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ANALYSIS ON RECENT ADVANCEMENTS IN INDUSTRIAL ENGINEERING

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ABSTRACT

Industrial engineering is the discipline of engineering that, due to its interdisciplinary character, has been instrumental in the creation and improvement of a wide variety of systems on both the macro and micro scales. The evolution of bottleneck analysis has recently shifted towards employing cutting-edge ideas and technology inspired by the Industry 4.0 movement. Nevertheless, research into the connections between bottleneck analysis and Industry 4.0 remains scant. This research addresses a knowledge gap by reviewing the literature from the most prominent scientific databases to learn how Industry 4.0 has influenced the evolution of bottleneck analysis in the manufacturing and production sectors. Quantitative and qualitative information was culled using bibliometric analysis and content evaluation. Studying the design principles and technologies of Industry 4.0 through the lens of bottleneck analysis reveals gaps in the literature, provides issues for further research, and proposes a number of potential development streams. With the help of Industry 4.0, industrial companies may adopt complex systems in a streamlined, well-thought-out manner. This article will explain the rationale behind Sector 4.0 and the measures required to implement it in the steel industry.

Key words: Industrial engineering, Industry 4.0, Steal industries.

1. INTRODUCTION

Industrial engineers "concern themselves with the design, improvement, and installation of integrated systems of people, materials, information, equipment, and energy," as stated in the Institute of Industrial and Systems Engineers' Body of Knowledge [1]. The discipline of industrial engineering can be formally described as follows. To specify, forecast, and evaluate the outcomes to be attained from such systems, experts in the fields of mathematics, physics, and sociology, as well as the concepts and methods of engineering analysis and design, are called upon.

Despite the assertions of some authors, the modern field of industrial engineering did not emerge until the Industrial Revolution of the 1800s and, more specifically, the early 1900s.Dr. Batson provides a superb overview of these early beginnings in his chapter later in the book. Standardization and specialisation initiatives, with a focus on the workforce, its tasks, and its management, were pioneered by Frederick Taylor (1911) [2]. [Note: As a result of this, IE subdisciplines such as production planning, scheduling, and inventory management were given more formal standing. Furthermore, Nadler [3] states that there have been three distinct periods of development in the discipline of industrial engineering. The first, which builds on Taylor's earlier work, focused on improving manufacturing facility productivity (also known as efficiency). The foundation of the IE field was laid during these early years of effort, which continued into the 1920s and 1930s. Phase two, beginning in the early 1970s and continuing through the middle of the 1980s, saw the concept of efficiency developed further with the use of mathematical, statistical, and computer-based methods [3]. There was operations research modelling and optimization, quality control and work measurement statistics, and the mathematics of engineering economics. During the 1970s and 1980s, when the focus of the economy shifted from manufacturing to service-based work, many of the same methods and tools that were used in manufacturing-based work continued to be used. IE were modified to work. Service personnel and the systems in which they operate can benefit greatly from the application of industrial engineering principles.

The third stage, as described by Nadler [3], involved a transition from "efficiency to effectiveness and quality, as well as from relatively small systems to huge or macro systems." It was in the 20th century that approaches were widely used to progressively partition activities to improve operations. These methods saw extensive use in the 20th century. The study of "whole systems" to boost productivity by integrating previously unrelated parts has been increasingly popular in recent years. The goal here is to boost productivity inside the company. When used to manufacturing, for instance, the analysis and improvement of the entire supply chain has replaced the old factory-centric perspective [4]. The IE principles were refined and improved over time, which allowed them to evolve and adapt to new situations. An earlier iteration of the supply chain focused on managing the arrival and departure of raw materials and finished goods from outside suppliers to the factory floor. Since then, however, the scope of supply chain analysis has broadened to incorporate not just the physical goods and services produced but also the information passed through from the originators of those goods and services [5]. The supply chain's original focus was on managing the transfer of raw materials and finished goods from suppliers to production departments. This paves the way for a value chain, the sequence of steps taken by a business to bring a valuable product to market.

Research in IE covers a wide range of topics, including managerial and technical issues. The primary issues were determined by conducting a poll that looked at the keywords used in the publications, the topics discussed at IE conferences, and the thoughts of professionals in this field.

Table 1 lists the IE topics along with the subjects that belong to them.

