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DIGITAL TRANSFORMATION AND TECHNOLOGICAL EVOLUTION IN THE MANAUS FREE TRADE ZONE: PATHS AND CHALLENGES BETWEEN INDUSTRY 4.0 AND SOCIETY 5.0

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ABSTRACT

This study analyzes the impacts and challenges of digital transfor-mation in the Manaus Free Trade Zone, highlighting how Industry 4.0 technologies can drive the transition to Society 5.0. The research employs a mixed approach, integrating qualitative and quantitative methods, with a case study and field research applied to the Manaus Industrial Pole (PIM). The results indicate that 75% of the companies analyzed have already implemented initiatives aligned with Society 5.0, with an emphasis on Production/Operations and Information Technology. However, barriers such as deficiencies in professional qualifications, organizational resistance, and high costs limit the full use of emerging technologies. On the other hand, benefits such as cost reduction, improved connectivity, and increased customer satisfaction are evident. The article proposes an

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integrative model that combines technological adoption with training strategies, tax incentives, and partnerships between companies and academic institutions. It is concluded that the digital transformation in the PIM has the potential to position the Manaus Free Trade Zone as a global example of sustainable development, promoting social inclusion and technological innovation.

Keywords: Digital Transformation, Industry 4.0, Society 5.0, Manaus Industrial Pole, Sustainability, Manaus Free Trade Zone.

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INTRODUCTION

Industry 4.0, often referred to as the Fourth Industrial Revolution, is a transformative milestone in the global industrial landscape. This paradigm is characterized by the integration of advanced technologies, such as the Internet of Things (IoT), Artificial Intelligence (AI), Big Data, advanced robotics, and cyber-physical systems (CPS), promoting automation, connectivity, and efficiency at unprecedented levels (Schwab, 2016). In Brazil, the Manaus Free Trade Zone (ZFM) emerges as a peculiar case, being an important economic hub that simultaneously faces structural challenges and seeks to align itself with the demands of an increasingly digitized global market.

Created in 1967 with the aim of promoting economic and social development in the Amazon, the ZFM has established itself as one of the main industrial engines in the region, covering sectors as diverse as electronics, chemicals, and two-wheelers (Silva & Silva, 2017). However, the technological modernization of local industries has become a requirement for the ZFM to maintain its relevance on the global stage. In this context, the digital transformation driven by Industry 4.0 technologies is not only an opportunity, but a necessity to ensure the competitiveness of the Manaus Industrial Pole (PIM).

The transition to Society 5.0, a concept introduced in Japan, presents a promising horizon for integrating technological advances with human and social needs (Fukuyama, 2018). This vision proposes an inclusive and sustainable digital economy, which utilizes technologies such as AI and IoT not only for economic gains, but also to solve societal challenges such as inequality, poor infrastructure, and climate change (Deguchi et al., 2020). Thus, aligning the principles of Industry 4.0 with the goals of Society 5.0 becomes essential to transform the ZFM into a model of sustainable and innovative development.

JUSTIFICATION

The relevance of this research lies in the need to modernize the Manaus Industrial Pole in the face of competitive pressures and challenges imposed by globalization and economic digitalization. Although the ZFM represents a significant portion of the Brazilian economy and plays a strategic role in job creation and environmental preservation, many of its production processes remain outdated in relation to global trends (CNI, 2018). In addition, the transition to Society 5.0 can contribute to addressing social and structural problems that have limited the full development of the region for decades.

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Investing in the implementation of Industry 4.0 technologies in PIM will not only increase its productivity and efficiency, but also create conditions to align industrial growth with social well-being, in line with the principles of Society 5.0. Initiatives such as process automation, the use of real-time data, and professional qualification can reduce regional inequalities and position the ZFM as an example of a sustainable and innovative economy.

In this context, this study seeks to explore how the implementation of Industry 4.0 technologies in the Manaus Industrial Pole (PIM) can enable the transition to Society 5.0, aligning industrial efficiency, technological innovation and social well-being.

The research seeks to understand the impacts of these technologies on industrial operations, focusing on productivity, efficiency and sustainability gains, while assessing the challenges and opportunities related to workforce training and adaptation to new technological paradigms. In addition, it investigates collaborative initiatives between industries, government and educational institutions, seeking innovative solutions to social issues, such as urban mobility and health, that can be tackled through digital technologies.

Finally, the study proposes an integrative model that aligns the adoption of Industry 4.0 technologies with the principles of Society 5.0, promoting a more inclusive and innovative economy, capable of transforming the Manaus Free Trade Zone into an example of sustainable and socially responsible development.

