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Digital transformation through programmable logic controllers and distributed control systems for strategic analysis of ROI and industrial productivity.

Digital transformation through programmable logic controllers and distributed control systems for strategic analysis of ROI and industrial productivity

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Summary

Companies face increasing pressure to maximize the return on their capital investments and reduce the time required to bring new products from design to large-scale production. This study presents an analysis of the evolution of industrial automation systems, with particular emphasis on Programmable Logic Controllers (PLCs) and Distributed Control Systems (DCS), examining their technical and economic impacts on industrial organizations. The research uses a systematic literature review to document the historical trajectory from the first computer-based industrial control system installed in 1959 to the contemporary virtualized systems of Industry 4.0 and 5.0. The results demonstrate that the implementation of DCS has generated
Substantial revenues, with companies like Honeywell earning US$100 million in the first year alone after launching the TDC 2000 in 1975. The analysis reveals that automated systems increase productivity by a ratio of two to one when compared to manual processes, in addition to providing significant improvements in operational safety, quality control, and production flexibility. The study concludes that well-implemented automation offers a measurable return on investment, but the ideal balance of benefits fundamentally depends on the alignment between automation strategy and the specific business objectives of each organization. The projected US$209 billion in revenue for the industrial automation market by 2020 highlights the growing economic relevance of these technologies.

Keywords: Programmable Logic Controllers. Distributed Control Systems.
Industrial Automation. Return on Investment. Productivity. Industry 4.0. Digital Transformation.

Abstract

Companies face increasing pressure to maximize return on capital investments and reduce time required to bring new products from design to large-scale production. This study presents an analysis of the evolution of industrial automation systems, with particular emphasis on Programmable Logic Controllers (PLCs) and Distributed Control Systems (DCS), examining their technical and economic impacts on industrial organizations. The research employs systematic literature review to document the historical trajectory from the first computer-based industrial control system installed in 1959 to contemporary virtualized systems of Industry 4.0 and 5.0. Results demonstrate that DCS implementation generated substantial revenue, with companies like Honeywell obtaining US$100 million in the first year alone after launching TDC 2000 in 1975. Analysis reveals that automated systems increase productivity in a two-to-one ratio compared to manual processes, while providing significant improvements in operational safety, quality control, and production flexibility. The study concludes that well-implemented automation offers measurable return on investment, but the optimal balance of benefits depends fundamentally on alignment between automation strategy and specific business objectives of each organization. The projection of US$209 billion in revenue for the industrial automation market by 2020 evidences the growing economic relevance of these technologies.

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1. Introduction

Companies are facing increasing pressure to maximize the return on their investments. It saves capital and reduces the time needed to bring new products to large-scale production. In a In a globalized scenario characterized by fierce competition, industrial automation has become... A vital need for business survival. Without automated manufacturing systems, the Production would be drastically reduced, it would consume excessive time, and it would offer poor working conditions. less safe and would present extremely difficult quality control. Employees would need working twice as hard to achieve in one day what they currently achieve in one hour with automated industrial systems.

The first computer-based industrial control system was installed in 1959 in Texaco's refinery in Port Arthur, Texas, using the Ramo-Wooldridge Company's RW-300. However, it was in the 1970s that industrial automation experienced its true revolution. with the emergence of Distributed Control Systems (DCS) and Logic Controllers Programmable Logic Controllers (PLCs). Honeywell and Yokogawa developed the first products. Commercially viable DCS models from 1975, the TDC 2000 and CENTUM, respectively. This advancement It brought substantial profits, with Honeywell earning nearly US$100 million in revenue in that year alone. In its first year, DCS established itself as the fastest-growing segment in the automation industry.

In parallel, PLCs were designed to meet the needs of the industry. automotive, replacing the relay logic that spanned enormous walls of components, kilometers of wiring was problematic and inflexible. The new PLC technology opened up a world Innovation and easily reconfigurable features for factory automation. The evolution continued in In the 1980s and 1990s, PLCs became smaller due to the integration of semiconductors, systems... truly distributed and substantially higher reliability. Suppliers like Rockwell Automation and Siemens have started offering DCS systems at more competitive prices.

