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Generative Artificial Intelligence in Industrial Engineering: Industry Applications and Educational Prospects

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Introduction

First, online teaching took educators by storm due to the restrictions imposed by COVID-19. Now, Artificial Intelligence (AI), particularly generative AI (GAI), is prompting us to rethink our teaching pedagogies. Technological tools are being integrated into every aspect of our lives at lighting speed, and these tools are readily available to learners at their fingertips. The instructional approaches through which we were educated -and which most of us have been employing in our teaching- must be critically examined and updated to ensure effective teaching and learning in this new era. Beyond the clear need for AI integration in education, the growing influence of AI in industry is a significant driving force behind this necessity as it is essential to equip students with the knowledge and skills matching industry expectations.

GAI, as defined by ChatGPT -a conversational AI model developed by OpenAI-, "*refers to a class of artificial intelligence models designed to create new content, such as text, image, audio, or video, that resembles human-generated data. These models "generate" content by learning patterns from large datasets during their training process*". Given its capabilities and rapid adoption across industries, integrating GAI into technical training may become essential for preparing students for the workforce.

With this in mind, this research aims to identify Industrial Engineering (IE) areas with significant GAI activity and use these insights to explore how IE education can be enhanced to better equip graduates for the evolving job market. As part of this study, this paper examined GAI applications in IE fields through a literature review guided by the PRISMA method. The findings highlighted GAI practices in both industry and education. In education, the use of ChatGPT as supportive instructional tool, particularly for course assessment, has emerged as a prominent trend, while in industry supply chain has stood out as a leading area for GAI adoption. To illustrate practical applications, hypothetical use cases were developed using ChatGPT and compiled in areas experiencing significant GAI growth. These cases were used as a basis for discussing opportunities to integrate GAI into IE education, with a focus on enhancing students' technical skills**.** Additionally, the paper provides terminology, definitions and descriptions of commonly used GAI tools.

Background

GAI is a subset of AI that produces novel content by learning patterns from its training data. Unlike traditional AI – primarily machine learning (ML) models- GAI differs in key aspects such as purpose, learning approach, and output. Traditional AI focuses on performing specific tasks using programmed rules, often relies on supervised learning, and generates pre-defined or task-specific outputs (e.g. price prediction, fraud detection). In contrast, GAI is characterized by three main features: (1) taking complex, varied and preferably nuanced prompts, (2) using deep learning models, and (3) creating new data [1]. One of the most common applications of GAI involves processing prompts in natural language format. These applications rely heavily on

Large Language Models (LLMs), which became popular with the launch of ChatGPT in 2022. GPT stands for Generative Pretrained Transformer. LLMs are transformer-based models that can generate, summarize, translate and answer questions about text. The most common foundational architectures in GAI models include adversarial networks, diffusion models, autoencoders, and autoregressive models [2]. A brief description of each model and its typical application is provided in Table 1.

Table 1 Commonly used GAI models

GAI Model	How they are trained & work	Common Applications
Generative Adversarial Network (GAN)	Uses two neural networks, a generator and a discriminator, which compete against each other. The generator creates new data (like images), while the discriminator evaluates how real or fake the generated data is. Through this adversarial process, both networks improve, leading to the generation of increasingly realistic data.	Image generation, video generation, enhancing image resolution
Variational Autoencoders (VAEs)	Learns a compressed representation of data (a latent space) and then generates new data by sampling from this latent space. They are effective at learning underlying patterns in data.	Image generation, data compression, anomaly detection
Transformer Models	Neural networks that use self-attention mechanism to weigh the importance of different parts of input data, enabling parallel processing and effective capture of relationships between elements, particularly in sequential data like text.	Language modeling, text generation, classification
Diffusion Models	Works by gradually adding noise to data until it becomes pure noise and then learning to reverse this process to generate new data from the noise. They are known for producing high-quality and diverse samples, especially in image generation.	High-quality image/video generation, audio synthesis
Autoregressive Models	Generates data step-by-step, where the generation of each step depends on the previous steps. They are particularly good at modeling sequential data like text and speech.	Language modeling, text generation, speech synthesis

Automating repetitive tasks, augmenting human creativity and innovation, and autonomously executing business and IT processes are often listed as the main prospective functions of GAI; the overarching benefits include enhanced customer experience, improved employee productivity, revenue growth and reduced cost [3].