THEORETICAL FRAMEWORK

INDUSTRY 4.0

Definition and Origin

Industry 4.0, also called the Fourth Industrial Revolution, symbolizes a new paradigm in industrial production, characterized by the integration of advanced digital technologies into production processes. Officially introduced in Germany in 2011 during the Hannover Messe, the initiative was designed to modernize the industrial sector and make it more competitive in a digitalized global environment (Kagermann, Wahlster & Helbig, 2013).

The evolution of previous industrial revolutions highlights the distinctions of Industry 4.0. While the First Industrial Revolution (Industry 1.0) marked steam-driven mechanization, Industry 2.0 brought mass production powered by electricity. In Industry 3.0, automation and the use of computers have advanced production lines. Industry 4.0, however, connects machines, systems, and products through digital networks, allowing processes to be adaptable and managed in real-time (Schwab, 2016).

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Key Technologies

The core of Industry 4.0 lies in emerging technologies that integrate the physical and digital worlds, promoting automation, connectivity, and personalization. Among the main technologies are:

- **Internet of Things (IoT):** IoT connects physical devices to the internet, allowing for real-time data collection and exchange. In smart factories, IoT sensors automatically monitor and adjust operations, optimizing production processes (Xu, He, & Li, 2014).
- **Cyber-Physical Systems (CPS):** Integrate physical and computational processes for real-time control and monitoring, enabling the adaptation of machines to production demands (Lee et al., 2015).
- **Big Data and Analytics:** The analysis of large volumes of data in real time offers insights for strategic decisions, optimizing efficiency and identifying potential failures in processes (Chen, Chiang & Storey, 2012).
- **Artificial Intelligence (AI) and Machine Learning:** AI enables machines to learn from data, resulting in predictive maintenance, automated quality control, and continuous adjustments to operations (Jordan & Mitchell, 2015).
- **Automation and Advanced Robotics:** Collaborative robots (cobots) perform complex tasks, increasing productivity and improving worker safety (Bahrin et al., 2016).
- **Blockchain:** Widely used for security and traceability, especially in supply chains, ensuring transparent and secure transactions (Kavalikov & Lagrange, 2018).

Impacts on Manufacturing

Industry 4.0 transforms manufacturing with significant impacts:

1. **Increased productivity:** Smart, connected, and autonomous machines operate continuously, reducing downtime (Schwab, 2016).
2. **Reduced operating costs:** Predictive maintenance and automation reduce labor costs and material waste (Porter & Heppelmann, 2014).
3. **Flexibility and customization:** Personalized mass production becomes feasible, allowing companies to meet the specific demands of consumers (Bahrin et al., 2016).
4. **Improved product quality:** Sensors and real-time monitoring identify defects, ensuring high quality standards (Jordan & Mitchell, 2015).

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5. **Sustainability:** More efficient processes reduce emissions and energy consumption by promoting environmentally responsible practices (Stock & Seliger, 2016).

Despite the advantages, challenges include high upfront costs, the need for robust infrastructure, and resistance to change by workers, as well as cybersecurity concerns (Caniato et al., 2018).

Industry 4.0 in the Brazilian Context and in the Manaus Free Trade Zone

In Brazil, the adoption of Industry 4.0 is at an early stage, but it has significant potential, especially in the Manaus Free Trade Zone (ZFM). The Manaus Industrial Pole (PIM), the core of the ZFM, concentrates industries that cover sectors such as electronics and chemicals, whose modernization is essential to maintain global competitiveness (Silva & Silva, 2017).

ZFM faces particular challenges, such as logistical limitations and a lack of advanced technological infrastructure. However, the adoption of technologies such as IoT and automation can increase efficiency and reduce costs. Investments in digital capacity building and infrastructure, including high-speed networks and big data solutions, are critical to the success of digital transformation in the region (CNI, 2018).

In addition, Industry 4.0 in the ZFM can promote sustainability, using technologies to reduce carbon emissions and minimize waste, aligning with the principles of Society 5.0 and contributing to the social and environmental development of the Amazon (Fukuyama, 2018).

SOCIETY 5.0

Concept and Development

Society 5.0, a concept introduced by the Japanese government in 2016 in the 5th Science and Technology Basic Plan, represents a new stage in human development, focused on integrating technological advances with social well-being. Unlike Industry 4.0, whose central objective is to optimize industrial processes and economic efficiency, Society 5.0 puts human beings at the center of innovations, using technologies such as the Internet of Things (IoT), Artificial Intelligence (AI), and Big Data to solve social problems, such as inequality, population aging, and climate change (Fukuyama, 2018).

