

# Sustainable Production Program in the Mexican Mining Industry: Occupational Risks\*

## Programa de Producción Sustentable en la Minería Mexicana: Riesgos Ocupacionales

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**Abstract**— Speaking of mining and sustainability sounds contradictory, as the environmental impact generated by resource extraction is well known. However, there are mining companies that are working to be safe and environmentally friendly. An example of this is presented in this study aimed at identifying occupational risks generated by the activities of a small-scale gold and silver mine located in northwestern Mexico. The methodology followed was a Sustainable Production Program (SPP) based on a continuous cycle of five steps in which the tools of cleaner production and pollution prevention are adapted. As a result of this project, it was possible to implement SPP activities: training for workers, use of personal protective equipment and adequate handling of chemicals. As a conclusion, it was verified that SPP application helped this mining company move towards sustainable patterns of production.

**Keywords**— Small-scale Mining, Sustainable Production, Occupational Risks, Northwest of Mexico.

**Resumen**— Hablar de minería y sustentabilidad suena contradictorio, ya que es bien sabido el impacto ambiental que se genera por la extracción de recursos. Sin embargo, existen empresas mineras que están trabajando para ser seguras y amigables con el ambiente. Un ejemplo de lo anterior se presenta en este estudio, cuyo objetivo fue identificar los riesgos ocupacionales generados por las actividades de una pequeña mina de oro y plata ubicada en el noroeste de México. La metodología que se siguió fue un Programa de Producción Sustentable (PPS), basado en un ciclo continuo de cinco pasos, en el cual se adaptan las herramientas de producción más limpias y prevención de la contaminación. Como resultado de este proyecto, se logró implementar el PPS en actividades de: capacitación a los trabajadores, uso de equipo de protección personal y manejo de sustancias químicas. A manera de conclusión, se establece que la aplicación del PPS coadyuva a transitar hacia patrones sustentables de producción.

**Palabras claves**— Pequeña Minería, Producción Sustentable, Riesgos Ocupacionales, Noroeste de México.

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## I. INTRODUCTION

### A. Occupational Risks in the Mining Industry

Mining industry has an important impact in global, national, and local economies since it has excellent profit levels and promotes local productive development [1]; moreover, during mineral extraction processes, a large investment is devoted to build adequate roads, hospitals, schools, and more, thus, helping the community through employment and the fulfillment of infrastructure needs [2].

According to data from [3], Mexico stands out for gold and silver production; it is eighth and second, respectively, in the mineral-producing world. In [4], a classification of Mexican mines is outlined; according to size, they are divided into small-, medium-, and large-scale mines. Nonetheless, regardless of their size, mining is considered as a high risk activity [5] because a considerable hazard to the health and integrity of miners (e.g. collapse, falls, noise, fire, explosion, pressure, heat, humidity, and other physical risks) is likely to take place [6].

Likewise, mining also generates chemical hazards due to silica (silicon dioxide), coal powder, and asbestos exposure, as well as to heavy metals like lead, cadmium, and others [5], [7], [8]; in a mine, workers are also liable to biological risks such as malaria, dengue, and leptospirosis, among others, depending on the mine location [9]. Other risks are related to bodily postures or ergonomic; they range from traumas as a result of physical effort to a permanent harm derived from heavy loads [6]. Miners are also exposed to psychosocial risks like drug and alcohol abuse [9]. Inherent results to the occupational risks aforementioned are respiratory and cardiovascular diseases, and cancer, among others [10], [11], [12].

Negative effects derived from mining are well known and documented; they are produced during the extraction of the mineral. Fig. 1 illustrates the extraction process from the mine studied: Virgen del Carmen Mine. As a consequence of mining, the application of tools inducing to a more sustainable approach is recommended, this includes being more efficient and having cleaner and safer operations that benefit neighboring communities and profit generation through practices that foster miners' well-being and the environment's protection, of course [13], [14].

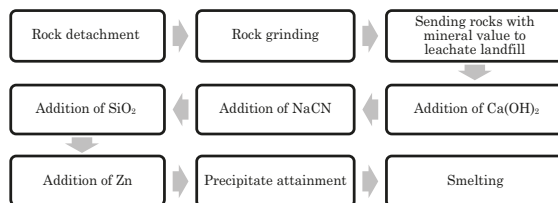


Fig.1. Gold and Silver Extraction Process in the Mine Virgen del Carmen.  
Source: Author

### B. Cleaner Production in the Mining Industry

Cleaner production is a tool conceived to prevent, reduce, and/or eliminate extraction process risks of mines [15]. However, to date, there is a limited set of guidelines for sustainable practices regarding mining operations; besides, these practices may have complications if applied for mining since a large amount of frameworks and indicators may be interpreted differently [13]. In accordance with [16], before introducing tools like cleaner production, they should be defined for the mining industry.

