Articles

Mathematical Modeling as a Tool for Occupational Safety and Health in Ecuador: Barriers, Potential, and Proposals

Modelación matemática como herramienta para la seguridad y salud en el trabajo en Ecuador: barreras, potencialidades y propuestas

Pablo Dávila*
Esteban Carrera*
Miguel Hernández*
Pablo Suasnavas*

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ABSTRACT

Mathematical modeling is a fundamental tool for optimizing occupational risk prevention; however, its application in Ecuador is still in its early stages. The objective of this study was to identify the academic barriers that limit the implementation of mathematical models in occupational safety and health management. A descriptive, cross-sectional methodology was employed, involving a comparative analysis of graduate programs in Ecuador, Spain, and the United States, evaluating admission profiles, curricula, and educational approaches. The results showed that, unlike the U.S. model—which prioritizes quantitative foundations and research-oriented tracks—programs in Ecuador are predominantly vocational in nature, with heterogeneous admission profiles and no training in advanced mathematics or predictive statistics. It is concluded that the lack of technical standardization and the absence of numerical skills in current graduate programs hinder the development of proactive prevention. As a solution, a new master's program design is proposed, featuring differentiated tracks (vocational and research-

* Master's Degree, SEK International University pablo.davila@uisek.edu.ec orcid.org/0000-0002-3166-9300
* Master's Degree, Edwards Deming University Institute, Ecuador, carrera@tecnologicodeming.edu.ec 0000-0002-9359-5853
* Master's Degree, SEK International University, Ecuador miguel.hernandez@uisek.edu.ec, 0000-0002-4399-5816
* Master's Degree, SEK International University, Ecuador pablo.davila@uisek.edu.ec , 0000-0003-3197-760X

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oriented) and preparatory courses that enable the use of simulation and data analysis tools for decision-making.

Keywords: Occupational safety and health, mathematical models, graduate education, accident prevention, professional training.

RESUMEN

La modelación matemática constituye una herramienta fundamental para optimizar la prevención de riesgos laborales, sin embargo, su aplicación en Ecuador aún es incipiente. El objetivo de este estudio fue identificar las barreras académicas que limitan la implementación de modelos matemáticos en la gestión de la seguridad y salud en el trabajo. Se empleó una metodología descriptiva y transversal, analizando comparativamente la oferta de posgrados en Ecuador, España y Estados Unidos, evaluando perfiles de ingreso, mallas curriculares y enfoques formativos. Los resultados evidenciaron que, a diferencia del modelo estadounidense que prioriza bases cuantitativas y trayectorias investigativas, en Ecuador predominan programas profesionalizantes con perfiles de ingreso heterogéneos y nula formación en matemáticas avanzadas o estadística predictiva. Se concluye que la falta de estandarización técnica y la ausencia de competencias numéricas en los posgrados actuales impiden el desarrollo de una prevención proactiva. Como solución, se propone un nuevo diseño de maestría con itinerarios diferenciados (profesionalizante e investigativo) y cursos propedéuticos que habiliten el uso de herramientas de simulación y análisis de datos para la toma de decisiones.

Palabras clave. Seguridad y salud en el trabajo, modelos matemáticos, educación de posgrado, prevención de accidentes, formación profesional.

INTRODUCTION

Mathematical modeling offers a robust set of tools (ranging from statistical regression models to computer simulations and optimization algorithms) that enable the estimation of accident probabilities, the identification of risk factors, and the optimization of the allocation of preventive resources. In international contexts, these techniques have

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proven to be valuable allies in improving occupational safety. For example, in the mining and construction industries, predictive models based on machine learning have been used to anticipate the severity of injuries and lost-time days with greater accuracy than traditional methods (Sari et al., 2020). These experiences suggest that OSH management supported by mathematical models can transform prevention, shifting from a reactive approach to a preventive, evidence-based one. However, in Ecuador, their adoption has been in its infancy or virtually nonexistent, raising the need to investigate what obstacles have hindered their implementation and how to overcome them. This leads to the central question of this study: What barriers exist to the implementation of mathematical models in Ecuadorian OSH, and how could they be overcome to harness their preventive potential?

MATERIALS AND METHODS

The methodology used in this study is based on a descriptive, cross-sectional approach, grounded in a comparative analysis of the academic offerings of master's programs in Occupational Safety and Health (OSH) at the national and international levels. Its purpose was to identify similarities, differences, and opportunities for improvement in curriculum content, entry and exit profiles, as well as in the programs' professional and research-oriented approaches.