Historically, Society 5.0 is seen as the natural evolution of previous societies:

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- **Society 1.0:** Hunting and gathering;
- **Society 2.0:** Agriculture;
- **Society 3.0:** Industrial Revolution;
- **Society 4.0:** Information Age and Digitalization.

Society 5.0 emerges as a fusion between the physical, digital, and biological worlds, promoting a super-intelligent and inclusive society. This paradigm expands the possibilities of Industry 4.0, applying its technologies in areas such as health, urban mobility, education, and sustainability (Deguchi et al., 2020).

Enabling Technologies

The technologies of Society 5.0 are the same as those of Industry 4.0, but their use is aimed at social and sustainable applications. Among the most relevant are:

- **Artificial Intelligence (AI):** Central to Society 5.0, AI automates processes and analyzes large volumes of data, with applications ranging from personalizing education to healthcare system improvements such as early diagnosis and remote patient monitoring (Roser & Nakamura, 2020).
- **Internet of Things (IoT):** Essential for creating smart cities, IoT connects devices and systems, enabling the efficient management of urban resources such as transportation, energy, and waste (Zanella et al., 2014).
- **Big Data:** It allows a better understanding of the needs of populations, planning public policies based on predictive analysis and ensuring the efficient use of resources (Gubbi et al., 2013).
- **Robotics:** It goes beyond industries and gains prominence in areas such as health, with elderly care robots, and transportation, with autonomous vehicles (Deguchi et al., 2020).
- **Augmented Reality (AR) and Virtual Reality (VR):** They offer solutions for training, education, and realistic simulations, with applications ranging from immersive educational environments to remote support for healthcare professionals (Schwab, 2016).

These technologies enable the creation of an environment where technological innovations solve everyday problems, while promoting social inclusion and sustainability.

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Benefits and Challenges

Society 5.0 has numerous benefits, including:

1. **Improved quality of life:** Applications such as digital health and smart urban mobility increase accessibility to essential services, promoting greater well-being for populations (Fukuyama, 2018).
2. **Social inclusion:** Technology is used to eliminate barriers, creating accessible solutions for people with disabilities, the elderly, and marginalized populations (Roser & Nakamura, 2020).
3. **Environmental sustainability:** Technologies such as IoT and Big Data help to optimize the use of natural resources, promoting cleaner cities with a smaller ecological footprint (Deguchi et al., 2020).

However, the implementation of Society 5.0 faces significant challenges:

- **Unequal access to technology:** In peripheral regions or with limited infrastructure, ensuring access to enabling technologies is a challenge, especially in developing countries.
- **Cybersecurity:** Increased interconnectivity increases exposure to cyberattacks, requiring strict digital security protocols (Roser & Nakamura, 2020).
- **Professional qualification:** Society 5.0 requires workers trained to deal with advanced and complex technologies, requiring investments in education and retraining (Schwab, 2016).

Applications in the Brazilian and Global Context

Japan is leading the way in implementing Society 5.0, with initiatives ranging from autonomous vehicles to assistance robots for elderly care. These solutions are developed to address challenges such as population aging and labor shortages (Deguchi et al., 2020).

In Brazil, although Society 5.0 is not yet widely discussed, there are initiatives that incorporate its principles. Examples include:

- **Smart urban mobility:** In cities like São Paulo, IoT systems are used to manage traffic and improve public transportation.
- **Digital health:** Telemedicine has risen to prominence during the COVID-19 pandemic, demonstrating the potential of technologies to expand access to medical care in remote areas (Roser & Nakamura, 2020).

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- **Sustainability:** Smart city projects, such as Curitiba, integrate Big Data and IoT to manage urban resources more efficiently.

These applications demonstrate the transformative potential of Society 5.0, especially when adapted to challenging contexts such as Brazil.

DIGITAL TRANSFORMATION

Definition and Strategies

Digital transformation refers to the integration of digital technologies into all aspects of an organization, resulting in fundamental changes in the way businesses operate and generate value for customers. More than adopting technological tools, digital transformation implies a complete reassessment of business models, organizational structures, and business cultures (Bharadwaj et al., 2013).

According to Rogers (2016), digital transformation is not a one-off process, but a continuous one, encompassing the modernization of technological infrastructure, the reinvention of business processes, and the adaptation of organizational strategies to the demands of an increasingly digitized environment. In the industrial context, this includes the use of technologies such as Big Data, IoT, AI, and automation to optimize operations and promote innovations in products and services.

