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Trends and Scope of Artificial Intelligence and Machine Learning in Pharmaceutical Industry

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This review showcases the current state and potential applications of AI (artificial intelligence) and ML (machine learning) in pharmaceutical industry. Due to the abundance of high-quality data, AI and ML methods play a pivotal role in drug discovery, development, and decision making. AI and ML advancements provide wings to Continuous Manufacturing and Industry 4.0. This rapid rise of advanced technologies brings inevitable changes in the pharmaceutical industry. Advanced and futuristic jobs in pharma can impact diverse drug discovery processes, drug repurposing, overall productivity, clinical research, and other pharmaceutical activities. Pharmaceutical manufacturing will change from batch manufacturing to continuous manufacturing by employing these advanced technologies with smart PAT (process analytical technology) tools. Industry 4.0 is defined by integrated, automated, and self-organizing manufacturing technologies in the pharmaceutical industry. This review also focused on cluster-based research to boost research, regional development, and nation-building.

Keywords: Artificial Intelligence, Machine Learning, Continuous Manufacturing and Industry 4.0.

Introduction

Artificial intelligence and machine learning have significantly influenced the pharmaceutical and consumer healthcare industries. Artificial intelligence is a computer technology discipline that analyses enormous amounts of data in the medical field. Their ability to leverage meaningful correlations within a data collection can be helpful in diagnosis, therapy, selecting individuals for clinical trials, pharmaceutical production, and making predictions. Artificial intelligence's primary benefit is that it lowers drug development expenses, improves returns on investment, and possibly even lowers end-user cost.[1] Practically all manufacturing processes have been done batch-wise in the past. Several pharmaceutical start-ups have recently started employing continuous manufacturing strategies to synthesize small molecule drugs, which can deliver over batch processing.[2]

Exploiting emerging technologies, Pharma Industry 4.0 improves long-term potential generation to a more flexible, innovative, and personalized pharma industry, allowing pharma firms to obtain long-term benefits in the marketplace. A much more long-term solution drug supply chain (DSC) needs to be developed to correspond upcoming management and control. To produce the next-generation medicines, pharmaceutical occupations have also begun to evolve from traditional careers to advanced careers. The scope of pharmaceutical research-based employment is expanding as professional prospects develop. As technology advances, cutting-edge and future job choices emerge, with the potential to enhance significantly pharmaceutical industrial production and bring the next generation of drugs to market through new research.[3,4]

Cluster-based research is increasing in regional areas in coordination with local institutes and industries. Cluster-based research increases market concentration and competition for all market participants. As cluster-based pharmaceutical research supporting manufacturing has become more prevalent in Ireland, the country's pharmaceutical industry statistics are becoming more impressive.[5]

AI in the pharma industry

According to some experts, by 2025, over half of all global healthcare corporations will have implemented AI plans, and it will be critical for how businesses operate in the future. Top pharmaceutical corporations partner with AI vendors for research & development and overall drug discovery and incorporate AI technology into their production processes. According to surveys, roughly 62% of

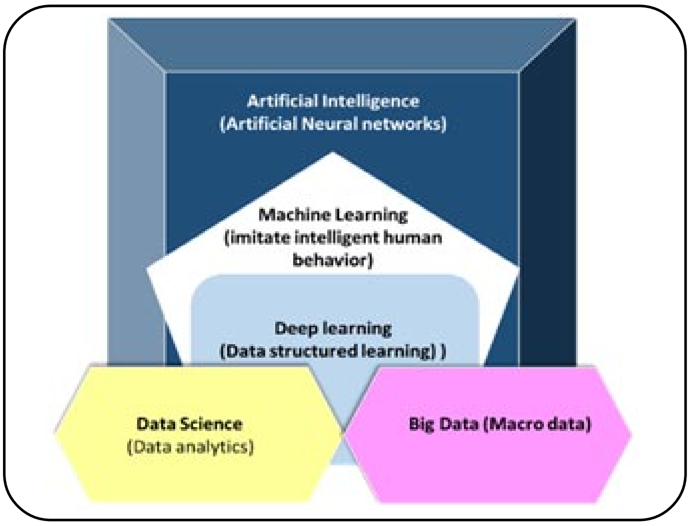

Figure 1A. Artificial Intelligence and its subsets.[7]