Furthermore, in [14] it is mentioned that cleaner production in the mining context refers to the organization and management aiming at minimizing or reducing problems derived from mineral extraction processes. Reinforcing this idea, [17] suggests that a mine that includes within their operations tools such as cleaner production belongs to a higher development category where efficient management techniques are implemented in order to control health hazards while allowing the reduction of occupational risks.

In [2], a list with six recommendations to be applied at any mine is put forward, this with the objective of facilitating sustainable production processes; these are: 1) Planning enhancement, 2) Enhancement of environmental management, 3) Implementation of clean technology, 4) Increasing the participation of the people involved in the process, 5) Creation of associations, and 6) Improve training of personnel. Despite some legislative, economic, and technology obstacles, the implementation of these tools is already bearing fruit as great benefits have been observed after their application.

The benefits from a sustainable operation in the mining sector are: 1) Reduction in labor and health costs by providing a suitable and safe workplace; 2) Cutting costs through the execution of cleaner production and innovation elements; 3) Easier access to financial loans, insurance companies, preferential loans, and insurance rates; 4) Reduction of closure and post-closure costs; 5) Influence of best practices; 6) Increased value of goodwill in the balance sheet, and 7) Market advantages for socially responsible enterprises [18]. Additionally, benefits like an improved corporate image, furtherance of social responsibility management, and a better relationship with the groups of interest [19].

## II. METHODOLOGY

The methodological approach used in this research was a Sustainable Production Program (SPP) [20], which is presented in Fig. 2. This program relates economic, social, and environmental aspects; foremost, SPP adapts cleaner production and pollution prevention tools and bases its procedures on a continuous enhancement cycle that identifies opportunity

areas to contribute with improvement ideas. The aim is to prevent and/or reduce, from the origin, risks and severe impacts in the process, operation or activities, as well as with workers, the environment, and in general, the society.

This program comprises five stages: the first consists of a written commitment for the SPP inclusion consented by the company's senior management; in the signed commitment, directives agree on preventing, reducing and/or eliminating health and environmental risks. The second stage comprises the preparation of teamwork, diagnosis or assessment, goal and objective statement, and sustainability options proposal to, in the end, elaborate a sustainable service program. In the third stage, the selected alternatives are implemented and monitored by the team through efficiency and sustainability standards. The fourth stage is designed to assess sustainability indicators so as to determine if the data obtained agrees with the program's goals and objectives. The last stage determines which features worked in the proper manner or, if on the contrary, they need a modification.

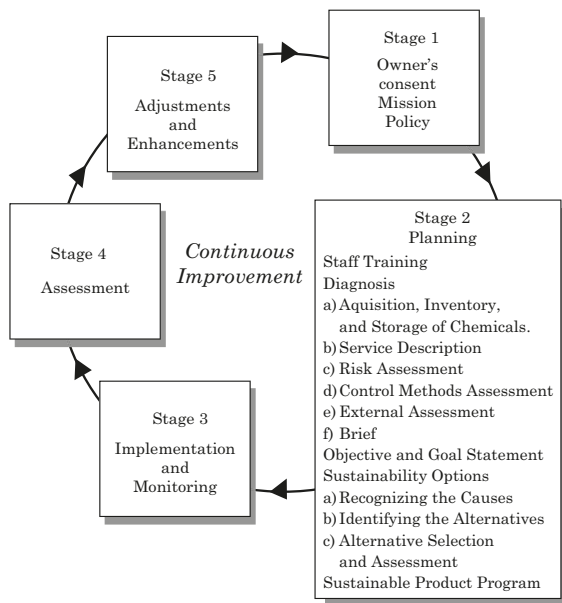


Fig. 2. Sustainable Product Program Scheme.  
Source: Author

The SPP was executed in the Virgen del Carmen Mine, which is a 2-year-old open-pit gold and silver mine located in the municipality of Divisaderos, Sonora, México. This mine was conveniently selected as the senior management showed great interest in adopting the program. The mine's facilities are distributed in a 16.23-acre land. The human resource consists of the president, fifteen workers, a cook, and two office clerks. The variables to analyze were the mine's workers and the environmental factors.

To identify chemical hazards, the information from the Material Safety Data Sheet (MSDS) was applied to manipulate the substances used to extract gold and silver in the mine. This sheet indicates the potential risks and correct handling of the different chemical substances. Regarding physical risks during extreme temperatures periods, in the hottest months of this region (July and August), permanent measurements were taken to assess the risks for high temperature exposure. This was carried through with a TM001 Honeywell environmental thermometer with Celsius (°C) and Fahrenheit (°F) readings. These readings were compared to the data provided by the National Water Commission [21]. Now, concerning ergonomic risks, the OWAS (Ovako Working Analysis System) method was applied to identify the ergonomic risks miners have due to incorrect positions during work. Finally, to assess psychosocial risks, Karasek's Demand-Control Model of job stress was applied. The results from this questionnaire were compared to the applicable regulations.