Successful digital transformation strategies typically include:

1. **Digitalization of operational processes:** Task automation and data integration reduce costs and improve efficiency (Bharadwaj et al., 2013).
2. **Product and service innovation:** The use of technologies such as AI and Big Data allows you to develop personalized products that are aligned with consumer demands in real time (Schwab, 2016).
3. **Creating digital business models:** Innovative companies leverage digital platforms to generate new revenue streams, such as subscription services or online marketplaces (Rogers, 2016).
4. **Empowerment and cultural change:** Digital transformation requires skilled workers and an organizational culture that values innovation and adaptability (Westerman, Bonnet, & McAfee, 2014).

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Role in Industry 4.0 and Society 5.0

Digital transformation is a central element in both Industry 4.0 and Society 5.0, serving as a bridge between industrial efficiency and social progress. In the context of Industry 4.0, it enables automation, connectivity, and personalization through technologies such as cyber-physical systems, IoT sensors, and AI. These advances allow for the creation of smart factories that monitor and optimize production in real-time (Lasi et al., 2014).

In Society 5.0, digital transformation transcends the industrial environment to improve people's quality of life. Enabling technologies are applied in areas such as health, education, and urban mobility, promoting social inclusion and sustainability (Deguchi et al., 2020). For instance:

- In healthcare, telemedicine platforms allow remote care, while AI assists in diagnosing and monitoring patients.
- In smart cities, connected sensors optimize traffic, reduce energy consumption, and improve waste management (Zanella et al., 2014).

Applications in the Manaus Free Trade Zone

In the Manaus Free Trade Zone (ZFM), digital transformation has great potential to modernize the Manaus Industrial Pole (PIM), increasing its competitiveness in the global market. Local industries can adopt technologies such as IoT and Big Data to monitor the efficiency of operations, reduce waste, and improve sustainability (Silva & Silva, 2017).

In addition, digital transformation in PIM can facilitate the integration of local industries into global value chains, increasing their attractiveness to foreign investors. For instance:

- **Predictive maintenance:** The use of IoT sensors and AI can predict machine failures, reducing unplanned downtime and operational costs.
- **Advanced automation:** Collaborative robots can be used for repetitive tasks, allowing workers to focus on more value-added activities.
- **Professional training:** Training programs in digital technologies are essential to prepare the local workforce for the demands of Industry 4.0 and Society 5.0 (CNI, 2018).

However, implementing digital transformation in ZFM faces significant challenges, such as the need for a robust technological infrastructure and the shortage of skilled labor.

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Government investments in digital connectivity, such as high-speed networks, and the creation of partnerships between companies and educational institutions are key to overcoming these barriers.

Digital transformation can also contribute to the sustainability of the Amazon region. Technologies such as Big Data and blockchain can track the origin and environmental impact of ZFM's products, strengthening its reputation in the international market. In addition, the digitalization of production processes can reduce the consumption of natural resources and the emission of pollutants, in line with the principles of the circular economy (Stock & Seliger, 2016).

METHODOLOGY

RESEARCH CATEGORIZATION

The methodology used in this study follows a solid scientific approach, combining different data collection and analysis techniques. Based on the classification proposed by Gil (2010), the research can be categorized as follows:

1. **As for the objectives:**

   The research is exploratory and descriptive in nature. It is exploratory because it seeks to understand how Industry 4.0 is being implemented in the Manaus Industrial Pole (PIM) and what challenges are faced in this process. Simultaneously, it is descriptive in detailing the impacts of this implementation in economic, social and environmental terms, as well as strategies to enable the transition to Society 5.0.

2. **Regarding the procedures:**

   This study uses two main methods:

   - **Case study:** Focused on PIM companies that have already adopted or are in the process of adopting Industry 4.0 technologies.
   - **Field research:** Including primary data collection through semi-structured interviews and questionnaires applied to managers and PIM workers. In addition, a comprehensive literature review was carried out to theoretically support the analyses.

3. **Regarding the data approach:**

   A multi-method approach was adopted, integrating qualitative and quantitative data.

   - The **quantitative aspect** included the analysis of the questionnaires applied in the field, with the use of descriptive statistics to identify patterns and trends.

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- The **qualitative aspect** was based on semi-structured interviews conducted with specialists and managers of the PIM, exploring perceptions and experiences related to digital transformation.