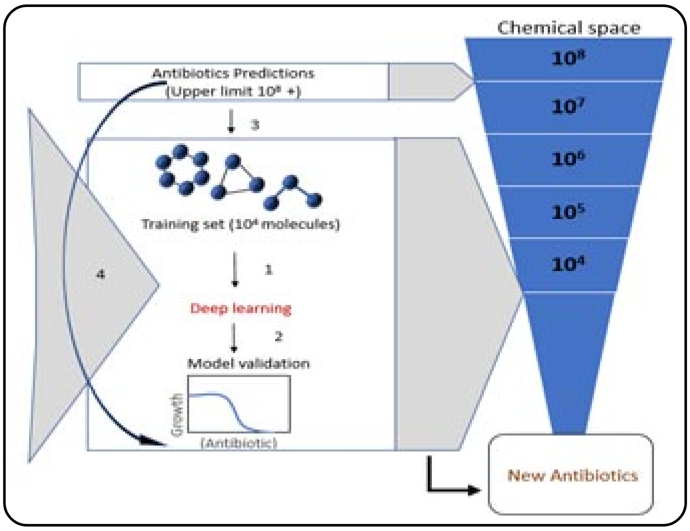

Figure 1B. Drug discovery assisted with AI tools.[11]

healthcare organizations consider investing in AI soon, and 72% of businesses feel AI will be critical to their future operations.[6,7]

Present scenario of AI in pharma

The usage of AI and ML technologies, according to researchers, enhances decision-making, maximizes innovation, increases the efficiency of research/ clinical trials, and creates useful new tools for physicians, consumers, insurers, and regulators. Roche, Pfizer, Merck, AstraZeneca, GSK, Sanofi, AbbVie, Bristol-Myers Squibb, and Johnson & Johnson are among the top pharmaceutical corporations that have already partnered with or purchased AI technologies. The Massachusetts Institute of Technology has launched a Machine Learning based on Pharmaceutical Research and Synthesis program teamed with Novartis and Pfizer in 2018 to change medication design and production. The consortium intends to bridge the gap between MIT's machine learning research and drug discovery research by bringing together researchers and industry to identify and solve the most pressing issues.[8]

GSK also formed a partnership with Cloud Pharmaceuticals to speed up the development of new medication candidates. GSK and Vir Biotechnology teamed in April 2020 to improve COVID-19 drug discovery using CRISPR and AI. Roche and Owkin, a medical research machine learning platform, have teamed up to accelerate medication discovery, development, and clinical trials. Abbott also just introduced an artificial intelligence-powered coronary imaging technology. AI platform can detect the severity of calcium-based blockages and evaluate channel diameter to improve decision-making during coronary stenting procedures.[9]

AI based - drug discovery

Biological testing of pharmaceutical compounds consumes enormous time in the drug development process. Novartis researchers employ ML algorithms on photographs to determine which chemicals are worth further investigating to speed up the screening process. Algorithms are significantly faster at revealing new data sets than traditional human analysis and laboratory tests. Unique and effective medications can be available sooner while simultaneously lowering the operating expenses associated with each compound's manual examination. The following are some of the top biopharmaceutical companies' current AI initiatives:

[a] mobile platform to improve health outcomes - the ability to refer patients based on real-time data, improving patient outcomes.

Table 1. Comparison between traditional and AI-based drug discovery.[8]

Traditional drug discovery	**AI tools based drug discovery**
Target driven	Data-driven
Work well for easy targeting	Machine learning with complex algorithms extractsvaluable insights from a given dataset
They have limitations as the complexity of cellular connections and a lack of understanding of complicated cellular pathways	Find chemicals that attach "undruggable targets" or proteins with undefined structures

