). Their connections provide a hierarchical structure of the problem situation combined with various alternatives to solve it. The edges of the graph link the PS both to the originating problem and to the new discovered problems31. The Network of Contradiction (NoC) is a subsequent interpretation of the NoP that integrates information about the contradictory requirements

In this step is necessary to identify the proposed idea-solution to be developed by teamwork. NoP model helps to elicited main problems and solutions that can emerge, considering the complexity of AI-IS situation and its various levels of analysis, according to companies’ current practices. The main actions to be performed during this stage are related to:

Identify the specific idea-solution to be implemented (or need for changes) occurred in the company, production line, etc. Taking into consideration different views of teamwork.

Generate a list of sub-problems or partial solutions that can emerge based on initial idea-solution in order to build the NoP by linking them logically.

If the teamwork recognizes a new problem he/she has to generate a partial solution to overcome the new problem. On the contrary, if the teamwork comes out with new partial solution, he/she should reflect to identify if new problems that might emerge when implementing that new solution.

Step 3. Network of Problems assessment based of TRIZ-Resource maturity level. The purpose of this step is evaluate each sub-problem and partial solution according to different parameters, in order to understand if exist potential gaps of teamwork to afford solution implementation. The maturity scale (Figure 1) will be used to rank the specific body-knowledge about situation, as a consequence teamwork can understand solution plausibility to continues with solution implementation or bring new knowledge and also if exist a necessity to bring new resources. The evaluation by using this maturity scale can then be considered as a company key indicator to measure the solution expected success.

In this step of the project analysis, a novel assessment approach is proposed, utilizing TRIZ (Theory of Inventive Problem Solving) logic. The objective is to gain insights into successful possibilities for overall project analysis. To quantify solutions, the assessment considers the levels of expertise, knowledge, and resources available to address the main problem. The sub-steps involves:

Identification of innovation parameters and constructs to reduce project development risk. This includes a reinterpretation of Essman's Innovation Capability Maturity Model (ICMM) from a risk perspective. Results and organizational support are contingent on the assessing team, differing from typical risk conditions.

Identification of relevant parameters and constructs for large applications in project development. This step involves narrowing down the model by filtering out constructs that may fit well with project development and planning but hinder resource availability for project execution.

Generation of scenarios with interpretation towards project management and implementation. Three maturity levels are established, inspired by Essman's model, representing varying degrees of project execution capability. These levels range from basic reactivity to circumstances (Level 1) to maximum maturity (Level 5) with formal processes, resource management, and specialized human capital.

The parameter analysis (PA) approach, specifically proposed for innovation cases, is employed. PA focuses on the conceptual project process, using a descriptive model based on observations of the teamwork analsysis process. The project concept space deals with "parameters," conceptual-level issues providing a basis for configurations of the potential scenario. For assessment, analysts or developers evaluate each scenario based on five parameters: developer knowledge/experience, system information, process material, product material, and time needed. These parameters align with TRIZ resource classification, facilitating a deep analysis of the solution's building and development stages. The assessment considers the first complex scenario that engineers and managers must address, providing descriptions and relevance for each issue/resource incorporated in Figure 1.

Step 4: AHP for different dimensions of TRIZ-resources: Given that the application NoP and assesment of partial solutions and sub-problems can make the number of variables challenging to manage in practice. As a consequence, the decision-making process for project imprelmentarion may be adversely affected. Therefore, it is necessary to integrate TRIZ with prioritization methods to focus efforts on critical problems that engineer may face. In this scenario, Analytical Hierarchy Process (AHP) assists in decision-making by quantifying parameters under analysis [31-34].The AHP process has various advantages in its application as it considers both quantitative assessments of the problematic situation and subjective judgments of experts or decision-makers[31]. AHP organizes information in an orderly and graphical manner, providing a deep understanding of the problem by ordering, decomposing, analyzing, and synthesizing [34]. For its application, the problem must first be hierarchically decomposed according to criteria and alternatives. In the decision matrix, judgments are synthesized, capturing the preferences and weights of one criterion over another as judged by decision-makers. The evaluation scale established by [34], shown in Figure 2, can be used for this purpose. The results of the comparisons are analyzed through a paired comparison matrix, as represented in equation (2).