LITERATURE REVIEW

The literature review was the initial stage of the methodology and aimed to build the theoretical basis for the analysis of the impacts and challenges of Industry 4.0 in the Manaus Industrial Pole (PIM), as well as the transition to Society 5.0. This review focused on relevant studies related to the topic, organized into three major areas:

1. **Industry 4.0:**
   The survey addressed key Industry 4.0 technologies such as the Internet of Things (IoT), Artificial Intelligence (AI), Big Data, automation, and cyber-physical systems. Its impacts on production processes were analyzed, including improvements in operational efficiency, mass customization and cost reduction. In addition, the challenges to implementing these technologies were highlighted, such as the high upfront costs, the need for robust technological infrastructure, and the upskilling of the workforce (Schwab, 2016; Kagermann, Wahlster & Helbig, 2013).
2. **Society 5.0:**
   The review explored the concept of Society 5.0, developed in Japan, as a model of society centered on the human being and sustained by technological innovations. The interrelationships between Industry 4.0 and Society 5.0 were analyzed, highlighting how technology can be used to address social problems, such as economic inequalities, climate change, and accessibility to essential services (Fukuyama, 2018; Deguchi et al., 2020).
3. **International case studies:**
   Examples of best practices in other countries were analyzed to identify successful implementation models of Industry 4.0 technologies. Special attention was given to cases involving emerging economies or industrial contexts similar to that of the PIM, offering insights on how to overcome structural barriers and adapt technological solutions to regional particularities (Porter & Heppelmann, 2014).

The literature review also included analyses on the benefits of digital transformation in terms of productivity, sustainability, and social inclusion. Finally, it consolidated the state

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of the art on the application of digital technologies in the industrial environment, providing a solid basis for the subsequent stages of research.

CASE STUDY

The case study was selected as a central methodological approach due to its ability to investigate contemporary phenomena within their real contexts. This methodology was applied to analyze companies in the Manaus Industrial Pole (PIM) that are already implementing or in the process of adopting Industry 4.0 technologies. The case study allowed a detailed understanding of the challenges and opportunities involved in this process.

1. **Company Selection:**
   The participating companies were chosen based on criteria such as:
   - Adoption of Industry 4.0 enabling technologies, such as the Internet of Things (IoT), advanced automation, artificial intelligence (AI), and big data.
   - Relevance of these technologies to industrial production and their impacts on operations. The selection criterion aimed to ensure the representativeness of different industrial sectors within the PIM, including electronics, chemical and metallurgical.
2. **Interviews with Managers and Experts:**
   To enrich the case study, semi-structured interviews were conducted with managers and specialists from the selected companies. The interviews focused on:
   - Identify perceived benefits of Industry 4.0 technologies.
   - Explore operational challenges related to the implementation of these technologies.
   - Map solutions and strategies adopted to overcome structural and cultural barriers.
3. **Case Study Objective:**
   The study sought to provide practical and detailed insights into best practices and challenges faced in integrating digital technologies into the unique context of PIM. These data served as a basis for the impact analysis and for the proposition of strategies aimed at accelerating the transition to Society 5.0.

The use of the case study contributed to contextualize the results, highlighting the regional specificities and the practical implications of the adoption of Industry 4.0 technologies in the PIM.

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FIELD RESEARCH

The field research complemented the case study, allowing the collection of primary data directly from workers, managers and other stakeholders in the Manaus Industrial Pole (PIM). This approach was essential to understand the perceptions and experiences related to the implementation of Industry 4.0 and the transition to Society 5.0.

1. **Questionnaires:**

   Questionnaires with open and closed questions were developed, applied to a representative sample of workers and managers from different companies in the PIM. The questionnaires sought:

   - Capture perceptions about the impacts of Industry 4.0 on the workplace.
   - Identify challenges faced during the adoption of digital technologies.
   - To assess expectations regarding the transition to Society 5.0.The quantitative data collected were analyzed using descriptive statistics to identify patterns and trends.

2. **Interviews:**

   Semi-structured interviews were conducted with managers and workers directly involved in the automated processes, as well as experts in industrial technology. This qualitative approach allowed for a deeper exploration of:

   - Perceived benefits of enabling technologies.
   - Solutions adopted to overcome challenges, such as lack of professional qualification and structural limitations.
   - Visions on the role of digital technologies in promoting social well-being and productive efficiency.

3. **Data Collection Process:**

   Data collection was carried out in two stages:

   - **Stage 1:** Application of questionnaires, ensuring the representativeness of different industrial sectors within the PIM.
   - **Stage 2:** Conducting interviews, providing a practical and detailed view of the impacts of technologies in the local context.

4. **Data Analysis:**

   The primary data were analyzed in an integrated manner:

   - Quantitative analysis used descriptive statistics to identify relevant correlations and trends.