Main Topic	Subjects
Production Management	Lean Production, Agile Production, Maintenance, Reliability, Total Productive Maintenance, Kanban System, Production Planning
Information Systems and Technology	Information Technology, Knowledge Management, Information Systems, MIS
Operations Research	Mathematical Programming, AHP, MCDM, Simulation, Genetic Algorithm, Tabu Search, Simulated Annealing, Heuristic Algorithms, Decision Support Systems, Chaos Theory, Constraints Theory
Project Management	Project Management, Project Control, Value Engineering and Management
Supply Chain Management	SCM, ERP, MRP, EOQ, MRPII
Total Quality management	TQM, 6 Sigma & Lean 6 Sigma, Quality Assurance, Quality Control, Quality Awards, BSC, DEA, Taguchi method, DOE, QFD, FMEA, CRM, Benchmarking, Kaizen
Advance Production Systems and Technology	Cellular manufacturing, FMS, CIM, GT, Reverse Engineering

2. LITERATURE REVIEW

The manufacturing industries are always looking for ways to increase the efficiency of their procedures (Schmenner, 2015). Efforts to boost output typically centre on speeding up the throughput of a production line, or the rate at which items are moved from one stage to the next (Lai et al., 2021). The "throughput bottleneck(s)" in a production system refer to the resource(s) that are limiting throughput (Possik et al., 2021). As much as 30% of throughput losses can be attributed to bottlenecks in both production and manufacturing, and this is general knowledge (Alavian et al., 2019). As a result of bottlenecks' impact on total productivity in industrial systems, bottleneck analysis (BA) has garnered significant attention from researchers and practitioners alike.

But it's tough to find and fix bottlenecks in practise, so practitioners have to rely on their expertise and intuition when they're putting BA into action (Zhang et al., 2021). That's according to a new study (Zhang et al., 2021). For the purpose of providing companies with efficient tools for business analysis, researchers have developed analytical and discrete event simulation models (Thürer et al., 2021). Changes in the real world necessitate that analytical and simulation models be regularly updated and revised (Lai et al., 2021). As a direct result of this, practitioners face a huge difficulty when it comes to the maintenance of analytical and simulation models. Thankfully, the growing digital transformation of manufacturing that's being driven by Industry 4.0 appears to have substantial implications for resolving the issues that are linked with BA.

Industry 4.0 is a German initiative with the intention of enhancing the capabilities of the manufacturing industry using digital means. It was originally launched in 2011. The "fourth industrial revolution," or "Industry 4.0," is what this phrase means (Lasi et al., 2014). Accordingly, modern digital technologies have grown to be synonymous with the phrase "Industry 4.0," which refers to the improvement of production procedures (Ghobakhloo, 2018). Knowledge of what comprises Industry 4.0 has undergone a dramatic transition during the past decade. With the emergence of Industry 4.0, digital transformation is no longer limited to the walls of individual businesses. Companies and their value networks across numerous industries are increasingly included in this digital revolution (Culot et al., 2020). Industry 4.0 will bring about a transition toward a more networked manufacturing sector. Production sites, smart storage facilities, supply chains, intralogistics, and even end users will all be seamlessly interconnected in this ecosystem (Ching et al., 2021).

As a technology-driven phenomenon, Industry 4.0 requires the integration of game-changing technologies like artificial intelligence into the established production infrastructure, operational technologies, and processes in order to realise its vision of "smart factories" (Büchi et al., 2020). Because they drastically restructure or reimagine the manufacturing process, the technologies that make up Industry 4.0 have been labelled disruptive (Benitez et al., 2020). One of the many innovative developments made possible by Industry 4.0 is the improvement of lean operations through the use of digital tools (Ghobakhloo and Fathi, 2020). As a result, bottleneck analysis, a method of continuous improvement closely associated with the lean manufacturing philosophy, will need to undergo significant changes in light of Industry 4.0. (Tu and Zhang, 2022).

Two I4.0 technologies, virtual reality and digital twins, stand out as having not been explored in BA but which look to be attractive subjects for further study. The utilisation of virtual reality led to the development of solutions such as the Augmented Go & See approach, which was described in the research carried out by Hofmann et al (2019). Using a virtual reality headset may make it unnecessary for engineers and practitioners to bring mobile devices such as smartphones, smartwatches, tablets, and laptops to the manufacturing floor. A virtual version of the production system would be available via the headset, making this a reality. The combination of virtual reality (VR) technology with real-time business analytics and self-learning, smart manufacturing systems will result in solutions that are highly adaptable and effective. The use of BA approaches may also be able to be improved thanks to the digital twin. A simulation model that is fed by real-time data is what makes up a digital twin. This model has the ability to make a significant contribution to the diagnosis and prediction of bottlenecks. In the process of bottleneck prescription, training an AI on a real-time simulation model can be a useful and powerful tool.

3. METHODOLOGY

3.1 Industry 4.0

Progression Germany issued a call to action in 2011 for the development of a "High-Tech Strategy Action Plan 2020." The primary purpose of the action plan was to combine a variety of technologies, including, but not limited to, CPS, IoT, and Big Data. An intelligent manufacturing operation was made possible as a result of the action plan's ability to connect things, individuals, and procedures. The progression of industrial revolutions over the course of history is depicted in Figure 1.