Saaty's scale		Reciprocal Scale	
1	Equal importance between both elements	1	Equal importance between both elements
3	Weak importance of one element over another	1/3	Slightly less important one element over another
5	Moderate importance of one element over the other	1/5	Less importance one element over the other
7	Strong importance of one element over the other	1/7	Much less importance one element over the other
9	Absolute importance of one element over the other	1/9	Absolutely less important one element over the other
2,4,6,8	Intermediate values	1/2, 1/4, 1/6 ,1/8	Intermediate values

Fig 2: Saaty's paired comparison scale

$$A = \begin{pmatrix} 1 & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & 1 \end{pmatrix} \quad (1)$$

The results obtained through the application of this tool are directly linked to the consistency of the prioritizations or comparisons established in the formulation of the paired comparison matrix. This is because there are subjective judgments and relative assessments between alternatives, which may lead to some degree of inconsistency or unreliable results. The way to measure this degree of inconsistency (Saaty, 1987) is through the Consistency Index (CI) expressed in the following expression

$$IC = \frac{\lambda_{max} - n}{(n-1)} < 0{,}1 \quad (2)$$

From equation 2, λ_{max} correspond to maximun postive eigen-value.. Subsequently, the value of the consistency index must be cross-verified with the values of the random consistency index (RCI). Finally, the consistency ratio (CR) is calculated by dividing CI by RCI (CR = CI/RCI). The final CR value should be checked according to the following criteria:

i. If RC equals 0, the matrix is consistent, and therefore, the prioritization judgment is valid.

ii. If RC is less than 0.1, the matrix has some acceptable inconsistencies.

iii. If RC is greater than 0.1, the matrix is inconsistent, and thus, the prioritization judgments are not valid and should be reformulated.

Ultimately, the evaluation of the CR indicator confirms the consistency of the prioritization process.

Finally, from proposed TRIZ-resources dimensions (Developer/experience; System Information; Process Material and Human Resources; Product Material; Time needed/availability), the AHP analysis need to be applied in order to understand the most important dimensions of the teamwork. At the same time, the evaluation is combination of the different dimensions and maturity level of each dimension. The following equation asses Problems and Partial solutions based on AHP and Maturity Level.

$$Overall\ Value = \sum_i^j W_i (AHP\ Value) * Maturity\ level\ (1\ to\ 5) \quad (3)$$

IV. CASE STUDY: MONITORING CONVEYOR BELT

In this section, the authors attempt to illustrate the effectiveness of the proposed methodology by discussing its application within the decision-making idea-solution process of a Chilean mining company. In more detail, Chile is one of the largest exporters of copper worldwide, contributing significantly to the world production of copper mining. Several studies report the advancements promoted by the Chilean government to increase the value proposition of this complex industrial field [35]. Currently, mining is the industry characterized by the largest investments in Chile. Specifically, its copper mining industry can be considered a technology receptor from different industries and countries [36][37]. As a result, Chile is one of the most important buyers of mining technology in the world. However, being an intensive-production and conservative sector, the implementation of new technological advances in the Chilean mining sector takes considerable time and faces several challenges.

First, being an energy-intensive industry, the Chilean mining sector is pressed by energy and resource shortages. Second, Chile's accession to the OECD has put pressure for stronger regulations in terms of sustainability indicators and accessibility to environmental information. Third, innovative technical solutions are needed to increase workers' safety and overall mine productivity. Hence, considering these needs and the strong intent of the Chilean mining industry to find new structured strategies to be more competitive on the worldwide market, the resulting context has been seen as very attractive and appropriate for developing and testing the authors' solution. Given the current technological changes, the company is interested in exploring the possibilities of incorporating new technologies into the production line to help identify failures, while maintaining an appropriate balance between new solutions and potential risks that may emerge. This is the starting point that has stimulated the company to introduce new solutions and organizational strategies in recent years to increase productivity and improve work quality for their employees through the use of technology.

STEP 1: Creation of working groups for gathering information about the specific situation was conceived by coordination with several employers at mining company. A specific teamwork was organized by different employers in specific: i) Human resources analyst to understand impact in labour contracts; ii) Operator employers, this employer was expert at monitoring conveyor belt, main failure and problems that can have operation line; iii) innovator, which was responsible to analyses solution according company perspective; iv) coordinator that was charge to understand real needs from different point of view.

STEP 2: In this step, the Network of Problems was created based on experience of teamwork, the initial solution of teamwork was related to use drone to monitored failure and potential failure at conveyor belt in mining. More detailed proposed about Partial Solution and Problems that emerged during the working sessions are presented at Figure 3. The company approached this step by recollecting all the problems they had experienced in the past and also envisiong potential situaiones by considering both the ones emerged during operation and those evaluated whenever the research and development department proposed solution concepts for them. Such solution concepts have been enriched by others intuitively generated by the teamwork involved in this activity. Figure 3 presents a manageable set of these concepts, organized according to the logic of the NoP, after several rounds of iterations.