First, a descriptive analysis was conducted, focusing on a review of the academic offerings of OSH master's programs available in Ecuador, Spain, and the United States, with the aim of characterizing their educational structure and curricular orientation. Subsequently, through the collection of secondary data, the admission requirements, entry and exit profiles, curricula, and study modalities of each identified program were systematized, using official sources from universities and regulatory bodies.

The study adopted a cross-sectional design, drawing on information current as of March and August 2025, which provided a current snapshot of the state of OSH education in the three countries analyzed. Finally, the study utilized qualitative variables defined based on inclusion and exclusion criteria: only OSH training programs approved by the Council for Higher Education (CES) or its international equivalents were included, while those not explicitly defined as OSH specializations or master's programs were excluded.

This methodology allowed for the establishment of a solid basis for comparison among the training models, ensuring the validity of the analysis and consistency in the interpretation of the results obtained.

The method applied in the research is based on a comprehensive and comparative analysis of the characteristics of OSH programs offered in Ecuador, with the aim of evaluating their potential to incorporate mathematical modeling and simulation tools into preventive management. This approach made it possible to examine the internal coherence of the programs, their professional or research orientation, and the competencies they promote in relation to international trends.

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In the first stage, the structural and academic characteristics of the Ecuadorian programs were analyzed, considering variables such as profile and admission requirements, duration, core training themes, competencies developed, type of master's degree, and graduate profile. This examination made it possible to identify the predominant approaches, curricular gaps, and the degree of technical specialization present in the national offering of OSH graduate programs.

The second phase focused on determining the potential of master's programs to integrate modeling and simulation, by evaluating the levels of training in advanced mathematics and statistics. This analysis sought to establish whether current curricula enable the development of quantitative competencies applicable to risk prediction, data analysis, and the design of evidence-based preventive strategies.

Twenty-eight institutions were analyzed, and based on information provided on their websites, the data was tabulated in an anonymized manner, as this article does not intend to stigmatize any institution or focus on any particular program; rather, it seeks to analyze the profiles of OSH graduate education in Ecuador.

Finally, the levels of development and structural limitations affecting OSH management in the country were analyzed. Opportunities were identified to strengthen predictive capacity, optimize resources, improve decision-making, and transform traditional reactive approaches into proactive models. Overall, this method provided insight into the academic and technical maturity of Ecuador's OSH training system and served as the basis for proposing a master's program that integrates advanced quantitative tools into the field of prevention.

RESULTS

The admission profile of the students expected to enroll in the programs was analyzed, and the following degree requirements were established (Table 1).

Table 1. *Admission profiles and percentage of programs requiring a specific profile.*

Main Category of Admission Profile	
Master's degree in Engineering (industrial, mechanical, environmental, process, civil, etc.)	4%
Bachelor's degree in Health Sciences (medicine, nursing, psychology, laboratory sciences, dentistry, public health)	8%
Admission open to any field with a college degree	88%

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The most common content areas in OSH-related graduate programs in Ecuador are shown in Table 2.

Table 2. *Percentage of most common content areas.*

Category	Frequent Topics	Occurrence (%)
Occupational Safety and Health (OSH) Management	Labor legislation, management systems, ISO 45001, preventive leadership	100%
Prevention and Control of Occupational Hazards	Physical, chemical, biological, biomechanical (ergonomic), psychosocial, and mechanical risks	95%
Hygiene and Ergonomics	Industrial hygiene, ergonomics	85%
Psychosociology	Psychosocial risks	61%
Research methodology	Thesis Preparation	32%
Statistics and Modeling	Statistics, Linear Algebra, Numerical Methods	0%

Subjects within the thematic areas and the percentage of programs that offer them as part of the curriculum.

Table 3. *Percentage of programs that include the subject.*

Subject or Thematic Area	% of programs that include it
Fundamentals of Occupational Safety and Health	100%
Legislation and Regulations	95%
Ergonomics	90%
Industrial hygiene	85%
Environmental and Sustainable Management	70%
Psychology / Psychosocial Factors	65%
ISO 45001 Auditing or Management	60%
Toxicology / epidemiology	40%
Seminar or Thesis Project	100%

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The competencies developed by graduate programs in the field of occupational safety and health in Ecuador are shown in Table 4.