### III. RESULTS

In this section, the results obtained with the SPP application for each stage are presented.

#### A. Senior Management Consent

To demonstrate the company's commitment on preventing, reducing, and/or eliminating occupational risks in the mine, a mission and a policy were established with this purpose and they were disclosed to all the staff in the mine.

#### B. Planning

To start the planning stage, a team was set up to make decisions derived from the SPP. This team was comprised of the president of the mine, a worker, and an external advisor.

#### C. Diagnosis: Acquisition, Inventory, and Storage of Chemical Products

From the assessment, it was established that the mine has an inventory record of chemical substances; nonetheless, storage lacks standard procedures from the Mexican regulations in force, especially the NOM-005-STPS-1998 which establishes the "Safety and hygiene conditions in the workplace for the handling, transportation, and storage of hazardous chemical substances" and the NOM-018-STPS-2000 which refers to the "System of identification and communication of chemical hazards and risks in the workplace".

*D. Occupational Risk Identification*

For occupational risk identification, the extraction process in the mine was described. Results are shown in Table I.

TABLE I. OCCUPATIONAL RISK IDENTIFICATION

ACTIVITY	RISK	OCCUPATIONAL RISK
Rock detachment and removal with machinery	Noise exposure Extreme temperatures Falls, cuts, and scratches	Physical Physical Other
Loading the truck with grinded material	Noise exposure Extreme temperatures Falls, cuts, and scratches	Physical Physical Other
Calcium hydroxide addition	Chemical substance exposure	Chemical
Preparation of mineralized rock levels	Noise exposure Extreme temperatures Falls, cuts, and scratches	Physical Physical Other
Sodium cyanide addition once there is an adequate pH	Chemical substance exposure Uncomfortable bodily positions	Chemical Ergonomic
Beginning of irrigation	Chemical substance exposure	Chemical
Irrigation hoses supervision to prevent leakage or obstruction	Chemical substance exposure Extreme temperatures	Chemical Physical
Silica addition in the mixing machine	Chemical substance exposure	Chemical
Zinc addition with dispenser	Chemical substance exposure	Chemical
Precipitate attainment	Chemical substance exposure	Chemical

Source: Author

*E. Assessment of Risk Identification*

Table II poses the assessment results of chemical, physical, and ergonomic risks.

TABLE II. ASSESSMENT RESULTS OF OCCUPATIONAL RISKS IDENTIFIED

RISK	RESULT
Chemical substance exposure	Information from MSDS reveals potential harms for the miners' health.
Extreme temperatures	Maximum temperature of 31.6°C and minimum temperature of 21.9°C.
Uncomfortable bodily positions	Risk 3 bodily positions
Stress	Labor stress surveys show that a 45% of workers manifest low stress levels, 33% high stress levels, and 22% very high stress levels.
Falls, cuts, and scratches	An accident was reported during the observation period.

Source: Author

*F. Control Methods Assessment*

The lack of a closed system for chemical use and adequate safety signs was identified; also, neither MSDSs nor a risk prevention program are available for employees. This fails to fulfill the NOM-023-STPS-2012 requirements related to "Underground and open-pit mines – Safety and health conditions at work".

*G. External Assessment*

A document and operating permits review was carried out: Manifestation of Environmental Impact (MEI), changes in land use, and the planning of stages where the Secretary of Environment and Natural Resources (SEMARNAT by its acronym in Spanish) acts as a grantor for the processes in the Virgen del Carmen Mine. These documents are in force and periodically checked.

*H. Brief*

Based on the external advisor's experience and knowledge each occupational risk was weighted, including: a comprehensive vision in regard to the worker's health, magnitude terms, severity of the impact, its duration and frequency or likelihood of occurrence, whether it is related to the fulfillment of a determined regulation or if it can be controlled or influenced by the members of the sustainability team; all these depend on their relevance for the company. Hence, the statement of objectives and goals for the SPP can be established.

*I. Sustainable Production Program*

Table III puts forward the Sustainable Production Program with its corresponding objectives and goals.

**TABLE III. OBJECTIVES AND GOALS SET UP IN THE SPP**

Objective 1. Prevent and/or reduce occupational risks produced by the handling of hazardous chemicals.
Goal 1.1. <i>All</i> the chemicals need to be transported safely so as to prevent any health risks.
Goal 1.2. <i>All</i> the chemicals in the mine must have their corresponding MSDS and a homogenous system for risk identification.
Goal 1.3. Establish an exclusive area for hazardous chemical storage.
Goal 1.4. Use technology and personal protection equipment recommended by NIOSH in <i>every</i> operation involving the use of hazardous chemicals.
Goal 1.5. Design and implement contingency plans.
Objective 2. Prevent and/or reduce occupational risks derived from the final disposal of hazardous materials.
Goal 2.1. Adequate treatment of solid waste generated.
Goal 2.2. Availability of an emergency pool.
Goal 2.3. Converting sprinkling irrigation systems to drip irrigation.