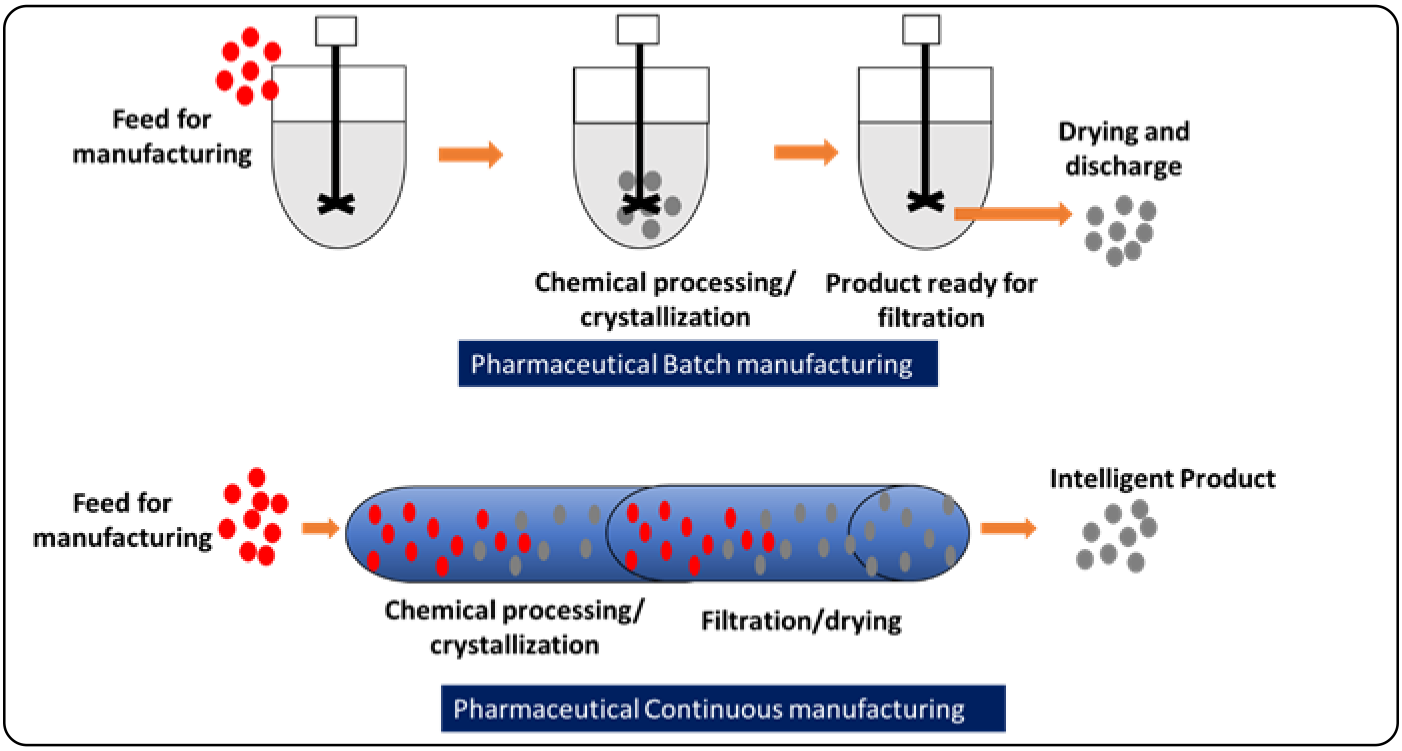

Figure 2. Comparison of batch manufacturing and Continuous manufacturing.[13]

[b] drug development- pharmaceutical corporations collaborate with software businesses to employ cutting-edge technologies in the costly and time-consuming drug discovery process.[9]

AI support antibiotic study

Antibiotic discovery has become more complicated in recent years with the rise of antibiotic resistance. Earlier, antibiotics were discovered by screening soil-swelling microbes for secondary compounds prohibited bacterial growth. However, antibiotic development is currently hampered by the discovery of the same molecules repeatedly. Recently, a study showcasing machine learning to find new antibiotics was released, where researchers employ machine learning to anticipate antibacterial chemicals in silico from a database of over 107 million molecules. This antibiotic, known as "Halicin," is effective against various bacteria, including tuberculosis and difficult-to-treat types. Other medications could benefit from this strategy, such as those used to treat cancer or neurological illnesses.[1]