Table 4. *Competencies that programs aim to develop in graduate students*

Competency / Approach	% of universities that include it
OSH management and leadership	100%
Application of national and international regulations	90%
Design and implementation of management systems	85%
Risk prevention and epidemiological surveillance	65%
Promotion of well-being, ethics, and social responsibility	80%
Environmental integration and sustainability	50%

.

The duration of the 28 programs offered in Ecuador (Table 5).

Table 5. *Program Duration in Ecuador*

Total program duration in years	
Programs longer than 1 year	14%
Programs lasting 1 year or less	86%

Twenty-eight universities were reviewed in the national analysis, and at the international level, the general profile of universities in the United States and Spain was analyzed due to their direct or indirect influence on the content of OSH programs. The results of this analysis are presented in Table 6.

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Table 6: Classification of programs and number of programs

Type of Master's Degree	Program Focus	Number of Programs
Vocational	Professional	13
	Management	3
	Technical	7
	Medical	3
	Preventive Environmental Specialist	1
	Public Health	1

The content of the curricula for occupational safety and health (OSH) programs in Ecuador was analyzed to determine the number of courses and credits that develop advanced research skills, mathematical skills, or numerical analysis skills, as shown in Table 7.

Table 7: *Courses that develop advanced mathematical or research skills.*

Courses that develop mathematical competencies to model aspects of OSH	
Advanced Research	0
Mathematics (linear algebra, numerical analysis, advanced statistics)	0

All OHS master's programs approved by the CES (Council for Higher Education) require coursework that typically includes basic statistics or research methodology, but do not include the development of mathematical competencies for advanced research or modeling, as none of them offer courses that address this profile.
The graduate profile established by SST programs in Ecuador (Table 8).

Table 8: *Occupational Safety and Health (OSH) Graduation Profile in Ecuador by Institution.*

Dimension	Consolidated description of the graduate profile	(%)
OSH Management	Plans, directs, and evaluates occupational safety and health management systems, applying principles of continuous improvement, leadership, and a culture of prevention.	100%
Risk Assessment and Control	Identifies, assesses, and controls physical, chemical, biological, ergonomic, and psychosocial risks using technical and analytical methodologies.	95%
Occupational Safety and Health (OSH) Legislation and Regulations	Applies the Ecuadorian and international legal framework (ILO, WHO, ISO 45001) in the development of policies and preventive plans.	95%

Results from Spanish universities regarding program type, admission, and graduation profiles (Table 9).

Table 9: *Entrance and graduation profiles for OSH programs in Spain by institution.*

University / Program	Admission Profile	Graduation Profile (Results)	Program Type
National University of Distance Education – University Master's Degree in Occupational Risk Prevention (distance learning)	To be admitted to the official Master's program, applicants must hold an official Spanish university degree related to the Master's subject matter, preferably in Psychology, Law, Sociology, Science, or Engineering.	Advanced training for technical roles in Occupational Risk Prevention; pathway to a doctoral program	Vocational

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Complutense University of Madrid – Master's in Occupational Risk Prevention (Faculty of Psychology)	Hold a university degree (Licenciado, Graduado, or Diplomado); for degrees from outside the European Higher Education Area (EHEA), official recognition or equivalence is required; foreign students must demonstrate proficiency in Spanish	Professional competencies in occupational risk prevention	Vocational
Polytechnic University of Catalonia – University Master's in Occupational Safety and Health (OSH)/Occupational Risk Prevention (ORP)	Given its interdisciplinary nature, the program is open to students with a wide range of academic backgrounds, from degrees in any field of study; therefore, depending on the student's undergraduate degree, supplementary coursework may be required. (basic sciences) No supplementary training is required for: Degrees in the fields of Architecture, Engineering, and Basic Sciences.	Skills of a Senior Occupational Risk Prevention Technician	Vocational
International University of La Rioja – Master's in Occupational Risk Prevention (online)	Official university degree	Trains students in occupational risk prevention management	Vocational

Results from U.S. universities regarding program type, admission, and graduation profiles (Table 10).

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Table 10: Entrance and graduation profiles for OSH programs in the United States by institution.