Source: Author

*J. Implementation and Monitoring*

In this section, SPP was implemented and monitored considering the team’s proposals for sustainability. These alternatives are presented in Table IV, where applicable regulations and their benefits are also put forward. Resource allotment to guarantee the application of the alternatives defined during the planning stage is the objective here. Moreover, this stage describes the job, technology, and financial resources needed to accomplish each of these options. The details of resource allotment depend on the mine’s managers, however, they must at least cover the necessary activities to achieve the alternatives during the required period of time.

**TABLE IV. ALTERNATIVES, APPLICABLE REGULATIONS AND BENEFITS OF SPP**

Alternative	Description	Applicable Regulation	Benefits
A1	Training program for workers	NOM- 005- STPS-1998	Development of skills
A2	Chemical transportation	NOM-003-SCT2-2000	Reduction of pollution
A3	MSDS for every chemical	NOM-018-STPS-2000	Awareness increase
A4	Storage of chemicals	NOM-05-STPS-2014	Leakage/Spilling and accident prevention
A5	Clean and safe workplace	NOM- 002-STPS-2000	Accident prevention
A6	Contingency plan	NOM- 002-STPS-2000	Accident prevention
A7	Solid waste treatment	NOM-052-SEMARNAT-2005	Reduction of pollution
A8	Emergency pool	NOM-023-STPS-2012	Pollution prevention
A9	Drip irrigation system	NOM-023-STPS-2012	Pollution prevention

Source: Author

*K. Assessment of the Plan*

In this section, the team checked the information collected to determine if the data obtained agreed with the program’s objectives and goals. The assessment allowed verifying if there were digressions from the original plan, and if so, making decisions in order to reorient the alternatives.

Table V poses the percentage of objective and goal achievement.

**TABLE V. OBJECTIVES, GOALS AND ACHIEVEMENT PERCENTAGE IN THE IMPLEMENTATION**

Objective	Goal	Achievement (%)
Objective 1. Prevent and/or reduce occupational risks produced by the handling of hazardous chemicals.	Goal 1.1. <i>All</i> the chemicals need to be transported safely so as to prevent any contingencies regarding public health.	100%
	Goal 1.2. <i>All</i> the chemicals in the mine must have their corresponding MSDS.	100%
	Goal 1.3. Use the personal protection equipment recommended by NIOSH in <i>every</i> operation involving the use of hazardous chemicals.	100%
Objective 2. Prevent and/or reduce occupational risks derived from the final disposal of hazardous materials.	Goal 2.1. Adequate treatment of solid waste generated.	50%
	Goal 2.2. Availability of an emergency pool.	100%

Source: Author



## IV. DISCUSSION

Mining involves health risks derived from the substances used during the extraction process [22]; additionally, it entails risk factors like stress, ergonomic problems, extreme temperatures, falls, cuts, and bruises, as evidenced in this project.

Obviously, the implementation of measures aimed at reducing pollution and occupational risk problems have positive impact regarding mining productivity in Mexico, since a permanent work in enhancement programs contributes towards a sustainable production [23, 24]. This study agrees on this because through the application of the SPP numerous benefits were obtained by reducing workers' occupational risks.

There are still limited guidelines in terms of the sustainable practices applied in the mining industry [13]. This project confirms that with a prudent execution of a design methodology, regarding extraction in Virgen del Carmen Mine, these practices can be achieved successfully, however, a permanent improvement of the processes is mandatory for a progressive enhancement.

It is strongly recommended a constant training of the staff so as to create awareness in the workers about every task they perform and their related risks. Likewise, monitoring of the alternatives implemented is also required in order to identify any possible malfunction and perform the necessary corrections or changes.

## V. CONCLUSIONS

Mining activities inevitably lead to occupational risks that may affect the health of workers and the neighboring communities. For this reason, a Sustainable Production program needs to be implemented. As described in this paper, a SPP by itself is not enough to guarantee sustainability in this industry; nevertheless, it certainly increases the likelihood of developing strategies that, besides assuring a long-term economic growth, include the betterment of the environment and labor conditions. This is ensured by the inclusion of cleaner production techniques in their activities aimed at preventing, reducing, and/or eliminating occupational risks generated by their operations.

However, and despite the implementation of this program was only executed in one mine, the success of this model largely depends on not only the commitment of the mine's owners and workers but also of the government, suppliers, mining associations, education institutions, research centers, and the society in general.

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