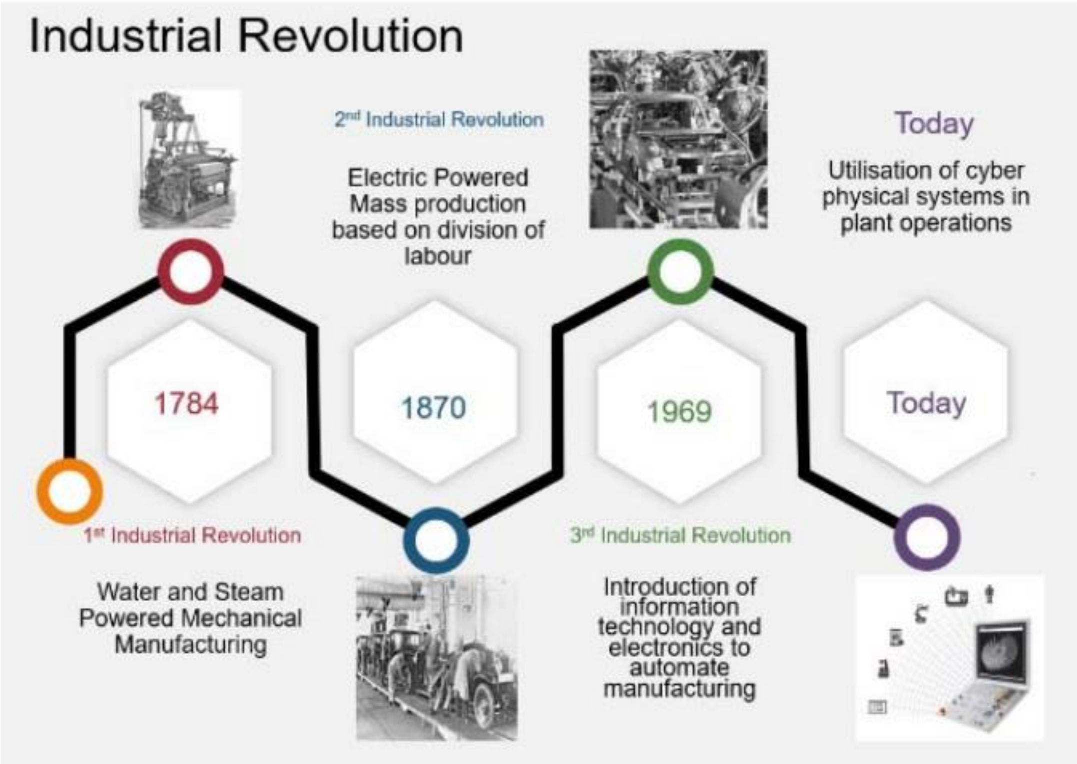

Fig. 1. Industrial evolution.

3.2 Current status and trends

The subject of industrial engineering is undergoing a variety of new shifts, possibilities, and breakthroughs at the start of this third decade of the 21st century, as detailed in a series of papers published by the Institute of Industrial and Systems Engineers (IISE). These newly developing patterns are based on historical precedents, do not compete with one another, and overlap and interweave to varied degrees, as follows:

- Applications in both the manufacturing and service sectors continue to develop and improve.
- Taking into account all relevant factors before making a call in the field requires a comprehensive systems strategy.
- better analytics done using existing data.
- This ultimately led to the development of the Fourth Industrial Revolution.

3.3 Continued evolution of manufacturing and service applications

As advances were achieved in both the service sector and the manufacturing sector, efficiency and effectiveness grew in tandem. There is still a strong emphasis on enterprises and countries improving their productivity and competitiveness in light of the emergence of global markets. Integrating and streamlining the product or service life cycle is a problem for IEs. In the following chapters, we'll look at how continuous improvement, six sigma, and lean manufacturing can help us achieve this goal. The lean manufacturing philosophy, for instance, focuses on streamlining processes by minimising lead times and other forms of waste. Six sigma improves the bottom line by eliminating wasteful processes and increasing productivity. In light of growing public awareness, regulatory pressures, and corporate social responsibilities, the field of industrial engineering has broadened to include considerations of safety and sustainability. The goal of occupational safety engineering is to "mitigate hazard exposures, minimise harm, and reduce liability by addressing the causes of workplace accidents, legislation, and management practises." Sustainability involves doing actions that are good for the environment, society, and the economy.

Unfortunately, the Steel Industry has been plagued by the use of legacy systems and technologies. "Brownfields" refers to the deployment of novel technologies in non-standardized, isolated "islands." The data is collected and summarised in real time and then sent to other systems. Information is further delayed or is not an exact reflection of current production levels due to the data collection process. The method used to bring the Steel Industry into line with the Industry 4.0 framework is shown in Fig. 2.