GAI applications encompass a broad range of domains including visual, audio, text, conversational interfaces, and software and coding [[4], [5], [6]]. Video and image generation are most common examples in the visual domain, while music composition, voice synthesis and podcast creation are typical in the audio domain. In text generation, common applications include writing, editing, and language translation. For conversational interfaces, common uses

involve chatting, information search and real-time language translations in data-driven conversations. Task automation, bug detection and code generation are frequently applied in the software and coding domain [4], [7]. Table 2 lists commonly used user-facing, standalone GAI tools, excluding platforms that aggregate multiple GAI tools, such as Poe and DeepAI.

Table 2 Commonly use GAI tools

Tool	Application	Use Case	Provider /Developer
ChatGPT	Conversational	Writing assistance, content generation, customer service, education	OpenAI
Gemini (previously Bard)	Conversational	Writing assistance, content generation, Q&A	Google DeepMind
Perplexity	Conversational	Information retrieval, Q&A, search assistance	Perplexity AI
Claude	Conversational	Writing assistance, summarization, Q&A	Anthropic
Llama	Conversational	Content generation, summarization, chatbot integration	Meta
Jasper (previously Jarvis)	Conversational	Marketing, copywriting, content creation	Jasper AI (previously UseProof)
Sora	Conversational	Conversational AI, virtual assistances	Sora Technologies
MS 365 Copilot	Conversational	Productivity enhancement, document editing, presentation creation	Microsoft
Midjourney	Visual/Image	Artistic creation, digital art, content design	Midjourney, Inc.
Leonardo	Visual/Image	Artistic creation, digital art, content design	Leonardo AI
NightCafe	Visual/Image	Artistic creation, digital art, content design	NightCafe Creator
Dall-E 3 (integrated into ChatGPT)	Visual/Image	Image generation from text prompts	OpenAI
Stable Diffusion	Visual/Image	Artistic creation, digital art, content design	Stability AI
Stable Video Diffusion	Visual/Video	Video generation from text prompts	Stability AI
Stable Audio	Audio	Audio generation, music creation	Stability AI
Gamma	Visual/Image/Text	Presentation creation, storytelling	Gamma
PixAI	Visual/Image	Anime and art generation	PixAI
Runway	Visual/Video	Video editing, content creation, film production	RunwayML
InVideo	Visual/Video	Video creation, marketing content, social media videos	InVideo, Inc.
Imagen Video	Visual/Video	High-quality video generation from text prompts	Google Research
Copilot	Software/coding	Software development, code assistance, debugging	GitHub

Since the field of GAI is rapidly evolving, new tools are frequently introduced. The tools presented here are selected examples that has high user traffic [4]. It is also important to note that while there are many tools on the market that incorporate AI or AI-enhanced features, not all

qualify as GAI. Tools such as ResearchRabbit (for writing assistance, grammar, and citations), Quillbot and Grammarly (for paraphrasing and writing enhancement), assist with tasks by leveraging GAI techniques but primarily focus on augmenting and refining existing content; hence, they are not considered core GAI applications and are excluded from this list.

Although there is considerable discussion about the promise of GAI on various aspects of life, research on its actual usage remains limited [4], and studies focusing on specific application fields are further rare [8]. This study aims to explore how GAI is influencing IE practice and to examine the implications for IE education.

Methodology

A systematic review guided by PRISMA framework [9] was conducted to identify scholarly work on the applications of GAI in IE. The review followed these steps: (1) Problem/Research question formulation; (2) Protocol development; (3) Literature search; (4) Screening for Inclusion; (5) Quality assessment; (6) Data extraction; (7) Data analysis and synthesis; and (8) Reporting findings [10].

The study focused on addressing the following questions: "*What are the application areas of GAI in Industrial Engineering fields*?" and "*What are the expected benefits of using GAI in these fields*?". The search terms "Generative AI" and "Industrial Engineering" were used, with Google Scholar serving as the primary database. Google Scholar was chosen for two reasons: (1) full-text access was readily available to the authors through their institution, and (2) the database is frequently updated with new publications, an important factor considering the rapid advancement of the field. Only peer reviewed publications in scholarly journals and conference proceedings were considered. The flow of the search and selection process is shown in Figure 1.