AI in diagnosis and treatment

Physicians can collect data using powerful machine learning techniques and analyze and evaluate patient healthcare data. Deep learning and machine learning are being used by healthcare practitioners worldwide to store patient data in a cloud securely, or a centralized storage mechanism Electronic Medical Records (EMRs) are the term for this. Physicians can use these health records to determine how a specific genetic trait affects a patient's health. Machine Learning algorithms can use data contained in EMRs to provide real-time estimates for diagnostic purposes and suggest appropriate treatment for the patient. Verge Genomics is tackling the major issues in drug discovery by employing automated data collection and analysis. In other words, they're using an algorithm to map out hundreds of genes involved in brain disorders such as Alzheimer's, Parkinson's, and ALS (Amyotrophic lateral sclerosis). Medications could benefit from this strategy, such as those used to treat cancer or neurological illnesses.[10]

They believe collecting and interpreting gene data will positively impact the drug discovery phase, beginning with preclinical trials. Starting in the preclinical stage, utilize AI to track the effects of various pharmacological treatments on the human brain. As a result, drug companies can better understand a medicine's impact on human cells earlier in the development process. Verge genomics, in particular, use artificial intelligence to track the effects of various drugs on the human brain with a specific focus on the preclinical phase.[10]

Treatment and management of rare diseases

Advances in information technology, particularly in the fields of artificial intelligence (AI) and machine learning, large, multivariate datasets are frequently used to "train" AI and machine learning algorithms, which are subsequently used to make predictions on new data. For example, by classifying tumours in radiological images as benign or malignant.[10]

Table 2. Features of batch production and continuous production.[16]

	Batch manufacturing	Continuous production
Raw material input/ product output	Raw materials are fed intermittently into the processing activity, and the finished product (products element) is released in a single batch	Raw materials are continually injected into the system, and the result (product material) is released continuously and consecutively after a set amount of time
Production processes	Operators handling continually start and stop each process	Without operator supervision, manufacturing is continuous thanks to integrated process units and automated technology
Production facility area	A lot of areas is required	Space can be saved
Scaling-up	Each scale has its own verification techniques and equipment at the prototype and validation stages, while commercial production requires special equipment	Experimental equipment can be developed to match current production, and a speedy transition to mass production can be achieved by simply changing the manufacturing time

Advances in AI have rekindled interest in cures for rare diseases. There are currently over 350 million people worldwide who suffer from over 7,000 uncommon diseases. Heal, a UK-based biotech business has acquired $10 million in Series A funding to employ AI to discover breakthrough treatments for rare diseases, so it is not all doom and gloom for people with uncommon conditions. Another Swiss biotech start-up, Thera chon, has acquired $60 million in investment to create medications to treat rare genetic illnesses using AI.[6,12] Artificial intelligence/machine learning (AI/ML) and its accompanying capabilities have opened up lots of new prospects for intelligent intervention, which, when properly harnessed, can greatly improve the rare disease treatment path.[12]

Continuous manufacturing in pharma

Continuous manufacturing refers to the production of a pharmaceutical product in a single continuous process. The entire process takes place in one location, from beginning to end, with no waiting times. Continuous manufacturing is a more flexible method that allows for better production scaling. For example, scaling up simply means running the continuous production process for a more extended period.[13] In other words, continuous manufacturing makes matching supply to demand much more manageable than producing in batches.

Currently, traditional "batch" procedures are used to manufacture most pharmaceuticals. Batch operations allow raw components to be added into the network at the beginning of the process and subsequently ejected as a final product together at once later. The finished batch must have consistent qualities and meet predetermined quality criteria. Between every production phase, the intermediate product is collected and frequently moved for the next step, which comprises several independent procedures (blending, granulation, drying, and so on). Batch production is a time-consuming, disjointed process that lacks agility and flexibility.[14]

