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Specifying Cognitive Solutions in Complex Informally Structured Domains: Empirical Approaches

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Abstract. The complexity of dealing with work-related stress as a Complex Informal Structured Domain (CISD) involves various social, technical, cultural, and scientific factors, which highlights the challenges posed by organizational decision-making and the need for cognitive solutions to improve understanding of such complex scenarios. The article discusses three empirical-theoretical approaches to conceptualizing and specifying cognitive solutions to real-world problems in CISD: A literature review examines the use of specific machine learning artificial algorithms to develop models for work stress prevention; the use of cognitive solutions as ontologies for explicit knowledge representation; and a systemic methodological framework that establishes a structured approach to conceptualization and specification. The exploration emphasizes the need for a methodological model that effectively supports these cognitive solutions, to improve organizational decision-making by leveraging systems thinking and knowledge management.

Keywords: cognitive solutions; knowledge management; systems thinking; complex domains.

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Определение когнитивных решений в сложных неформально структурированных доменах: эмпирические подходы

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Аннотация. Сложность борьбы со стрессом, связанным с работой, как сложной неформальной структурированной областью деятельности (CISD), включает в себя различные социальные, технические, культурные и научные факторы, что увеличивает организационные проблемы и подчеркивает необходимость когнитивных решений для улучшения понимания таких сложных сценариев. В статье рассматриваются три эмпирико-теоретических подхода к концептуализации и определению когнитивных решений реальных проблем в CISD: Авторами изучалась литература по использованию специфических алгоритмов машинного обучения нейронных сетей для разработки моделей профилактики стресса на работе; использованию когнитивных решений, в частности онтологий, для четкого представления знаний; также изучалась системная методологическая основа структурированного подхода к концептуализации и спецификации. Проведенное исследование показывает необходимость построения методологической модели, которая должна эффективно поддерживать эти когнитивные решения, для улучшения качества осуществляемых организационных мероприятий за счет использования системного мышления и управления знаниями.

Ключевые слова: когнитивные решения; управление знаниями; системное мышление; сложные домены.

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Благодарности. От имени всех соавторов и сотрудников мы выражаем нашу самую искреннюю благодарность и вечное восхищение доктору Жасмин Георгиане Ликона-Олмос. Ее вклад был неоценим, и ее наследие остается на этих страницах. Она была блестящим исследователем, исключительным наставником и вдохновляющим человеком. Первый автор также выражает свою благодарность Национальному совету по гуманитарным наукам и технологиям (Conahcyt) за стипендиальную поддержку, оказанную во время ее учебы в докторантуре по программе инженерных наук Автономного университета Сьюдад-Хуарес (UACJ).

1. Introduction

Complex domains are characterized by their dynamic nature, open boundaries, and ambiguous relationships, necessitating customized approaches due to their unique characteristics. These domains lack formal structures that feature non-linear and interdependent factors and are marked by uncertainty, diverse perspectives, and continuous change, with tacit knowledge being predominant. Understanding these domains is crucial for developing artificial intelligence (AI) based cognitive solutions, which formalize domain concepts and relationships, such as Decision Support Systems and Predictive Analytics Tools. These solutions help organizations make informed decisions, drive innovation, and enhance performance by deeply comprehending complex situations.

Complex Informal Structured Domains (CISD) arise when external specialists, unfamiliar with the domain, are brought in to develop cognitive solutions. This introduces complexity but is essential for bringing fresh perspectives and innovative approaches. Challenges in CISD include knowledge elicitation, representation, reaching consensus among specialists, and designing effective solutions.

The complexity of CISD, characterized by informal knowledge, multiple perspectives, ambiguity, and uncertainty, complicates establishing clear relationships between concepts. For instance, work stress, a global issue with unpredictable behaviors like emotional exhaustion and symptoms such as anxiety and depression, affects organizational productivity and can also have positive impacts. Developing cognitive solutions involves navigating diverse data and viewpoints, making work stress particularly challenging (see Fig.1).