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- The qualitative analysis was based on content analysis techniques, allowing the identification of emerging themes and patterns in the interviewees' answers.

The field research provided a solid basis for the assessment of the economic, social and environmental impacts of Industry 4.0 on the PIM, as well as contributing to the formulation of practical strategies for the transition to Society 5.0.

IMPACT ANALYSIS

The impact analysis was a central component of the research, evaluating how the adoption of Industry 4.0 technologies affects the economic, social and environmental dimensions in the Manaus Industrial Pole (PIM). This step built on the data collected during the case study and field research, providing a comprehensive overview of the benefits and challenges faced.

1. **Economic Impact:**

   The economic analysis focused on the effects of enabling technologies on:

   - **Productivity and efficiency:** Industry 4.0 technologies, such as automation and IoT, have contributed to reducing operating costs and increasing production efficiency in PIM companies.
   - **Creation of business opportunities:** Digitalization has opened up new markets and enabled more agile business models that are connected to global demands.
   - **Cost reduction:** It has been observed that technologies such as predictive maintenance and real-time monitoring systems have significantly decreased costs related to operational failures.

2. **Social Impact:**

   Automation and digitalization have had both positive and challenging societal impacts:

   - **Generation of qualified jobs:** The adoption of digital technologies has created demands for trained professionals, encouraging the qualification of the local workforce.
   - **Changes in the professional profile:** Despite new opportunities, there were challenges related to the replacement of traditional jobs with functions that require greater technical qualification.

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- **Improvement in working conditions:** The automation of repetitive and dangerous tasks has contributed to the reduction of occupational risks, promoting a safer environment.

3. **Environmental impact:**

   Sustainability was another point evaluated, with emphasis on:

   - **Reduced emissions:** The use of technologies such as big data and IoT has made it possible to optimize industrial processes, reducing energy consumption and carbon emissions.
   - **Waste minimization:** Digital processes have facilitated the adoption of sustainable practices, such as the circular economy, reducing material waste.
   - **Clean and efficient solutions:** Companies that have adopted advanced automation have reported increased efficiency in the use of natural resources.

4. **Analysis Methodology:**

   The analysis was structured based on the data obtained in the previous steps:

   - Quantitative indicators, such as cost reduction and productivity increase, were measured through descriptive statistics.
   - Qualitative results, such as perceptions about social and environmental impacts, were evaluated through content analysis of the interviews.

The impact analysis provided an integrated view of the benefits and challenges associated with Industry 4.0 in the PIM, supporting the strategic propositions presented in the subsequent stages.

PROPOSITION OF STRATEGIES

Based on the results of the literature review, the case study and the field research, this stage of the research proposes practical strategies to overcome the identified challenges and accelerate the transition of the Manaus Industrial Pole (PIM) to Society 5.0. The strategies were formulated considering the regional particularities and the specificities of the companies in the context of the Manaus Free Trade Zone.

1. **Elaboration of a Roadmap for the Transition:**

   A structured action plan was developed in stages to guide PIM in the adoption of Industry 4.0 technologies and in preparing for the challenges of Society 5.0. Key guidelines include:

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- **Technological infrastructure:** Investments in digital connectivity, such as high-speed networks and big data systems, are essential to enable advanced automation.
- **Professional training:** Partnerships with educational institutions to offer training focused on enabling technologies, such as IoT, AI, and automation.
- **Government incentives:** Public policies to support companies in the acquisition of innovative technologies, reducing financial barriers for small and medium-sized companies.

2. **Practical Recommendations for PIM Companies:**

   Based on best practices observed in international case studies and local analysis, specific actions were suggested for companies:

   - **Modular automation:** Adopt scalable solutions that allow for the gradual integration of Industry 4.0 technologies while minimizing upfront costs.
   - **Focus on sustainability:** Prioritize technologies that reduce energy consumption and promote environmentally responsible practices, aligning with the circular economy.
   - **Digital integration:** Utilizing blockchain and IoT-based systems to improve traceability and efficiency in supply chains.

3. **Recommendations for Public Policies:**

   The role of government and regulatory institutions was highlighted as fundamental to foster technological innovation and promote social and economic development:

   - **Tax and financial incentives:** Tax reduction for companies that invest in digital technologies and sustainable practices.
   - **Digital inclusion programs:** Initiatives to bring connectivity and technological training to the most isolated populations in the Amazon region.
   - **Promotion of research and innovation:** Support R&D projects that connect universities, companies and research centers in the creation of local technological solutions.