On the other hand, continuous manufacturing techniques allow essential raw materials to be continually fed into the process on a regular basis, and the outcome continuously gets cleared. Compared to batch manufacturing, continuous processing is more adaptable, allowing it to adjust to fluctuations in economics more quickly. This is especially useful in times of crisis, such as when there are crucial drug shortages or pandemics. By running the process for extended periods, using parallel processing lines, or boosting the pace of the process, continuous manufacturing can theoretically allow faster output volume increases.[14]

Relevance of continuous manufacturing during covid-19 pandemic

During this life-threatening pandemic of covid-19, the pharmaceutical industries face unprecedented challenges, reinforcing the need for rapid, efficient, and scalable drug development and production. At this critical juncture in global health, when demand for low-cost vaccines and other pandemic-related treatments is at an all-time high, continuous manufacturing can assist in meeting that demand,

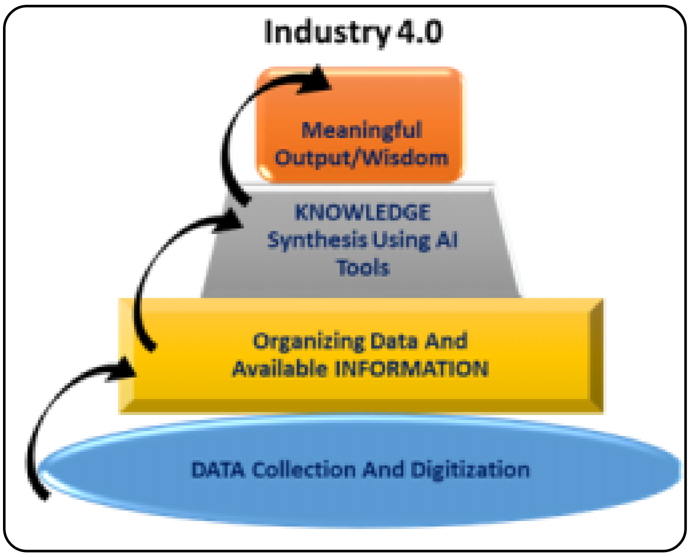

Figure 3. The several steps of data processing and the way to realizing Industry 4.0.[18]

as all major pharmaceutical companies are stepping up for continuous manufacturing.[15]

Factors that are causing continuous manufacturing to gain traction

Small batch industrial production, characterized by the sequential framework of large tanks, controlled individually for each procedure, has been the standard approach to producers in the medicinal and fine chemicals companies. In contrast, continuous manufacturing, including big factories for industrial chemicals, hasn't been widely adopted. Continuous manufacturing technology is a flow production approach that uses a constant supply of raw materials to make or treat products without disruption while the production system is in operation. So far, the pharmaceutical industry's transition from batch to continuous manufacturing has been slow.[2,16]

However, a problem concerning product quality arose in the United States during the mid-1990s, when defective batch-produced medications were introduced onto the market, becoming a public concern. Furthermore, batch manufacturing was lacking for future production adjustment capability, which has been noted as a negative, fueling the movement more towards a continuous manufacturing technology that allows for the creation of the requisite volume whenever needed. In 2004, the US(FDA) issued commercial guidance, including suggestions for continuous pharmaceutical production. The pharmaceuticals and fine chemical industries' use of continuous manufacturing was cited as an essential issue in its annual report in 2018.[13]

Future of continuous manufacturing

Continuous manufacturing will be an evolution rather than a revolution. Some pharmaceutical companies have already adopted continuous technologies. Still, industry experts predict that it will be another five to ten years before fully integrated continuous biomanufacturing is commonly employed commercially.[16,17]

Pharma Industry 4.0

The 4th industrial revolution, known as Industry 4.0, combines fast-evolving technology such as the