University / Program	Admission Profile	Graduate Profile (Outcomes)	Program Type
Georgia Tech – PMOSH (2 years, 10 courses, hybrid)	Minimum undergraduate GPA of 8.3/10, 1 year of professional experience in the field, interview, and, for international students, proof of English proficiency	Manage complex occupational safety and health (OSH) programs; leadership; culminates in an applied project	Professional
Johns Hopkins (Whiting) – MSc in Occupational and Environmental Hygiene (ANSAC/ABET)/ 2 years	Minimum undergraduate GPA of 8/10; must have undergraduate credits in basic sciences (mathematics, physics, calculus, etc.); if these courses have not been completed, they must be taken beforehand; experience in the field of occupational health or safety; must be currently employed, as the final project must be carried out at the workplace; and, for international students, proof of English proficiency is required.	Anticipate, identify, assess, and control risks; IPP (project), thesis, and presentation	Blended program with analytical research components
University of Utah (RMCOEH) – Master's in Occupational Health / Master's in Occupational Safety, 30 credits. Online, 2 years	Minimum undergraduate GPA of 8/10, 2 letters of recommendation, Graduate Record Examination (GRE) scores, a statement of purpose, a resume, and if these courses have not been completed, they must be taken beforehand; experience in the field of occupational health or safety; and applicants must be currently employed, as the final project must be carried out at their	Skills applied to safety roles; preparation for certifications (e.g., CSP)	Blended program with analytical research components

	workplace; international applicants must demonstrate proficiency in English.		
Auburn – M.Eng. in Industrial and Systems Engineering (non-thesis, 33 credits) / MSc in IIYS (thesis, 34 credits) – Ergonomics and Safety / Injury Prevention / 2 to 5 years	Minimum undergraduate GPA of 8/10, 3 letters of recommendation, Graduate Record Examination (GRE) scores, a statement of purpose, a resume, and, if these courses have not been completed, they must be taken beforehand; experience in the field of occupational health or safety; and, for international students, proof of English proficiency.	Professional tracks (non-thesis) or research (thesis); PhD option	Blended program with analytical research components

The study began by identifying universities in Ecuador that offer graduate programs in Occupational Safety and Health (OSH) and comparing admission requirements, applicant profiles, and relevant data on coursework, program duration, and delivery formats, among other factors; This research shed light on a latent problem in higher education in occupational safety and health in Ecuador: there is no standardization process or professional guidance based on foundational training—which forms the basis of a professional's body of knowledge—and these foundations vary greatly among professionals in different fields, such as the sciences and the humanities. And within these groups, there are varying levels of depth of knowledge; for example:
In the health sector, among nursing professionals, midwives, physical therapists, clinical psychologists, and physicians, there are various fields and levels of specialization and depth of knowledge.

As for engineering, there are various specializations: chemical, mechanical, civil, industrial, safety, environmental, etc. However, there are degree programs in which fields such as management, services, or administration have been labeled as "engineering" without requiring a solid foundation in the basic sciences (mathematics, physics, chemistry, and biology).
For this reason, applying a single curriculum to such a heterogeneous group upon admission to degree programs prevents students from gaining in-depth knowledge during their training and results in the loss of the unique strengths of each professional. An emerging problem that has revealed regulatory gaps in academic credit transfer processes is the lack of strict regulation governing such transfers. This leaves the decision of what and how to grant credit at the discretion of higher education institutions, without standardized criteria to ensure that the student whose credits are being transferred has the foundation to support the new competencies they must develop in the professional field for which the credits are being granted.

Given the current context of admission profiles for higher education programs, it is not possible to develop the knowledge needed to facilitate the use and development of mathematical modeling tools for risk prevention, particularly in a context of high accident rates that demands new solutions.
The barriers explaining this lag were identified as generic admission profiles and the absence of research-focused programs. Among the main barriers are the lack of high-quality OSH statistical data and systems for its analysis, the limited quantitative training of OSH professionals, and an organizational and institutional culture still centered on basic regulatory compliance rather than on continuous improvement based on scientific evidence and technological development—which would enable cultural changes within organizations and in society's view of the strategic role of OSH in sustainable development. These technical, educational, and institutional barriers reinforce one another and have kept Ecuador's OSH sector from keeping pace with the advances observed in other areas of organizational and business management.

However, the study also showed that there is significant potential if mathematical modeling can be successfully integrated into OSH. The analyses suggest that, with appropriate predictive and analytical models, it would be possible to make better decisions based on:

- preventing adverse events,
- targeting preventive actions where they are truly needed, and
- ultimately, reducing rates of occupational accidents and illnesses.