4. **Sustainability and Social Inclusion:**

   The strategies were aligned with the principles of Society 5.0, integrating technological advances with human well-being:

   - **Community projects:** Develop initiatives that use technology to solve social problems, such as urban mobility, health, and education.

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- **Regional partnerships:** Stimulate collaborations between PIM companies to promote an innovative and sustainable ecosystem.

The propositions presented aim to transform the PIM into a reference model for the integration between Industry 4.0 and Society 5.0, simultaneously promoting industrial competitiveness and social development.

EXPECTED CONTRIBUTIONS

The contributions of this research cover three main dimensions: theoretical, practical and social, offering a broad and integrated view on the impacts of Industry 4.0 and the transition to Society 5.0 in the context of the Manaus Industrial Pole (PIM).

1. **Theoretical Contributions:**
   - This study contributes to the advancement of the academic literature by exploring the integration between the concepts of Industry 4.0 and Society 5.0 in a specific context of emerging economies.
   - The detailed analysis of the challenges and opportunities faced by PIM provides relevant insights on how to adapt these technologies to regional realities.
   - The development of an integrative model that considers the particularities of the ZFM can serve as a reference for future studies in other industrial centers with similar characteristics.
2. **Practical contributions:**
   - The survey offers practical and direct recommendations for PIM companies, helping them implement Industry 4.0 technologies and adapt to the demands of Society 5.0.
   - The proposed strategies, such as the transition roadmap and recommendations for professional training, can be applied immediately, contributing to the modernization of local industries.
   - Economic, social, and environmental impact analyses provide concrete data to support business decisions and public policies aimed at innovation and sustainability.
3. **Social Contributions:**
   - The research highlights the potential of digital technologies to reduce socioeconomic inequalities in the Amazon region, promoting digital inclusion and human development.

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- Suggested solutions, such as telemedicine projects and digital education, can significantly improve the quality of life of the local population, especially in remote areas.
- By aligning the principles of Society 5.0 with the needs of the PIM, the research reinforces the role of technological innovation as an engine for sustainable and socially inclusive development.

These contributions demonstrate the relevance of the study not only for theoretical advancement, but also for practical application and social impact. By connecting the concepts of Industry 4.0 and Society 5.0 to the realities and challenges of the PIM, this research proposes solutions that can transform the Manaus Free Trade Zone into an exemplary model of integration between industrial competitiveness and social development.

RESULTS AND DISCUSSION

RESULTS

The survey carried out with companies in the Manaus Industrial Pole (PIM) revealed important aspects about the adoption of Industry 4.0 practices and the preparation for Society 5.0. These results were organized into the following categories:

Preparing for Society 5.0

About **75% of companies** reported having started projects related to the transition to Society 5.0. The main initiatives focus on areas such as Production/Operations and Information Technology (IT). However, **12.5% of companies** have not yet started specific activities, and another **12.5%** plan long-term implementations.

Main Objectives

The companies' objectives reflect a combination of economic and social goals:

- **Increased operational efficiency:** Cited as an isolated objective by **25%** and in combination with others by **62.5%.**
- **Product and service innovation:** Highlighted by **12.5%** as a central priority.
- **Environmental sustainability and improving the customer experience:** Cited as complementary in some responses.

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Challenges Faced

The main barriers to the implementation of Society 5.0 were:

- **Lack of qualified labor:** Identified by **62.5%** of the companies.
- **Resistance to change:** Cited by **50%.**
- **High implementation costs:** Also mentioned by **50%.**
- Inadequate infrastructure and regulatory issues were highlighted, but less frequently.

Observed Benefits

While **50% of companies** have yet to realize tangible benefits, reported positive impacts include:

- Reduction of operating costs.
- Faster, more connected processes.
- Improvement in product quality and customer satisfaction.

Technologies Used or Planned

The most cited technologies were:

- **Big Data and Data Analysis:** Used or planned by **50%** of companies.
- **Artificial Intelligence (AI) and Internet of Things (IoT):** Highlighted as pillars for modernization.
- Technologies such as robotics, automation, and augmented/virtual reality were mentioned by a smaller share.

DISCUSSIONS

The results obtained corroborate the theoretical framework and highlight the challenges and opportunities faced by PIM companies in the technological transition. This discussion was organized into the following dimensions:

Technological Readiness and Maturity

While most companies have begun the transition to Society 5.0, inequality in the stages of preparation reflects a lack of uniform access to resources and training. This is in line with the literature, which emphasizes the need for a robust digital infrastructure to support technological transformation.