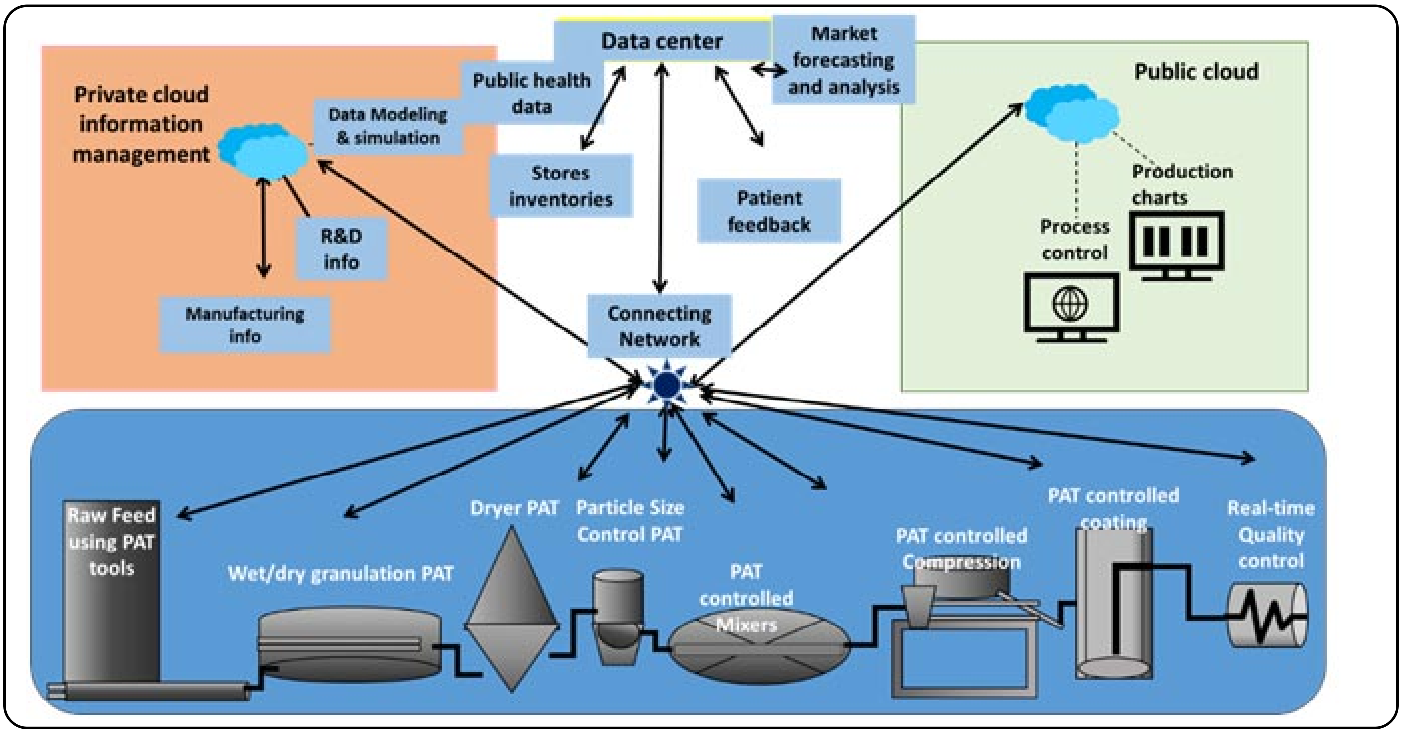

Figure 4. A cyber-physical system (CPS) representation for futuristic pharmaceutical manufacturing 4.0.[20]

internet of networks, artificial intelligence, robotic systems, and powerful computing to disrupt the manufacturing landscape significantly. In a nutshell, automated, independent, and self-organizing production systems define Industry 4.0. It may not be simple to implement various new technologies to allow Industry 4.0. It may be valuable because it can boost output, improve production safety, improve quality, provide better value characteristics, offer flexibility, and decrease waste. Pharma industry 4.0 is a paradigm for tailoring digital solutions to the specific needs of the pharmaceutical industry. In practice, this translates to increased connectivity, increased efficiency, easier compliance, and the marshaling of production data to address problems as they arise. Equipment, PAT instruments, and real-time release testing (RTRt) make up a production floor).[3,18] Using the internet the local networking and storage are connected to the unit operations. In Industry 4.0, a cyber-physical system (CPS) for drug industry includes three types of cloud computing: cloud provider, cloud platform, and manufacturing floor. External consumers can also use application services in the public cloud. The data for significantly greater elements like remote surveillance systems and manufacturing, monitoring and controlling, results from the laboratory, and modeling as well as experiments are stored in the cloud platform.[19]

The core idea is that CPS connects and regulates all of the value chain processes. Gadgets may, for example, forecast faults and initiate maintenance operations on their own or self-organize operations in response to changes in output.