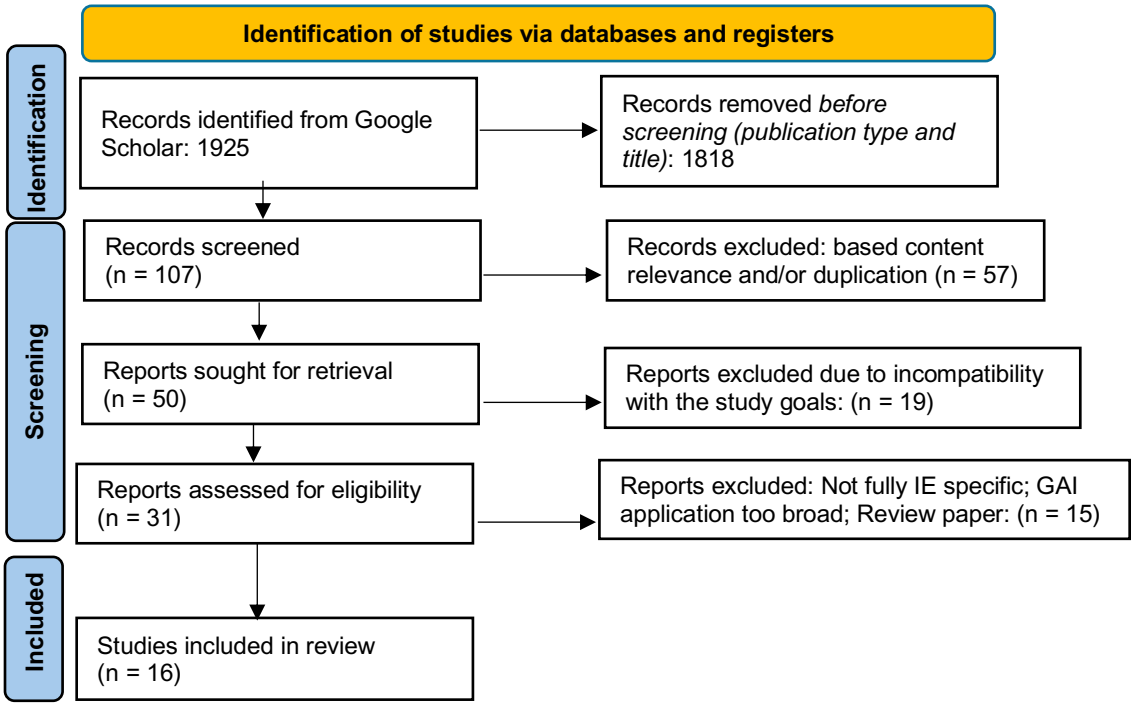

Figure 1 Identification of Studies – Search and Selection Process

The search yielded 1,925 publications which were reduced to 107 after removing non-journal articles and non-conference papers. The first screening involved a high-level review of content relevance and removal of duplicates, resulting in 50 publications. The second screening focused on eliminating studies irrelevant to research goals, further reducing the list to 31. The final screening focused on studies with involving GAI tools and applications directly related to IE, narrowing the list to 16 articles. These articles were then grouped based on the application categories, and the results were analyzed to identify current trends in GAI usage in IE-related fields (listed in Table 3).

Table 3 Search Results

Authors	Tool	Applications Identified	Benefits Listed	Real-world Examples
Area: Supply Chain/Operations				
Wamba *et. al.*(2024) [18]	ChatGPT (and others)	Inventory management, demand forecasting, resources planning, process efficiency, cost reduction	Customer satisfaction; cost reduction; process efficiency; reduced errors; risk management.	Maersk; Walmart; Unilever; Mercedes-Benz; Tel Aviv Sourasky Medical Center
Jackson *et. al.* (2024) [19]	GAI in general	Forecasting, distribution and transportation strategy, inventory management and warehousing, process design, production planning and control, production strategy, quality management, revenue management, sales and operations planning, scheduling and routing, sourcing strategy, supply chain design, supply chain risk management	Enhanced prediction leading better projections and more robust and resilient SC; enhanced customer experience; more robust and effective decision-making.	Walmart; Maersk; DHL; Instacart
Ye (2024) [20]	GAI in general	Inventory optimization, predictive maintenance, fraud detection, risk management, logistics optimization, demand forecasting, warehouse layout optimization	Operational efficiency; reduced worker stress; increased productivity.	Domino's Pizza in the UK and Ireland;
Haddud (2024) [21]	ChatGPT	Procurement operations, supplier management, operations and manufacturing, inventory management, logistics and customer relationship management	Enhance customer satisfaction; support promotional activities; streamline supplier communication; improve data analysis; better demand forecasting; provide sustainability reports; reduce cost; enhance process efficiency.	N/A
Ahmad *et. al.* (2024) [22]	GAI in general	Risk identification, risk mitigation	Enhanced supply chain resilience.	N/A
Yandrapalli (2024) [23]	GAI in general	Sourcing assessment and procurement; risk mitigation; logistics, distribution and transportation; demand forecasting and inventory management	Procurement and inventory accuracy; improved productivity; shortened retrieval times; maximized storage spaces.	N/A
Wamba *et. al.*(2023) [8]	GAI in general	Customer support, inventory management, purchasing	Efficiency; responsiveness; service level; revenue/profit; agility.	DHL, Instacart, Salesforce, Zalando,
Panigrahi *et. al.* (2023)[24]	GPTs	Customer assistance, task automation, manage logistics activities	Reduce costs; efficient inventory management; streamlined warehousing activities; improved customer service.	N/A