This article presents three approaches to developing cognitive solutions for work stress in CISD within the maquiladora industry on Mexico's northern border: (1) a literature review of the application of machine learning (ML) algorithms, to model work stress prevention; (2) using cognitive solutions with explicit knowledge representation, such as ontologies; and (3) the creating of a systemic methodological framework for conceptualizing and specifying cognitive solutions in CISD. As a result of this analysis, this paper introduces a methodological model that employs systemic thinking and knowledge management to support organizational decision-making. The paper is structured as follows: Section 2 covers CISD and work stress characterization, Section 3 reviews the approaches, and Section 4 discusses results and future work.

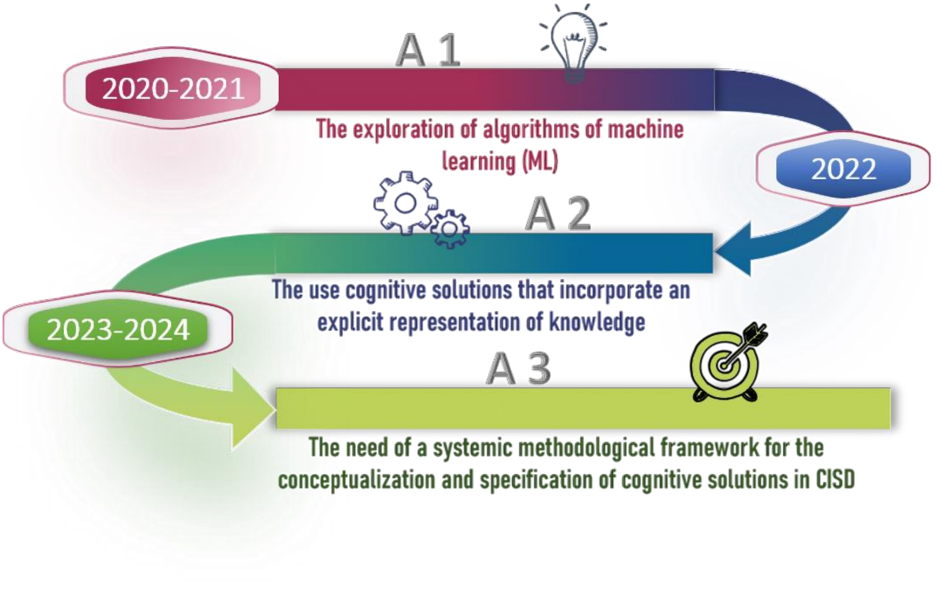

Fig. 1. Implemented approaches. Based on [1].

2. Background

2.1 Complex Informal Structured Domains

Complex Informal Structured Domains (CISD) arise when a team of domain experts and newcomers collaborate to create cognitive solutions tailored to the domain's needs. CISD involves multiple interacting elements, making reductionist approaches potentially ineffective. The key characteristics and components of CISD, illustrated in Fig. 2, include:

a) CISD is composed of an Application Domain (AD) and a Solution Domain (SD).
b) Domain Specialists (DS) with expertise in specific areas provide critical insights and guidance, although their perspectives may vary based on their roles.
c) The AD encompasses human, technological, cultural, and scientific factors, characterized by ambiguity, uncertainty, dynamism, and emergent properties.
d) Solution Providers, managed by a Cognitive Architect, specialize in conceptualizing, specifying, designing, and implementing cognitive solutions.
e) All participants form an ad hoc Collaborative Network.
f) Cognitive Solutions Specification includes both functional and non-functional requirements, derived from and synthesized between AD and SD.