Fig. 2. Systems Development Life Cycle.

Specifically, the researchers are interested in the Systems Development Life Cycle (SDLC) phases that involve requirements engineering and system design. In order to get started, we need to know what kinds of technology and infrastructure a South African steel industry is already using. Participants from all levels of this organisation participate in the seminars and interviews. Variations of Business Requirements Specification (BRS) documents are produced as the present and future of a company are investigated and documented. Finalized versions of the BRS are then used to create documents like the Functional Design Specification (FDS) and the Technical Design Specification (TDS), both of which are essential parts of any system's design (TDS). Using the Industry 4.0 paradigm, the design documents depict an organisation that is completely wired and operational.

3.4 Emergence of industry 4.0

This new phenomenon, termed "Industry 4.0," is the result of the intersection of these three developments. According to, "Industry 4.0" and "Manufacturing 4.0" define the newest phase of the Industrial Revolution. Variable technological advancements prompted each epoch. In the early days of manufacturing, steam power was used to run the machines. Energy, automation, and division of labour were all put to use in the 2.0 version of industry. Industry 3.0 emerged as a result of the convergence of computer automation, electronics, and information technology to further automate manufacturing through the employment of robotic devices that augmented or replaced operators.

Integrating digital and physical systems (i.e., cyber physical integration) across the value chain enables intelligent manufacturing activities, also known as the "smart factory," which are key to the development of Industry 4.0. Some examples of Industry 4.0's enabling technologies are:

- Artificial intelligence and machine learning
- Internet of Things
- Additive manufacturing
- Cloud computing
- Big data analytics

A device that is "internet of things" (IoT) enabled can be loosely defined as one that is connected to the internet and can have its data accessed and its operations controlled remotely by users. When used in production systems, for instance, data collected from all factory workstations can reveal the inner workings of the system, allowing for data-driven decisions to be made regarding how to optimise certain critical performance parameters. IoT makes available in real time a massive amount of data on several subjects, devices, and equipment that are all similar to one another. There is typically a huge volume and variety of data kinds in the collected data. The collection of data with its own peculiarities, as well as the necessity for predictions and judgements to be made in real time, frequently at very high frequencies, necessitate a rethinking of many conventional predictive and prescriptive methodologies.

3.5 Smart Manufacturing

To put it simply, a smart plant is one in which everything from machinery to employees is linked together. The best possible plant performance is achieved through the analysis and verification of data from all sources. A smart plant has the following features:

1. Maintenance: Maintaining and implementing procedures that change in response to data from the devices, therefore minimising or eliminating down time.

2. Analytics: Making data gathered from IIoT and CPS devices visible so that it can be used to inform plans for enhancing operational efficiency.

3. Monitoring: Monitoring operational equipment in real-time for remote management and maintenance via IIoT.

4. Process Optimisation: Monitoring and controlling changes made inside an organisation based on collected data, with the goal of establishing a baseline for determining whether or not the alterations are indeed beneficial to business processes.

5. Utilities Management: Energy peak control can be achieved by coordinating energy consumption and production.

6. Automation: To increase productivity and quality, routine tasks might be automated.

7. Flexibility: In the event that product specifications or quality criteria are altered, the processes must be flexible enough to accommodate the shifts without requiring extensive modifications.

8. Supply Chains: Proactive problem solving is made possible through the sharing of real-time data amongst supply chains, operations, and customers.

CONCLUSION

The Steel Industry can become a unified, real-time decision-oriented entity by adopting a smart manufacturing strategy that is in line with the Industry 4.0 framework. Real-time operations optimization presents a difficulty when dealing with legacy equipment that has either limited data availability or no data structure at all. Keeping business data and production data separate is a difficult task for steel companies. The IIoT allows suppliers and buyers to see how things are running and receive notifications when materials or finished goods are ready for shipment. In order to warn or alert relevant parties, IIoT device data is received by MES, where it is consolidated and contextualised using ERP or other data sources. Organizations can use the plethora of real-time data at their disposal to anticipate maintenance problems using IIoT data and sales using ERP data. In order for an organisation to successfully respond to changing market conditions, it is essential that data be managed and cleansed on a regular basis. The Industry 4.0 framework has advantages over other approaches since it is not technology-specific and can be used and integrated with pre-existing structures and practises. This article describes the organisational framework and technological architecture required to implement Industry 4.0 in the steel industry. Aligning present and future demands in the steel industry is a key goal of the proposed characteristics and technologies. Standardization, data centralization, and the re-use of technologies are all encouraged under the Industry 4.0 framework. The framework's long-term benefits include the potential to shed light on problems plaguing current operations and to enhance established practises.

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