Table 3 Search Results (con't)

Authors	Tool	Applications Identified	Benefits Listed	Real-world Examples
Area: Education/Research				
Onal & Kulavuz-Onal (2024) [11]	ChatGPT	Supportive instructional tool, particularly in assessment tasks	Time savings; creativity and flexibility.	Courses: Project Analysis and Control; Manufacturing Processes
Mardikar *et. al.* (2024) [12]	ChatGPT; Gemini; Copilot; Claude; Llama-2	Automate the development of LP models (Formulate mathematical optimization)	Useful aid for formulating LP problems (however, limited).	Textbook/online problems
Tellez *et. al.* (2023) [13]	ChatGPT	Formative assessment for LP problems	Tailored student feedback.	Course: Linear Algebra
Alzoubi & Topcu (2024) [2]	ChatGPT	Data processing and analysis, hypothesis formulation, prediction and forecasting, research directions (systems engineering)	Time savings; enhanced effectiveness of the research process; enhanced research collaboration.	N/A
Area: Quality				
Manukonda (2023) [17]	GPTs	Defect detection and classification, maintenance and repair, pattern analysis, task automation	Reduced workflow inefficiencies; reduced human bias.	N/A
Area: Manufacturing				
Xiang *et.al* (2024) [14]	GAI in general	Predictive maintenance, quality control, CoBots, personalized products or services	Reduced downtime; improved performance; operational efficiency; improved customer experience.	N/A
Ghobakhloo *et. al.* (2024) [15]	GAI in general	Customer support, agile production decisions, advanced quality management, advanced training and knowledge transfer, data-driven production insights, enhanced data quality and consistency, generative design optimization, operational resilience operator satisfaction enhancement, on-demand workforce empowerment	Enhanced customer support experience; operational efficiency; cost effectiveness; heightened competitiveness; enhanced quality; reduce training time and resources; efficient resource utilization; more engaging and satisfying work environment.	N/A
El Hassani *et. al.* (2024)[16]	GPT models	FMEA application in product development process	Improved data analysis; better risk assessment; improved decision making; reduced manual effort and time.	N/A

Findings and Discussion

It is worthwhile to note -though unsurprising- that 98% of the search results were published between 2022 and 2024, with only 2% appearing in earlier years, dating back to 2014. All studies included in the review were published in 2023 and 2024, emphasizing the emerging nature of the field. Additionally, while many relevant preprints appeared in the search, they were excluded from the review as they had not undergone peer review.

Most of the publications were survey papers providing a comprehensive review of existing techniques, tools or theories (9 papers) followed by theory papers offering conceptual frameworks or maps for usage (6 papers). There was one review paper focusing on applications of GAI in Systems Engineering particularly and three papers with case studies and use case examples. Notably, ChatGPT (or GPT) was the most frequently mentioned user-facing tool, appearing as either the sole tool studied or listed as an example tool in over half of the publications. Other LLM models such as Gemini, Claude, and Llama-2 were referenced only in education-related studies. The remaining publications addressed GAI in general without specifying particular tools. The IE domains covered, ranked by frequency, were supply chain and operations, education and research, manufacturing, and quality. All real-world examples cited in studies were from the supply chain domain and involved the use of chatbots and GPT models including ChatGPT.

The applications were diverse, ranging from automating repetitive tasks to enhancing complex decision-making processes, with domain-specific usage categorized as follows: (1) Supply Chain and Operations: inventory management, demand forecasting, resource planning, logistics and risk management, (2) Education and Research: supportive instructional tool, particularly in assessment tasks and formulating mathematical optimization, (3) Manufacturing: predictive maintenance, customer support, and agile production decisions, and (4) Quality: data-driven production insights such as pattern analysis and defect detection and classification, and task automation.

The primary goals of GAI were *efficiency* and *cost reduction* through time savings, streamlined operations, and inventory management and *productivity and performance improvement* through better risk assessment and improved data-driven decision making. Additionally, key impact areas included enhanced customer satisfaction, increased creativity and flexibility, and improved collaboration and engagement.