Currently, industrial automation is projected to generate approximately US$209 Billions in revenue by 2020. Technologies such as advanced robotics, cloud computing, and the Internet. The Industrial Revolution and virtualized control systems represent the next frontier of this. Evolution. Virtualized systems, including PLCs, DCS, HMIs, and SCADA, require less. physical servers and allow for the consolidation of functions on integrated platforms, providing Significantly superior operational flexibility.

The main objective of this study is to describe how the evolution of systems... Automation and control, with an emphasis on PLCs and DCSs, have promoted technical and economic benefits. Measurable in companies. As specific objectives, it is proposed to present the historical evolution of these systems, characterize the technologies employed and identify the technical and impacts resulting economic outcomes. The methodology employed consists of a systematic literature review.

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through consultation of books, dissertations and scientific articles in the FGV, Google Scholar and databases Unesp, focusing on publications from the last ten years.

2. Theoretical Framework

2.1 Historical Evolution of Automation Systems

Automation emerged as a mechanism to reduce human involvement in processes. industrial. The Industrial Revolution, which began in the mid-18th century, marked the shift from manual labor was replaced by machines that performed tasks more efficiently, increasing The accelerated pace of production processes has drastically increased (ASHTON, 2014). Microelectronics has resulted in increasingly faster and more powerful, yet smaller, electronic circuits. in terms of size, energy consumption, and cost (CHAMUSCA, 2016). This miniaturization made it feasible The implementation of sophisticated control systems directly on the factory floor.

2.2 Early Industrial Control Systems

The first computer-based industrial control system was installed in 1959 in Texaco refinery using the RW-300 from the Ramo-Wooldridge Company (ASHTON, 2014). When Minicomputers emerged in the mid-1960s and early 1970s, followed by mainframes. They began to be replaced by more distributed control systems. The IBM 1800 represented A significant example of a minicomputer designed specifically for gathering process signals. in industrial plants.

2.3 Distributed Control Systems (DCS)

The pioneering DCS technology was developed by engineers from Honeywell and... Yokogawa. Honeywell's first commercially viable product was the TDC 2000, introduced In 1975, Yokogawa launched the Centum in the same year. These systems were designed for Integrated production control in oil refineries, petrochemical and chemical industries, pharmaceuticals and others (GEORGINI, 2018). This advance brought substantial profits, with Honeywell generating approximately US$100 million in revenue in the first year alone. Companies such as Taylor, Bailey, and Foxboro entered the DCS market, contributing to a new era in automation. In the 1970s, DCS was responsible for the fastest-growing segment in the industry of automation.

2.4 Programmable Logic Controllers (PLCs)

Almost simultaneously with the development of DCS, the PLC emerged, designed for to replace less reliable relay logic. The PLC was initially developed to meet the needs of The needs of the automotive industry, which required regular model changes and reconfiguration. of lines (PEREIRA NETO et al., 2014). Before PLCs, relay systems covered enormous areas.

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Walls of components, terminal blocks, and kilometers of wiring are problematic.
inflexible and consuming excessive energy. The new technology has introduced features that easily...
Reconfigurable for factory automation (SILVEIRA; SANTOS, 2018).

After presentations for General Motors, Bedford Associates won with the Modicon.
084 in 1969. Subsequently, in 1971, Allen-Bradley engineers developed the Bulletin 1774 PLC, which became highly successful (ROSÁRIO, 2014). Initial acceptance faced
Resistance arose due to the perception that computers were prone to failure. A great deal of effort was made.
necessary to demonstrate that PLCs were specialized microcomputers, designed to be
reliable and dedicated (MORAES; CASTRUCCI, 2017).