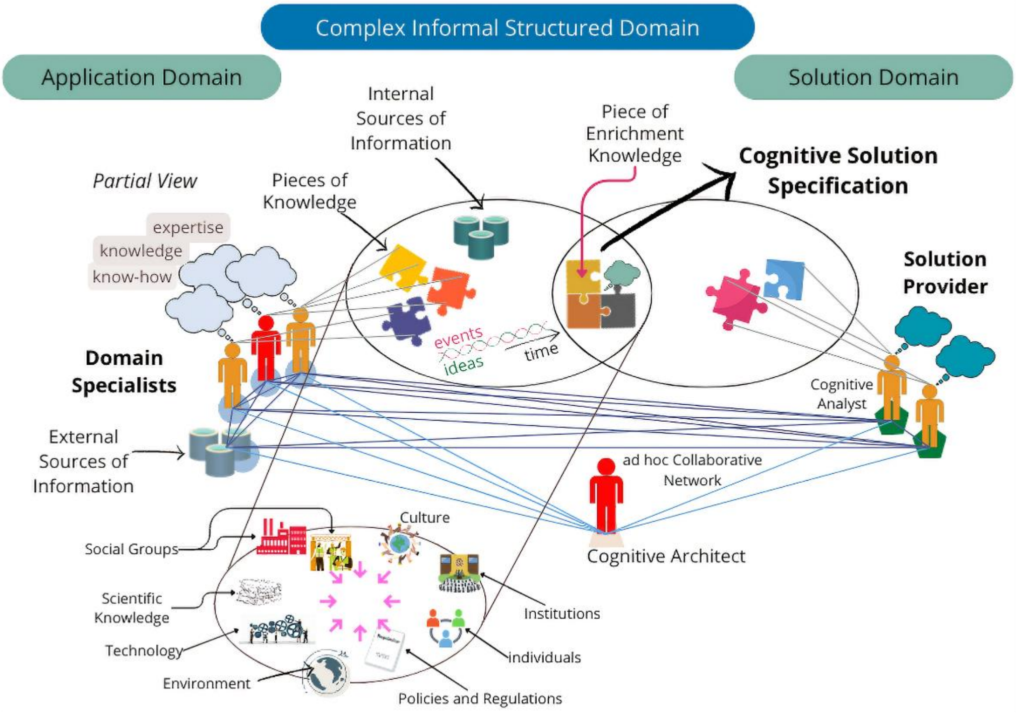

Fig. 1. CISD Characterization. Based on [2].

2.2 Work stress as CISD

Work stress impacts 75% of workers in Mexico, resulting in various disorders due to factors like work overload, harassment, insufficient support, and autonomy issues. The COVID-19 pandemic has worsened stress due to increased uncertainty. To address this, organizations such as the World Health Organization, National Human Rights Commission, and Secretaría del Trabajo y Previsión Social (México) recommend identifying psychosocial risks, implementing work-life balance policies, conducting risk assessments, and promoting mental well-being practices.

Effective intervention involves collaboration between the government, employers, and workers, with the government enforcing policies like NOM-035-STPS-2018, employers addressing risks, and workers engaging in management training. In the maquiladora industry, which encompasses human, technological, cultural, and scientific factors, work stress is influenced by various aspects including interpersonal dynamics, technological changes, and cultural and scientific research. Domain Specialists and Solution Providers work together in a collaborative network, addressing dynamic and emergent stress factors, which vary based on individual resilience and coping skills.

3. Approaches to addressing CISD

As was mentioned before, three approaches were analyzed:

1) a literature review of ML techniques,
2) cognitive solutions with explicit knowledge representation, and
3) a systemic methodological model for CISD.

3.1 Approach 1: Use of artificial intelligence techniques

The initial approach involved a literature review of cognitive solutions aimed at preventing work stress in the maquiladora industry through AI and ML. Databases like Science Direct and Taylor & Francis helped identify 21 relevant articles from a total of 61.

ML algorithms are increasingly applied to manage and prevent mental disorders, gaining traction in healthcare due to their ability to learn from data. Advances in data availability and computing have furthered ML research. ML is used in various domains, including gaming and mental health, to enhance data analysis and understanding of psychological conditions [3–5].