According to Statistical Bulletin No. 28 of the Ecuadorian Social Security Institute (IESS, 2024), the historical trend of workplace accidents in Ecuador between 1990 and 2023 shows a general upward trend, with a notable increase in cases of temporary disability.

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The year with the highest number of recorded accidents was 2017, with a total of 19,997 incidents, while in 2023, 15,823 were reported, of which 15,613 resulted in disability and 212 in fatalities. However, over the years, these statistics have not been used to develop mathematical models for decision-making that support OSH management; for example, the application of risk forecasting models, scenario simulation, and resource optimization could result in a substantial reduction in harmful events, as international cases have demonstrated (Junlong Peng, 2023).
Specifically, a data-driven OSH approach would enable a shift from reactive prevention (acting after an accident occurs) to proactive prevention (acting before an accident occurs, when the model alerts to a hazard).
In Spain, admission to the master's degree program in Occupational Risk Prevention is characterized by its broad accessibility, allowing professionals from any field of study to enroll. This flexibility has led to these programs being offered in departments as diverse as Law, Psychology, Architecture, Engineering, and Social Work. Unlike other graduate programs, in most cases there are no minimum grade requirements or entrance exams, which broadens the pool of candidates but limits the homogeneity of the initial academic profile.

Furthermore, there is no standardized curriculum that defines minimum training requirements. Although all programs qualify graduates in the three recognized specializations:

- Occupational Safety,
- Industrial Hygiene,
- Ergonomics, and Psychosociology.

The depth and focus vary by university. The duration typically ranges from nine to eighteen months, with online formats predominating, which reinforces the programs' vocational rather than research-oriented focus.
A significant contradiction lies in the fact that, despite the diversity of admitted candidates' backgrounds, all graduates receive the same legal certification as Senior Technicians in Occupational Risk Prevention. This fact leads to disparities in technical competence: while a chemical engineer could competently manage the safety of complex industrial processes, a professional without prior scientific training would lack the fundamentals to ensure reliable technical control of occupational risks.
This phenomenon contrasts with the strict regulation of Occupational Medicine in Spain, where professionals must pass the MIR exam and complete a clinical- y specialization. This model ensures a solid foundation based on scientific evidence and serves as a benchmark for how specialized training in occupational safety and health should be structured.

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Royal Decree 958/2024, which regulates the Advanced Technician in Occupational Risk Prevention certification, establishes training modules with explicitly technical learning outcomes—for example, the application of physical-dynamic formulas to reconstruct workplace accidents or the assessment of noise and vibration sources in the workplace. However, this regulation does not apply directly to university master's programs in Occupational Risk Prevention, creating a disconnect between the technical level required in vocational training and the less uniform standards observed in university master's programs. This discrepancy highlights the need to strengthen technical depth and curricular standardization in master's programs to ensure competencies equivalent to the regulated basic levels.

Finally, the absence of specific doctoral programs in OSH and the inclusion of the subject only as a research track within other generic doctoral programs limit the development of scientific research specific to the field. Taken together, these factors reveal a lack of coherence between the diversity of entry requirements, the uniformity of the degree awarded, and the technical depth achieved, which impacts the quality of preventive management and the sector's actual professionalization.

In the case of the United States, graduate programs in Occupational Safety and Health (OSH) offered by universities with direct ties to the Occupational Safety and Health Administration (OSHA) and other accrediting bodies were reviewed. It was observed that these programs are generally housed within Schools of Public Health or Colleges of Engineering, particularly within the departments of Industrial Engineering or Systems Engineering. This placement reflects the technical and scientific nature of the field, which combines risk management with principles of engineering, epidemiology, and toxicology. Furthermore, U.S. programs clearly distinguish between professional tracks and research tracks, which have similar durations (one to two years) but different emphases: the former are oriented toward professional practice and applied management, while the latter prioritize research, modeling, and quantitative analysis. This distinction allows students to choose their educational path based on their career or academic goals.

Regarding admission requirements, programs affiliated with engineering schools require a Bachelor of Science degree in engineering or a related scientific discipline. Candidates without this background must complete preparatory courses in basic sciences (mathematics, physics, chemistry, and biology) before beginning the graduate program. Similarly, programs offered by Schools of Public Health limit admission to professionals with training in health sciences, biology, or related fields, excluding the humanities and law from the technical scope of occupational safety and health (OSH). This differentiation demonstrates an educational structure consistent with the scientific nature of the discipline and the need for a solid quantitative foundation.