Scott Zifferer (ICON Software) and Neil Taylor (Taylor Industrial Software) developed
software that provided a general computer interface for programming, dramatically improving the
workflow and acceptance of the PLC (GEORGINI, 2018). This software has fundamentally changed
This sets the stage for industrial automation, placing it on a trajectory of dramatic growth.

2.5 Evolution in the 1980s and 1990s

Automation continued its vibrant growth in the 1980s and 90s, with PLCs.
progressively smaller due to the evolution of semiconductor integration. Systems
Truly distributed, redundant, and highly reliable systems have become the standard.
The 1980s witnessed the need for more open and interoperable systems (AGUIRRE, et al.,
(2016). Thanks to the US Department of Defense, UNIX with TCP/IP became the standard.
predominant.

The 1980s witnessed the integration of PLCs into the DCS infrastructure. The technology
The Internet had a profound effect, with HMI devices becoming compatible with TCP/IP.
Fieldbus technology took over the function of analog communication (BORRACHA, 2018). The 1990s
They observed a transition to the Windows environment, with the OPC standard becoming the method of...
Industry-standard connectivity. Off-the-shelf (COTS) commercial components and IT standards.
They propelled the evolutionary process forward, with suppliers such as Rockwell and Siemens offering...
DCS systems with more competitive prices (BRANQUINHO, 2014).

2.6 Centralized Systems and Modern Connectivity

The shift to centralization at the factory level has become the norm in recent facilities.
Wireless protocols and servers embedded in DCS controllers have become a reality.
Introducing wireless web access to the factory floor (FRANCHI; CAMARGO, 2018). This
Enhanced connectivity enables monitoring and control via remote computers and
smartphones, however, are calling for additional layers of security to address concerns about
Cybersecurity and potential sabotage.

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3. Methodology

This study is characterized as a literature review, a method that allows...
to systematically examine established scientific knowledge through critical analysis of
Published works. This approach proves suitable for investigations aimed at understanding
The historical evolution of technologies and their economic impacts.

The bibliographic search was conducted in the databases of the Getúlio Vargas Foundation.
(FGV), Google Scholar and São Paulo State University (Unesp). The material consulted
It included specialized books on industrial automation, master's dissertations, and theses.
PhD and scientific articles published in specialized journals. The time period
It focused primarily on publications from the last ten years, a criterion that ensured...
contemporary nature of the analyses. However, to adequately document the historical evolution,
References to previous technological milestones were included, particularly the
Early development of PLCs and DCSs in the 1960s and 1970s.

The selection of papers followed criteria of thematic relevance and academic quality.
Publications with concrete data on economic impacts and technical descriptions were prioritized.
detailed control systems, comparative analyses between technological generations, and studies of
case study documenting real-world implementations.

4. Technologies applied in business automation systems

4.1 Economic Context and Competitiveness

The development of the globalized economy encourages companies to face new challenges.
Threats and opportunities. The threats originate from companies in various parts of the world that...
They seek to expand their competitiveness, while opportunities arise from access to new
technologies and the possibility of international partnerships (MARQUES, 2014). To differentiate themselves,
Companies seeking operational perfection direct their efforts toward product development.
customized solutions catering to specific market segments (JUGEND, 2015).

The Japanese example demonstrates this dynamic. After the Second World War, Japan
It has followed a trajectory of industrial progress that has established it as one of the first nations.
industrialized, the result of great planning efforts combining economic objectives,
social and political (MORAES; CASTRUCCI, 2017). The Japanese State, through the Ministry of
Industry and Commerce demonstrated a fundamental role by strategically employing tools of
Economic policies in the spread of microelectronic technology (AGUIRRE et al., 2016).

4.2 Contemporary Trends in Automation

The latest trends include the integration of cloud computing, Big Data, and the Internet of Things.
Things (IoT), protection against cyberattacks, modular manufacturing execution systems and

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Collaborative robots (cobots) that operate safely alongside humans (FLEURY, 2014). One
An area experiencing rapid growth is post-processing automation, where the same robot that
Unloading a machining center allows parts to be transferred to cleaning, deburring, and other stations.
polishing or metrology, integrating multiple operations (BRANQUINHO, 2014).