Despite these promising developments, the focus on work stress remains limited, and previous studies often lacked enough characterization of prior knowledge, which impacted the quality of the results. Recent research underscores the importance of explicit knowledge representation in cognitive system design. Peruvian regulations, for example, require ISO/IEC 12207 compliance for software requirements validation [6], and studies highlight the benefits of validation for quality and efficiency improvements [7]. Models like CMMI and ISO/IEC 15504 are essential for process improvement [8], with advancements in the Analytic Hierarchy Process (AHP) proposed to enhance prioritization accuracy [9].

ML faces challenges such as ambiguity, unclear definitions, incomplete data, and the need for domain-specific knowledge, necessitating the use of complementary techniques to address these issues effectively.

These insights emphasize the need for a more robust solution that integrates knowledge management and representation, particularly tacit knowledge, to effectively address work stress in complex domains like the maquiladora industry.

3.2 Approach 2: Cognitive solutions that have an explicit knowledge representation

For this approach, we applied the KMoS-RE (Knowledge Management on a Systematic Process for Requirements Engineering) approach to develop a knowledge representation of work stress in the maquiladora industry. KMoS-RE focuses on capturing and enhancing tacit knowledge in Informally Structured Domains (ISD) through cognitive techniques and a spiral knowledge evolution cycle [10]. It is based on the Knowledge Evolution Model for Requirements Engineering and Nonaka and Takeuchi's knowledge creation model [11] and includes domain modeling, system modeling, and requirements specification development [12]. During domain modeling, we created essential components such as the KDEL (Knowledge Domain Extended Lexicon), a conceptual model, and an OWL ontology, based on a review of standards and literature. Despite involving domain specialists for validation, several limitations were identified:

- KMoS-RE struggles with ambiguity and uncertainty, relying on consensus for defining concepts.
- A single model approach can delay understanding by lacking multiple perspectives.
- The knowledge representation is partial and does not fully capture the domain.

While KMoS-RE aids in explicit knowledge representation, a broader approach that includes diverse perspectives and cultural factors is necessary for effective cognitive solution development.

3.3 Approach 3: Systemic methodological framework for conceptualization and specification of cognitive solutions in CISD

In this approach, we use a systemic methodological framework to develop cognitive solutions in CISD, drawing on Morin's complexity theory [13] and Checkland’s Soft Systems Methodology (SSM) [14-15]. Morin's theory focuses on understanding interconnected, nonlinear systems, while Checkland’s SSM addresses complex, poorly defined problems through diverse perspectives and structured debate. Applying these approaches, we used a cause-effect problem tree to analyze CISD issues, identifying key challenges: neglect of tacit knowledge, poor communication, and incomplete domain observation [16].

The third approach focused on developing a systemic methodological model for conceptualizing and specifying cognitive solutions in Complex Informal Structured Domains (CISD). This model combines systems thinking with knowledge management principles to address domain complexities. Key results include:

- Model Development: The KMoS-SSA (Knowledge Management of Strategic options through Soft Systemic Analysis) framework merges SSM with the KMoS-RE process, allowing for flexible, evolving analysis and continuous solution adaptation based on new domain information [2].
- Systems Thinking: This approach assesses interrelationships and dynamics within CISD, crucial for tackling complex issues like work-related stress that involve multiple social, technical, and cultural factors.
- Enhanced Knowledge Elicitation: The framework improves the elicitation and representation of domain knowledge by integrating specialist perspectives and creating a shared language for addressing diverse needs.
- Requirements Specification: It establishes a clear process for defining both functional and non-functional requirements, ensuring solutions are desirable and feasible by deriving insights from interactions between application and solution domains.
- Positive Results: The model has effectively conceptualized cognitive solutions for work stress in the maquiladora industry, improving understanding through varied perspectives.

These findings support the proposed systemic approach for managing complexity in CISD. In summary, the proposed systemic approach provides a strong framework for developing and defining cognitive solutions within CISD. It enables more efficient handling of the intricate and evolving aspects of issues such as work stress.