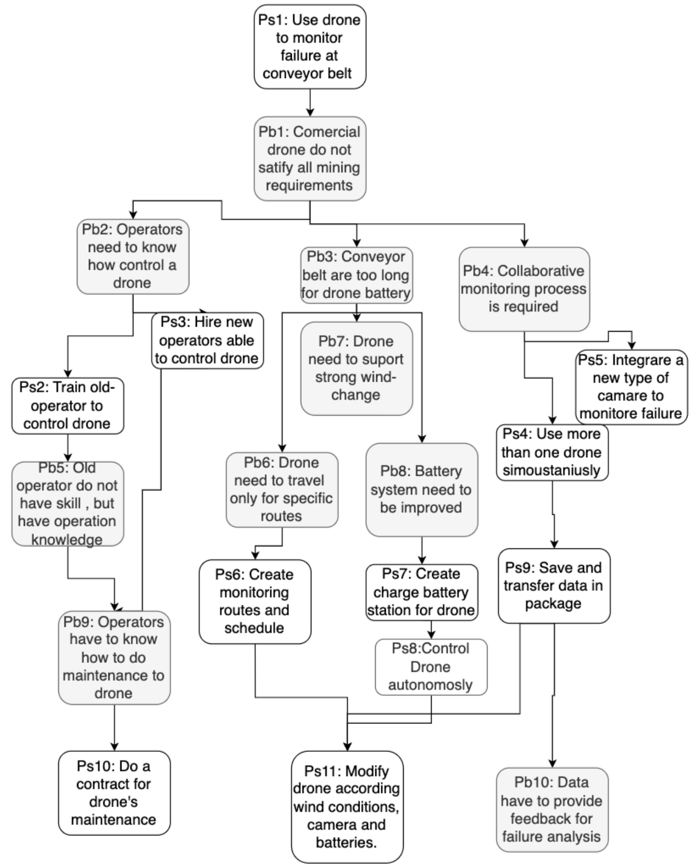

Fig. 3: Network of Problems proposed by teamwork related to use drone for monitoring conveyor belt.

STEP 3 and STEP4: In this step, teamwork evaluate every Problem and Partial Solution based on proposed maturity level. Teamwork evaluate overall situation based on their experiences and knowledge about each situation that can introduce the use of drone at operative mining line. In specific related to STEP 3, it is interesting to notice in Figure 4 that usually mining teamwork focused their potential solution as requirements for new contracts better than real solution development inside of company. As a consequence, evaluation help them to understand that is really complex develop their idea based on current company knowledge. Indeed, their technical knowledge about use drone for solution is really poor for real company development. In specific, the STEP 4 related to AHP and evaluation of levels, AHP with Consistence Ratio of 0.9 showed that teamwork is really focused on timespan solution rather than quality, solution. Indeed, the teamwork considerer most important value time need/availability for solution implementation.

	(DK)	(SI)	(PrHr)	(PdM)	(T)	O.V.
AHP(weight)	7%	3%	13%	22%	56%	
Pb1: Commercial drone do not satisfy all mining requirements	1	1	3	3	3	**2,83**
Pb2: Operators need to know how control a drone	1	1	3	1	1	**1,27**
Pb3: Conveyor belt are too long for drone battery	3	3	3	3	3	**3,03**
Pb4: Collaborative monitoring process is required	1	1	5	1	2	**2,09**
Pb5: Old operator do not have skill , but have operation knowledge	3	3	1	3	2	**2,21**
Pb6: Drone need to travel only for specific routes	1	1	3	1	3	**2,39**
Pb7: Drone need to support strong wind-change	1	1	1	3	3	**2,57**
Pb8: Battery system need to be improved	1	1	1	3	3	**2,57**
Pb9: Operators have to know how to do maintenance to drone	1	1	1	3	1	**1,45**
Pb10: Data have to provide feedback for failure analysis	1	1	1	3	3	**2,57**
Ps1: Use drone to monitor failure at conveyor belt	1	1	3	2	3	**2,61**
Ps2: Train old-operator to control drone	1	3	3	2	1	**1,55**
Ps3: Hire new operators able to control drone	5	1	3	3	3	**3,11**
Ps4: Use more than one drone simultaneously	1	1	3	1	3	**2,39**
Ps5: Integrate a new type of camera to monitored failure	1	1	3	1	1	**1,27**
Ps6: Create monitoring routes and schedule	3	3	3	1	3	**2,59**
Ps7: Create charge battery station for drone	1	3	3	1	1	**1,33**
Ps8:Control Drone autonomously	1	1	3	1	1	**1,27**
Ps9: Save and transfer data in package	2	2	3	3	2	**2,37**
Ps10: Do a contract for drone's maintenance	4	4	5	2	3	**3,17**
Ps11: Modify drone according wind conditions, camera and batteries.	1	2	2	1	2	**1,73**

Fig 4: Evaluation of Problems and Partial solution based on Maturity levels and AHP-values.