Integrating internet, artificial intelligence, and automation empower systems to function with little or no personal participation. There are the quintessential aspects of Industry 4.0. To maximize manufacturing and corporation management, linked automated and robotics combine manufacturing systems with authentic online data and artificial intelligence. Interconnecting external and internal communication, multiple sources can be linked simultaneously. Internal data, including control of vitality and resources, outcomes of modelling and simulations, and laboratory values for pharmaceutical industries, could be integrated with data sources, such as consumer satisfaction, consumer expectations, vendor stocks, and outbreaks.

It is feasible to achieve exceptional real-time response, monitoring, control, and forecasting by combining multiple data sources. The result is a highly digitalized ecosystem and pharmacy value chain for producers.[3]

An Industry 4.0 smart factory's fundamental techniques

Two critical technologies are employed to acquire and store data from a manufacturing process:Computer storage technology, like the networking cloud, and information acquisition technique including improved sensors utilized in operations, are both available. Computer storage technologies allow the long-term preservation of digitized data collected. Multidisciplinary robotics that is intelligent, precise, and real-time and enhanced or virtual reality systems enable intelligence, correctness, and real-time manufacturing. The modern broadband access network and proper encryption permit the factory.[20]

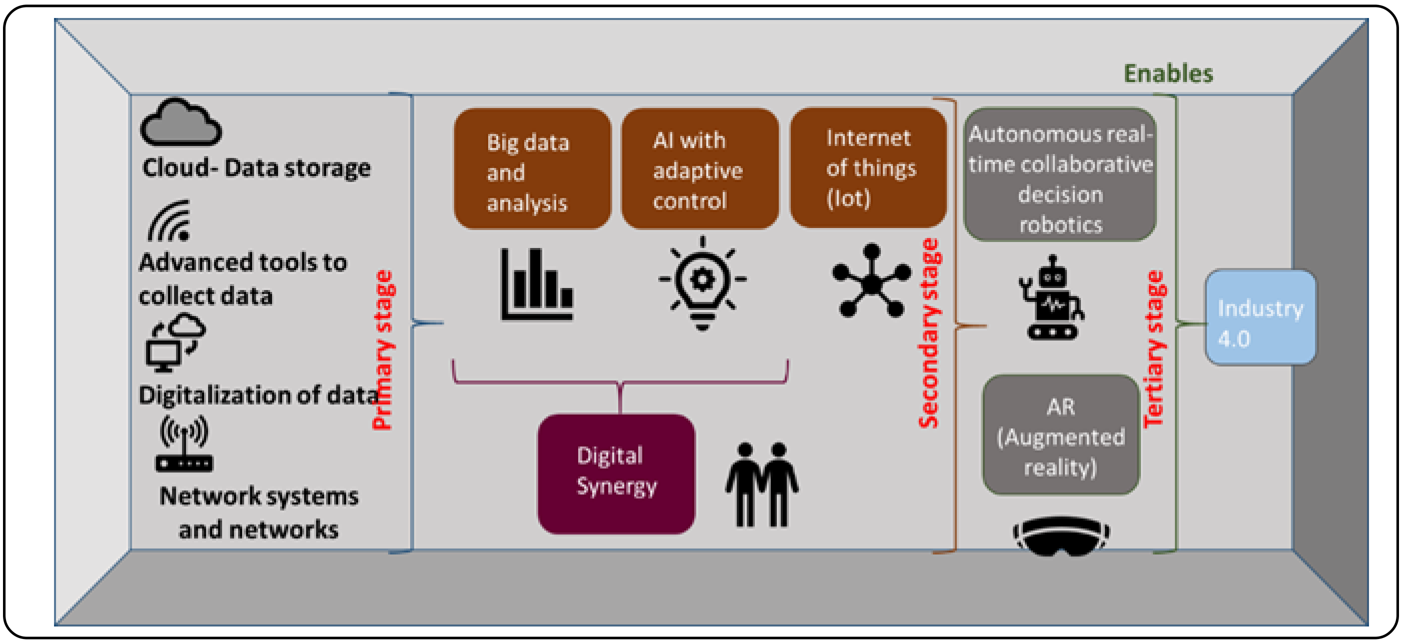

Figure 5. Enabling Technologies of Industry 4.0.[18]