4. Results

The KMoS-SSA model aims to conceptualize and specify cognitive solutions for CISD issues using systemic thinking. It enhances domain understanding and supports the development of effective, feasible solutions for organizational decision-making through its Knowledge Enrichment Cycle and methodological model [2].

4.1 Methodological Model for CISD: Knowledge Enrichment Cycle

The knowledge enrichment cycle model is an iterative framework that integrates systems thinking with real-world perspectives (Fig. 3). It combines the SECI model, the KMoS-RE knowledge evolution model, and systemic thinking principles. The SECI model involves four stages – socialization, externalization, combination, and internalization – to generate and interact with both tacit and explicit knowledge. The KMoS-RE model adapts these concepts for Requirements Elicitation. The cycle includes

a) Knowledge Elicitation, which gathers and organizes information;
b) Knowledge Enrichment, which validates and connects the information;
c) Model Generation, which creates artifacts representing the domain;
d) Model Discussion, which involves presenting models to specialists for feedback; and
e) Model Validation, where specialists assess and adjust the models.

This iterative process supports the continuous refinement of domain understanding and solution development.

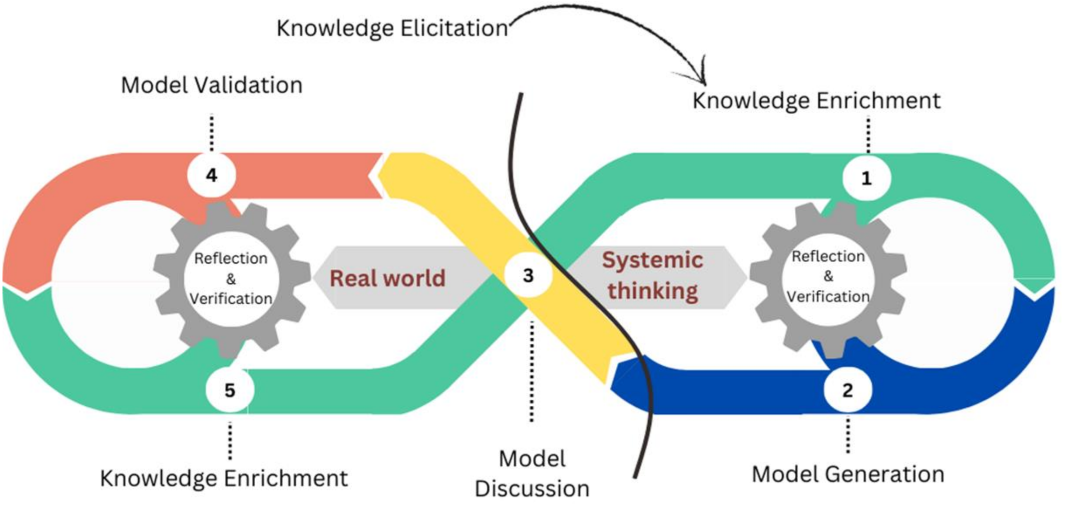

Fig. 3. Knowledge Enrichment Cycle. Based on [2].

4.2 Methodological Model for CISD: general activities, processes, and methods view

The CISD methodological model (Fig. 4) involves a set of activities and processes divided into real-world and systems-thinking tasks.

Real-world tasks cover ***elicitation*** and ***decision-making*** stages, while systems thinking tasks include ***structuring***, ***generation***, and ***enrichment*** stages [2]. Elicitation involves rigorous knowledge gathering, and decision-making includes validation and enrichment. Domain structuring formalizes the CISD, while model generation focuses on creating and validating artifacts. The enrichment stage involves thorough analysis and enhancement of knowledge.

5. Future work

We are currently working on the application of the proposed methodological model to the work stress phenomenon in the maquiladora industry, a real-world problem. We are also applying the methodology to generate solution alternatives in other areas such as academic accreditations and psychological therapies to provide evidence of its functionality.