To comprehensively address the identified problems and maximize the effectiveness of the partial solutions, several key strategies could be implemented. Firstly, it is crucial to improve the technical specifications of commercial drones to face all necessary minimum requirements, so collaboration among drone supplier and mining companies should be usefull. This idea can be also achieved through the integration of advanced technologies and periodic updates, ensuring that commercial drones not only meet current standards but also remain relevant in the future.

Additionally, it is essential to improve and optimize the energy management of drones, particularly in contexts where the conveyor belt is too long for the drone's battery duration. Implementing charging stations along the conveyor belt will ensure that drones maintain sufficient energy to complete their tasks without interruptions, thereby increasing operational efficiency and reducing downtime.

Regarding personnel management, hiring new operators with specific skills in drone control is a fundamental strategy. It is not only important to hire qualified operators but also to ensure they receive continuous training to maintain and enhance their competencies, given the technologies requirements and technology evolution. This strategy is complemented by formalizing maintenance contracts for drones, ensuring regular and preventive service that minimizes interruptions and prolongs the equipment's lifespan.

To improve developer knowledge and system information, it is vital to implement intensive training programs and maintain a comprehensive database. These programs should include workshops and periodic refresher courses that keep developers and operators informed about the latest technologies and best practices. The database should contain detailed manuals, guides, and technical data that are easily accessible in order to exploit new data obtained from drones.

Finally, increasing productivity and maintenance through the implementation of a predictive and preventive maintenance system is essential. The use of data analysis and monitoring technologies will allow anticipating and preventing failures before they occur, thus optimizing operations and ensuring a high level of efficiency in all activities related to the use of drones. If implemented appropriately, these recommendations will significantly contribute to solving the identified problems and maximizing the performance of the proposed solutions.

V. CONCLUSIONS.

This paper focuses on the critical issue of the relationships between dproject development and risk related to appropriate implementation and communication, which is addressed by the integration of a problem-solving approach and an enhanced Resource Maturity analysis. The approach employed integrates a problem-solving methodology with an enhanced Resource Maturity analysis, offering a comprehensive solution. The authors present a method leveraging OTSM-TRIZ concepts to identify and address complex problems, effectively representing company drivers, barriers, and available resources. As a result, a significant reduction in resources wasted due to the execution of high-risk tasks without knowing the level of resources available nor a robust communication strategy among team members is expected. Moreover, the proposed method aims to identify the actual capabilities of teamwork to address specific project tasks with available resources and evaluate communication-associated risks by integrating new information on a Network of Problem. The method is articulated into 4 steps aiming at gathering relevant information about the context of the problem, resources available, team experience required, the kind of tasks to be done and their relation, using this information to propose multiple context-driven solutions. Moreover, its application provides a complete overview of the relationships between elementary problems and the consequences of the implementation of trivial or intuitive solutions for solving them to create a more holistic scenario. The methodology was inspired by the theory of inventive problem-solving and OTSM-TRIZ, the aim of which is to provide instruments to increase the efficiency of problem-solving sessions in the case of non-typical and complex interdisciplinary problems. Currently available integration models can aid decision-makers in selecting the optimal compromise solution among several alternatives but rarely guide the implementation stage in terms of the possible consequences or effects to take into account. The decision process of the risk problems and solution was supported by using additional decision assessment techniques, such as AHP. It is important to mention that solution assessment is largely dependent on teamwork skills to develop the plausible solution according to the initial problem. However, the proposed assessment aims to identify a lack of resources that are required to execute a project successfully. The proposed methodology aids in structuring and assessing information based on traditional problem identification, which is integrated with a problem-solving approach to improve the analysis and decision process based on novel assessment. During the case study, one of the main issues was related to knowledge, given that the team suffered from a lack of knowledge in several areas of the solution proposal. That is, in this case, the developers knew what they should do, but in practice, they did not know how to do it. Identifying this type of lack of knowledge was found to be useful to reinforce the group with people who have experience using drones in different fields. According to the proposed algorithm, it is important to include certain considerations regarding repeatability: the competences of the teamwork to develop the project and time consumption for developing the analysis may be high if the team members do not have previous experience using the OTSM-TRIZ approach. The decision process of the risk problems and solution was supported by using additional decision assessment techniques, such as AHP. It is important to mention that solution assessment is largely dependent on teamwork skills to develop the plausible solution according to the initial problem. However, the proposed assessment aims to identify a lack of resources that are required to execute a project successfully. Nevertheless, the results of the case study were considered successful because it was not necessary to introduce high investments for the creation of a more holistic and real scenario of the proposed solutions. The execution of this case study was useful to understand the benefits of the proposed methodology. Indeed, the teamwork considered the method as useful and highly intuitive to be used not only following step by step but as a single-step application too.

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