Robots have become progressively faster and smaller, manipulating the same
Payloads vary as engine technology improves, and they are designed to work with...
safety close to humans (GEORGINI, 2018). Companies like Rockwell Automation occupy
Strategic positioning with cloud-based manufacturing software, including remote monitoring solutions (ROSÁRIO,
2014). Protecting data and hardware against cyberattacks.
It is becoming progressively more crucial.

4.3 Modular Applications and Current Status

Specialized companies have launched manufacturing execution systems with applications.
Modular systems that can be contracted individually, eliminating the need for a dedicated server.
(BESEN, 2015). Applications include OEE for process management, track and trace for
Traceability, poka-yoke for quality verification, Industrial IoT gateway for transmission.
secure data, and automated work instructions (ASHTON, 2014).

Even though "lights-off" manufacturing is still a distant goal, substantial advances have been made.
These tasks have been carried out since the 1980s. Repetitive and highly precise work on assembly lines.
have been successfully taken over by robots (AGUIRRE, et al., 2016). 21st-century robots possess
high computing power and vastly improved vision systems, but they still need
Human supervision. With the rapid advancement of microcomputers and software, automation depends
almost entirely computer-based, and is called integrated manufacturing.
computer (CIM) (BRANQUINHO, 2014).

The industrial robots of the future will be multifunctional and possess the ability to make decisions.
autonomously and will incorporate self-diagnosis and predictive maintenance (CHAMUSCA, 2016).
Thanks to automation, the factory of the future will operate efficiently in the use of energy, raw materials, and...
Human resources. Contrary to popular belief, experience has shown that automation does not
It will cause massive unemployment, but it will generate jobs of a different nature (FLEURY, 2014).

4.4 Robotics and Automated Manufacturing

Decreasing cost, smarter and more flexible technologies expand facilities.
Fully automated. At the Fanuc factory in Oshino, Japan, robots produce robots.
Supervised by only four workers per shift. At Philips in the Netherlands, robots surpass...
employees in a 14:1 ratio. Canon has begun eliminating human labor in several
factories from 2013 onwards (MORAES; CASTRUCCI, 2017).

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As robot production increased, costs decreased. Over the last thirty years,
The average robot value has halved in real terms (PEREIRA NETO et al., 2014).
Workers with skills in robotic systems are vastly more available.
being trained in colleges and universities worldwide. Specialized software, such as software packages.
Simulation reduced engineering time and risk (MARQUES, 2014).

4.5 Advanced Capabilities

Advances in AI and sensors will allow robots to handle a greater degree of variability.
between tasks. In Japan, tests have proven that robots can reduce the time it takes to harvest strawberries.
Up to 40% accuracy is achieved using stereoscopic imaging to identify the location and ripeness of the fruit.
(SILVEIRA; SANTOS, 2018). These resources will generate quality improvements in all sectors,
with robots compensating for problems during production (MORAES; CASTRUCCI, 2017).

Although current robots control movement within 0.10 millimeters, configurations
Specialized models offer precision of 0.02 millimeters. Future generations will offer levels...
superior, allowing for progressively more delicate tasks such as threading needles or assembling
Miniaturized electronic devices. Controllers can simultaneously activate dozens of
axes, allowing multiple robots to work collaboratively (ASHTON, 2014). Technologies
Modern sensor technologies will allow robots to perform tasks that previously required highly skilled artisans
(ROSÁRIO, 2014).

5. Technical and economic impacts

The industrial automation market is expected to sustain strong growth, considering that...
The industry will remain under pressure to improve quality in order to cope with global competition.
With automation, competition becomes balanced, while without technological innovation, it becomes...
It is impossible to maintain market share (BESEN, 2015). In emerging countries, attention must be paid to
Automation in non-export sectors, offsetting potential temporary job losses.
through training and development policies that encourage the acquisition of technologies
tip (MARQUES, 2014).