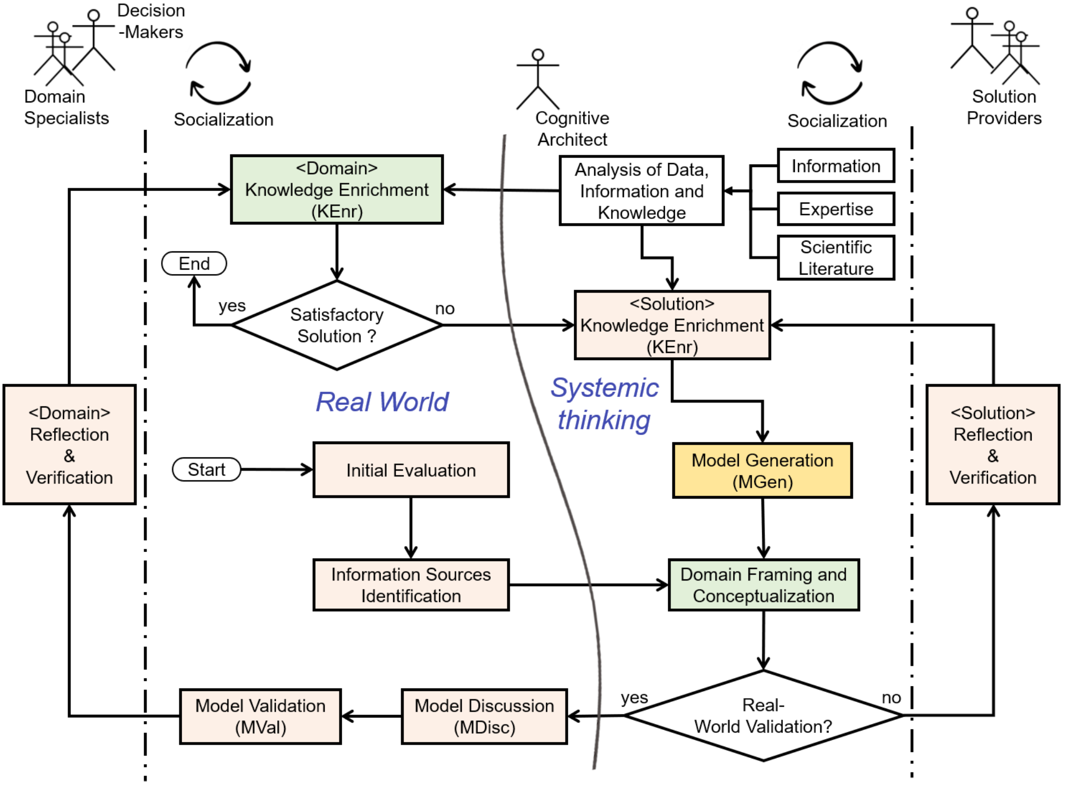

Fig. 4. Methodological model for CISD: general activities, processes, and methods view. Based on [2].

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Информация об авторах / Information about authors

Алисия Маргарита ХИМЕНЕС-ГАЛИНА имеет степень магистра прикладных вычислений, с отличием окончила Автономный университет Сьюдад-Хуарес и в настоящее время готовится к защите диссертации для получения степени PhD в области передовых инженерных наук. Координатор по инновациям в Центре инноваций и интеграции передовых технологий (CIITA) Национального политехнического института Мексики (IPN). Область научных интересов: архитектура сложных систем, инновации в системах мониторинга окружающей среды, разработка заказного программного обеспечения и управление базами данных.