In addition, these programs typically establish rigorous selection criteria, including a minimum grade point average (GPA) of 3.0 (8/10), passing the Graduate Record Examination (GRE)—which assesses quantitative and verbal reasoning—and the submission of academic letters of recommendation. The GRE and letters of

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recommendation are mandatory requirements for research-oriented tracks, although they may be optional for professional programs. However, in all cases, admission is based on demonstrating prior quantitative competencies and a good fit between the applicant's academic profile and the technical nature of the program.
Overall, the U.S. model features a systematic alignment between admission, curriculum, and graduation, ensuring that students have the necessary scientific foundations to address occupational safety and health from a predictive and analytical perspective. This contrasts with the flexibility observed in the Ecuadorian and Spanish systems, where a more generalist approach to admission limits graduates' technical specialization.

In the case of doctoral programs, there are specific OSH programs with research tracks within OSH.
In selecting Spanish universities, we relied primarily on their institutional relevance and academic standing within the European Higher Education Area (EHEA). We sought to prioritize those institutions offering a Master's Degree in Occupational Risk Prevention aligned with Royal Decree 39/1997 and its respective updates. In this way, we were able to ensure that the programs analyzed fully complied with the three official specializations: Occupational Safety, Industrial Hygiene, and Ergonomics and Applied Psychosociology.
We also sought to capture the structural and pedagogical diversity of the Spanish model. To this end, we included universities with different organizational structures and teaching modalities, encompassing public, private, and online options. Institutions such as the Complutense University of Madrid, the Polytechnic University of Valencia, UNIR, and UNED allowed us to construct a more comprehensive and representative picture of the academic landscape in that country.
On the other hand, when evaluating the case of the United States, the selection criteria centered on the institutions' strong research track record and professional accreditation. We focused on universities that operate under rigorous standards, recognized by key organizations such as OSHA, CEPH, and ABET.
Thus, we included renowned institutions such as Georgia Tech, Johns Hopkins, the University of Utah, Auburn, and West Virginia, among others. All of them stand out for offering master's programs that integrate applied research, safety engineering, and preventive management. Our goal in selecting this sample was to reflect the two predominant approaches in the U.S. system: professionally oriented programs and research-oriented programs. Both maintain high technical and scientific standards, which allowed us to effectively compare their educational models with the realities in Ecuador and Spain.

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CONCLUSIONS

This research leads to the following fundamental conclusions regarding the state of graduate-level OSH education in Ecuador and its capacity to integrate mathematical modeling:

Structural gap in quantitative training: There is a critical disconnect between the demands of modern preventive management and Ecuador's academic offerings. The fact that 0% of the programs analyzed include courses in advanced statistics, linear algebra, or numerical methods—coupled with the fact that 86% of master's programs last one year or less—demonstrates a curriculum design focused exclusively on regulatory compliance and administrative management, making it impossible to develop competencies for risk prediction and simulation.

Heterogeneity of the admission profile without leveling mechanisms: Open admission to 88% of the programs—without distinguishing between the scientific foundations of the health sciences, engineering, or the humanities—leads to a forced homogenization of knowledge. Unlike the U.S. model, which requires prerequisites in basic sciences or standardized tests (GRE), the Ecuadorian system lacks mandatory preparatory courses that ensure all students possess the minimum threshold of quantitative reasoning necessary to tackle mathematical modeling.

Impact on National OSH Management: The absence of this specialized training has a direct impact on the country's labor reality. Despite having historical accident rate data (e.g., IESS reports), the lack of professionals trained in data analysis and predictive modeling condemns the system to a reactive approach (investigating after the accident), squandering the opportunity to optimize resources and prevent incidents through evidence-based anticipation.

Need for a Dual and Standardized Educational Paradigm: A comparison with U.S. models and, to a lesser extent, with regulatory discrepancies in Spain, demonstrates that excellence in OSH requires specialization. The proposal for a two-year master's program with two clear tracks—a professional track with specific technical branches based on the student's background profession, and a research track—is a viable and necessary solution. The inclusion of preparatory courses in basic sciences and physiology is not an obstacle but rather an indispensable mechanism for ensuring technical coherence, raising the national academic standard, and training professionals capable of leading the digital and predictive transformation of occupational safety and health in Ecuador.

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