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Strategic Objectives

The objectives of the PIM companies demonstrate a convergence between the principles of Industry 4.0 (efficiency and innovation) and Society 5.0 (sustainability and human focus). However, the absence of structured strategies compromises the maximization of benefits.

Structural Challenges

Challenges such as lack of skilled labor, resistance to change, and high costs are widely discussed in the literature on Industry 4.0. Overcoming these obstacles requires investments in professional training, economic incentives and infrastructure improvement.

Benefits and Impacts

The reported benefits confirm the expectations around advanced technologies. However, the absence of clear metrics to assess the medium and long-term impacts prevents a more robust analysis of the progress made.

Technologies as Enablers

The technologies mentioned, such as IoT, Big Data, and AI, reaffirm their central role in digital transformation. However, the disparity in responses demonstrates that many companies are still exploring possibilities without a consolidated implementation.

CONCLUSIONS

Based on the results of the research and the discussions developed, it is possible to conclude that the implementation of Industry 4.0 in the Manaus Industrial Pole (PIM) represents a strategic opportunity to promote technological innovation and transition to Society 5.0. This process, although challenging, has significant potential to transform the industrial and social environment of the region.

KEY FINDINGS

The main findings of this research highlight:

1. **Preparation of Companies:**

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- **75% of companies** have already initiated specific actions to adopt practices aligned with Society 5.0, focusing on areas such as Production/Operations and Information Technology (IT).

2. **Main Motivations:**
   - The objectives identified include product/service innovation, increased operational efficiency, and improvements in the quality of life of workers and customers. These objectives reflect a convergence between the pillars of Industry 4.0 and the humanized values of Society 5.0.
3. **Challenges Faced:**
   - The main challenges include a lack of skilled labor, resistance to change, and high implementation costs. These factors highlight the need for job training and economic incentives to accelerate digital transformation.

4. **Observed Benefits:**
   - Companies that have implemented technologies have reported benefits such as cost reduction, greater customer satisfaction, and more agile and connected processes.
5. **Support and Partnerships:**
   - Collaboration between companies, universities, and startups has emerged as a critical factor for the success of the initiatives, reinforcing the importance of an innovation ecosystem.

RECOMMENDATIONS

Based on the findings, the following recommendations are suggested to facilitate the transition to Society 5.0 in the context of the PIM:

1. **Investments in Education and Training:**
   - Develop specific professional qualification programs aligned with the demands of Industry 4.0 and Society 5.0. Partnerships with local educational institutions are essential to train skilled workers in the use of technologies such as IoT, AI, and Big Data.
2. **Public Incentive Policies:**
   - Establish tax incentives and credit lines for companies that invest in enabling technologies and sustainable practices.

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3. **Promoting Collaborative Innovation:**
   - Encourage partnerships between companies, universities and startups to foster the creation of technological solutions adapted to regional needs.
4. **Technological Infrastructure:**
   - Expand investments in digital infrastructure, such as high-speed networks and advanced data systems, to support the implementation of technologies.
5. **Adoption of Sustainability Indicators:**
   - Develop clear metrics to assess the environmental, economic, and social impacts of Industry 4.0 practices, ensuring alignment with the principles of Society 5.0.

SUGGESTIONS FOR FUTURE WORK

The research suggests the following directions for future studies:

1. **Socioeconomic Impact:**
   - Investigate how digital transformation can reduce regional inequalities and promote greater social inclusion in the Manaus Free Trade Zone.

2. **Development of Sustainable Models:**
   - Create business models based on the circular economy and the reduction of industrial waste in the context of the PIM.
3. **Cost and Benefit Analysis:**
   - Economically evaluate the investments needed for the transition to Society 5.0, comparing them with the long-term benefits.
4. **Detailed Case Studies:**
   - Investigate companies that have already implemented advanced practices, highlighting critical success factors and lessons learned.
5. **Integration of Smart Urban Mobility:**
   - Explore how digital technologies can be applied to improve mobility in the region, promoting efficiency and sustainability.

FINAL CONSIDERATIONS

The challenges for the implementation of Industry 4.0 and the transition to Society 5.0 in the Manaus Free Trade Zone are complex, but the results demonstrate that the transformative potential is significant. The combination of efforts from the public, private and

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academic sectors can position the PIM as a global example of technological integration and sustainable development.

Society 5.0 offers a vision of the future in which innovation and well-being go hand in hand. The Manaus Free Trade Zone, with its strategic position, is poised to lead this movement, becoming a model for how the digital revolution can drive socioeconomic transformation and environmental preservation.

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