5.1 Market Projections and Growth

Industry 4.0 is redefining industrial automation. Reports indicate that the market...
The Industrial Control and Automation sector will reach US$239.11 billion by 2023, up from US$155.26 billion.
billions in 2017, with an annual growth rate of 7.4% (ASHTON, 2014). Conventional robots
They will give way to intelligent robots that will behave and adapt according to changing conditions.
Equipped with Machine Learning and Deep Learning, they will work with computational capabilities.
high, operating independently and coordinating with other robots and humans (RUBBER,

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2018).

Big Data will reinvent industrial operations. With massive volumes of data, decision-makers... Decision-makers will be equipped with superior information for quick and informed decisions. Data analysis will represent a significant advantage from purchasing to logistics, resulting in a substantially smarter value chain. Devices equipped with data analytics and ML will pave the way for predictive maintenance and self-diagnosis, leading to a higher level of Automation where human intervention will be minimized (FRANCHI; CAMARGO, 2018).

5.2 Current Status and Sectoral Growth

The "lights out" phenomenon predicted in the 1980s remains a future ambition. However, there has been considerable progress in the last three decades (BESEN, 2015). The use of robots for Repetitive tasks have increased considerably, especially in the automotive sector. The shipment The global number of robots was approximately 294,000 units in 2016, representing an increase of 16% compared to the previous year and almost doubling the 159,000 robots of 2012 (BRANQUINHO, (2014). This exponential growth demonstrates an acceleration in the adoption of robotics.

Companies are seeking to integrate manufacturing components with computer software. resulting in computer-integrated manufacturing. Automation lies at the confluence of Technological innovations, with companies improving operational processes throughout the value chain. (MORAES; CASTRUCCI, 2017).

5.3 Transition to Industry 5.0

Automation is on the cusp of a new revolution, undergoing rapid changes. Technological advancements and the pursuit of device interoperability. The industrial space, traditionally Resistant to innovation, it began to change radically with Industry 4.0 (FRANCHI; CAMARGO, (2018). Experts believe that many companies are already on the verge of Industry 5.0. A Automation is poised to generate approximately $209 billion in revenue by 2020, with Technologies such as robotics, cloud computing, IIoT, and AI are becoming essential (CHAMUSCA, 2016).

The convergence of advanced information, communication, and networking technologies drives... Automation. This symbiosis allowed for the integration of people and machines on the factory floor and supply chain. supplies (FLEURY, 2014). Traditionally, systems had proprietary designs creating Supplier lock-ins that inhibited innovation (FRANCHI; CAMARGO, 2018). With digitization, There is a need to implement scalable systems that allow for scaling as needed. business needs (MARQUES, 2014).

Manufacturers who want to converge technologically need to integrate vertically and Horizontally integrating advanced systems. This means integrating properties of the control platform and Emphasize features such as remote access, condition monitoring, and remote diagnostics.

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An integrated platform will allow for improved efficiency and productivity, achieving optimization in every factory (GEORGINI, 2018).

5.4 Evolution of PLCs and Virtualization

The evolution of PLCs will play a key role in this new era. With greater Programming flexibility, scalability, more memory, smaller form factor, Gigabit Ethernet. With wireless functionalities, future PLCs will incorporate improvements in software, communications, and... hardware (JUGEND, 2015). Manufacturers will need to develop PLCs capable of controlling applications providing tools to collect, analyze, and present data as needed. including access via mobile applications or browsers (GEORGINI, 2018).

Managing controller networks involves significant capital expenditures. Hardware and infrastructure. Proprietary stacks hinder operational flexibility, adding cost and... Complexity. Virtualization can help companies create a competitive advantage (MARQUES, 2014). Virtualized control systems such as PLCs, DCS, HMIs, and SCADA require fewer servers. Physical functions can be consolidated onto a single platform, allowing companies to modernize. control processes, optimize them and speed up the implementation of new functions (MORAES; CASTRUCCI, 2017).