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Карла ОЛМОС-САНЧЕС закончила аспирантуру и получила степень PhD по инженерным наукам в Автономном университете Сьюдад-Хуарес (UACJ) по инженерии и управлению знаниями. Получила степень магистра в Национальном центре исследований и технологических разработок (CENIDET) по обработке естественного языка и входит в состав научного совета по прикладному искусственному интеллекту. При подготовке своей диссертации работала над методами управления знаниями о стратегии разработки требований (KMoS-RE), которая в первую очередь фокусируется на выявлении требований к знаниям в областях с неформальными структурами для концептуализации когнитивных решений. Эта стратегия была опубликована в различных книгах и международных журнальных статьях, и с 2015 года используется в прикладных вычислительных проектах при подготовке магистерских диссертаций. Имеет более чем 25-летний опыт преподавания предметов по программе компьютерной системной инженерии в университете UACJ. Руководила научной работой соискателей нескольких дипломных работ, магистерских и

докторских диссертаций. Координировала научную программу подготовки магистров прикладных вычислений и руководила концептуализацией, анализом и дизайном научной программы подготовки магистров прикладной кибербезопасности в UACJ.

Karla OLMOS-SÁNCHEZ completed her PhD studies in Engineering Sciences at the Autonomous University of Ciudad Juárez (UACJ) in Engineering and Knowledge Management. Additionally, she pursued her Master's degree at CENIDET (National Center for Research and Technological Development) in natural language processing and is currently part of the Applied Artificial Intelligence academic body. During her PhD, she developed the KMoS-RE strategy (Knowledge Management on a Strategy for Requirements Engineering), which primarily focuses on eliciting knowledge requirements in domains with informal structures to conceptualize cognitive solutions. This strategy has been published in various books, and international journal articles, and has been used in applied computing master's projects for thesis solution conceptualization since 2015. In her academic career, Dr. Olmos has over 25 years of teaching experience in computer science-related subjects in the Computer Systems Engineering program at UACJ. She has also supervised several undergraduate, master's, and doctoral theses. Additionally, she has coordinated the Applied Computing Master's program and led the conceptualization, analysis, and design of the Applied Cybersecurity Master's program at UACJ.

Аида Арасели МАЛЬДОНАДО-МАЧИАС получила степень PhD в области промышленной инженерии в Технологическом институте Сьюдад-Хуарес. В настоящее время она является профессором и научным сотрудником Автономного университета Сьюдад-Хуарес (UACJ). Сертифицированный профессиональный эргономист Коллегии эргономистов Мексики и действующим Президентом общества эргономистов. Член Национальной системы исследователей уровня II. Обладатель Государственной премии Мексики в области науки и техники 2018 года, награждена медалью штата Чиуауа 2020 года. Публиковала свои научные работы в нескольких индексируемых и известных журналах на английском и испанском языках, автор или соавтор более чем 100 статей и 10 книг на английском и испанском языках, в том числе во всемирно признанных издательствах. Рецензент и редактор известных журналов.

Aide Aracely MALDONADO-MACÍAS holds a Ph.D. in Industrial Engineering from the Instituto Tecnológico de Ciudad Juárez. She is currently a full-time Professor and Researcher at the Universidad Autónoma de Ciudad Juárez (UACJ). She is a Certified Professional Ergonomist by the Colegio de Ergonomistas de México and the current president of the Society of Ergonomists. She is also a member of the National System of Researchers as an SNI II. Dr. Maldonado received the 2018 State Science and Technology Award and the 2020 Distinguished Chihuahua Medal. She has published in multiple indexed and high-impact journals in both English and Spanish, with over 100 articles as an author or co-author and more than 10 books in English and Spanish. She is a reviewer and editor for prestigious journals and has also contributed to book chapters and authored books for internationally recognized publishers.

Жасмин Георгина ЛИКОНА-ОЛМОС, получила магистерскую степень по промышленной инженерии в Автономном университете мексиканского штата Идальго и степень PhD по системной инженерии в Национальном Политехническом институте. Она неоднократно публиковала результаты своих прикладных исследований по систематизации и сложным системам. Более 20 лет она ведет преподавательскую деятельность, осуществляя руководство студенческими работами.

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