Cluster-based research

The emergence and growth of pharmaceutical clusters are examples of radical reforms in the pharmaceutical sector, which leads to increased market concentration and competition for all market participants.[6]

A critical feature of pharmaceutical clusters is that the organizations increase both their competitive advantage and the competitive advantage of the cluster itself by complementing one another. Clusters are most common in the United States of America and Europe. Clusters are typically based on universities and research institutes. Regional budgets provide primary capital, with additional funding provided by attracting investments. For the cluster policy within the European Union, the European Institute of Technology and Innovation contributes to its development. The main direction of cluster policy in European countries over the past five years is the unification of innovations and support for government procurement for product development. Clusters tend to occur in under developed areas. The development and growth of pharmaceutical clusters as a territory's innovative activity revealed that more than ten pharmaceutical clusters are currently of interest to well-known members of the global pharmaceutical industry. The Kaluga Pharma Cluster, for example, is a research centre that focuses on biomedicine. and biotechnology.[6] The Pharmaceutical Solid State Research Cluster (PSSRC) was developed to stimulate solid-state research by sharing facilities, working on specific projects, and allowing research students to interact with other academics in the field.

Synthesis and Solid-State Pharma Cluster (SSPC)is a Science Foundation Ireland (SFI) and industry-funded Global Hub of Pharmaceutical Process Innovation and Advanced Manufacturing in Ireland. It is one type of collaboration, with 24 industries, nine research organizations, and 12 international scientific collaborators. The SSPC's mission is to bring together skilled scientists from academics and the pharmaceutical sector to tackle pressing research issues.[21,22]

The cluster's research activities are focused on two key areas: the development of breakthrough analytical technologies using Artificial Intelligence/ Machine learning and their application to advanced process engineering of conventional pharmaceutical unit operations.

As technology evolves, Advanced and futuristic career options develop, dramatically increasing the industrial production of medicines and bringing the next generation of pharmaceuticals with new research. Advanced and futuristic careers in pharmaceuticals include Continuous manufacturing, AI in pharma, Industry 4.0 in pharma, Cluster-based research centers.[4,23]

Indian pharma company overview

As a leading producer of low-cost, high-quality generic drugs, India supplies roughly 20% of global pharmaceutical demand in terms of volume. The entire industry is 45 billion US dollars with 24 billion US dollars exports. Between 2020 and 2045, the economy is expected to grow by 600%. Generic drugs have traditionally been India's stronghold, accounting for more than 70% of total market revenue. Outside of North America, India has the highest number of US FDA-approved generic drug manufacturing plants. However, the recent coronavirus (COVID-19) pandemic has revealed weak links in the Indian pharmaceutical sector.[24]

Conclusion

To conclude, the potential of AI and machine learning in the pharma industry appears to be quite promising. As more and more pharmaceutical industries use AI and ML, these modern technologies will become increasingly democratized, making themmuch more readily available to small and moderate enterprises. Advanced pharmaceutical occupations may be able to address the growing need for pharmaceuticals. The pharmaceutical industry's use of technology can revolutionize the country's economy. AI isn't just changing the way the pharmaceutical industry operates; it's also giving drug companies new ways to increase brand value. Continuous manufacturing, for example, is one of the job alternatives that can assist in fulfilling the world's expanding demand for pharmaceuticals. Artificial intelligence (AI) can help to improve the research and development process. Industry 4.0 advancements will promote the computerization of manufacturing and boost the competitiveness of the regions where clusters operate.Cluster-based research can alsohelp to improve the country's economy. Overall, advanced pharmaceutical careers have the potential to transform pharmaceutical research and production.

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