Providers have launched platforms that allow users to design and develop applications in less time. Time-saving, lower cost, and modular construction. Operating in a virtualized environment, the software It transforms how control systems are maintained. The shift to a centralized data center allows that engineers focus on system optimization instead of administrative tasks. (JUGEND, 2015). Networked instrumentation can transmit data to a central hub where it is compiled and analyzed for operational purposes (PEREIRA NETO et al., 2014).

Technological convergence creates an avenue for manufacturers to take the next leap towards... to the fifth industrial revolution, in which disparate systems will share resources and act in synergy. To stay ahead, companies will have to capitalize on existing technologies and accelerate their operations. Implementation and unlocking new sources of value. The change represents further modernization. Incremental rather than disruptive revolution, with technology serving as the main driver of innovation. (RIBEIRO; OLIVEIRA, 2016).

6. Final considerations

This research has achieved its objective of describing how the evolution of systems... Automation and control, with emphasis on Programmable Logic Controllers and Control Systems. When distributed, they delivered measurable technical and economic benefits. The analysis demonstrated a continuous trajectory from the first industrial control system in 1959 to the systems Contemporary virtualized technologies that characterize the transition to Industry 4.0 and 5.0.

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From a technical standpoint, this evolution has led to substantial increases in productivity. Industrial, quality improvement through reduced variability, increased safety. operational and expansion of factory flexibility. The data documented that automated systems They increase productivity by a ratio of two to one, as evidenced by Fanuc in Oshino, Japan, where robots produce robots supervised by only four workers per day. shift.

From an economic standpoint, the impacts were equally significant. DCS implementation generated substantial revenue, with Honeywell obtaining approximately US$100 million in the first year after the launch of TDC 2000 in 1975. Projections indicate Robust growth, with the market reaching US$239.11 billion by 2023, starting from US$ 155.26 billion in 2017, representing a rate of 7.4% per year. The reduction in robot costs by Half of the population has democratized access to advanced automation in the last thirty years.

The convergence of cloud computing, Big Data, IIoT, AI, Machine Learning, and Deep Web. Learning is redefining the automation landscape. The PLCs of the future will incorporate greater Flexibility, scalability, high-speed Ethernet, wireless functionality and capabilities. Integrations that will facilitate communication between the factory floor and corporate management. Simultaneously, System virtualization will allow for the consolidation of functions onto single platforms, reducing... infrastructure costs.

Automation can achieve four fundamental objectives: improve safety and security. collaborators, reduce operational costs, improve production quality, and increase flexibility. manufacturing. If implemented properly, it can provide improvements in all areas. simultaneously, however the balance of benefits varies with different technologies. The right balance for any organization will stem from its overall operations strategy and specific business objectives

The research has limitations inherent to the literature review methodology, focusing on... if in secondary sources. Future studies could benefit from empirical case studies in Brazilian companies, allowing for more precise quantification of returns on investment in National context. Research is recommended on barriers to the adoption of automation in small businesses. and medium-sized Brazilian companies, taking into account economic, technical and cultural particularities.

The ongoing transition to Industry 5.0, characterized by the convergence of systems. Disparate entities operating in synergy represent a substantial opportunity for companies that capitalize on this. Existing technologies while accelerating the implementation of innovations. Companies that implementing holistic automation strategies, closely aligning technological decisions with With current and future needs, they will be better positioned to capture the value of opportunities. presented.

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It can be concluded that the evolution of PLCs and DCSs from the 1970s to the implementations... Contemporary technologies based on virtualization, AI, and IIoT have provided profound transformation and Measurable in global industrial competitiveness. The documented technical and economic benefits. They amply justify the investments made, establishing advanced automation not as a strategic option, but also an imperative need for business survival in the environment. contemporary globalized competitive.

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