IE Education in the GAI era

Despite the limited number of scholarly publications, existing work shows that GAI is making its way into the workplace. This limitation is likely a reflection of the academic publication process which tends to be lengthy. The rapid advancement of the field is making it difficult to keep pace with the advancement and adoption of GAI tools in industry, and study and document their use in scholarly work. Nevertheless, it is evident that AI, particularly GAI, is changing how we think and learn [25], [26]. Therefore, its integration into education is becoming essential - not only to support student learning but also to equip students with the knowledge and skills necessary to thrive in today's tech-driven environment.

In discipline specific education, it is important to identify relevant application areas and incorporate real-world examples along with the necessary training to ensure that students can apply these tools effectively. Use cases serve as a valuable instructional approach in this context

as they illustrate how users interact with systems. To explore opportunities for integrating GAI into IE education, four hypothetical use cases were generated through a ChatGPT session for the supply chain, operations, manufacturing, and quality domains. The education/research application area was excluded for two reasons: (1) applications in this area primarily focus on the instructor perspective with most attention given to assessment tasks and (2) this study focuses on providing integration resources to enhance the ISE curriculum and capture industry applications.

The following initial prompt was used to develop the use cases: "*For the following domains, please provide a use case example and identify the following elements (1) scenario description, (2) goals, (3) generative AI tools that can be used in this scenario - make sure that the tool is generative AI, not a traditional AI. and (4) which IE course it could be integrated into. the domains are (1) Supply chain, (2) Operations, (3) Manufacturing, and (4) Quality*". The output was refined over several iterations with follow-up prompts to ensure the examples were accurate and relevant, particularly for the manufacturing and quality domains. The final use cases are presented in Table 4.

As the examples show, the issues or the goals to tackle remain familiar. Fundamental IE principles and concepts such as demand forecasting, job shop scheduling, design for manufacturing and quality control, continue to form the foundation of analysis. However, addressing challenges in these domains can be significantly enhanced with the use of technology, specifically GAI in this case. Potential learning objectives and relevant GAI tools are shown in the third column of Table 4, while the last column lists the common IE courses where these tools could be integrated.

What does this mean for the educators? Are we expected to master every new tool and integrate them into instruction? Not necessarily. Incorporating this new technology into our courses should not be different than how we previously adopted to advancements in Information Technology. For example, in statistics, we once relied on manual calculations before adopting software packages such as SPSS, SAS, and Minitab. While we integrated these tools into our courses, we did not adopt all of them at once, and most likely we did not aim to master every tool ourselves. Later, tools such as Statistica, JMP, and MS Excel ToolPak were introduced, followed by R and Python for statistical analysis. Each time, we updated the tools we taught to better prepare our students for industry expectations. The tools have always been a means to achieve deeper insights, solve complex problems and support informed decision making, but never the ultimate goal in themselves. The challenge and opportunity with GAI are similar. GAI has the potential to augment technical skills, and its rapid adoption in industry makes a strong case for IE educators to begin transforming their teaching methods and incorporating GAI into discipline-specific education.

Table 4 Use Case Examples

Domain/Use Case	Goals	GAI usage/Example Tool	IE Course
Supply Chain: A company manages a global supply chain where demand fluctuates due to seasonal trends and economic changes. The primary concern is to maintain optimal inventory levels while minimizing stockouts and overstock situations.	• Improve demand forecasting accuracy. • Optimize inventory levels to reduce holding costs and increase service levels. • Respond dynamically to changes in demand patterns.	Generate models that simulate demand scenarios and recommend optimal ordering policies based on real-time data. **OpenAI Codex (GPT model)** Generates outputs (as source codes, comments or explanations of code) based on natural language prompts or partial code snippets.	*Supply Chain Management; Inventory Control and Logistics*
Operations: A manufacturing facility operates as a job shop, where various jobs require different processing times on different machines. Traditional scheduling methods struggle to keep up with frequent changes in job priorities.	• Generate optimized schedules dynamically as new jobs arrive. • Minimize machine idle times and job tardiness.	Generate control policies for dynamic scheduling **MS Project Bonsai (autoregressive model)** Generates outputs (as control policies or sequence of actions) input data from the system (such as sensor data, operational parameters)	*Production and Operations Management; Advanced Scheduling Techniques*
Manufacturing: A company specializing in consumer electronics is looking to innovate their product designs. They want to create new, optimized design variations of their product casing that are both aesthetically pleasing and functional, while reducing material waste and improving durability. Traditional design methods are time-consuming, and they want a tool that can generate multiple design alternatives quickly.	• Generate a variety of product casing designs based on predefined performance goals (e.g., durability, weight, aesthetics). • Reduce material usage while maintaining product strength. • Create new, innovative design concepts that would be difficult to produce manually.	Generate novel design alternatives that adhere to the specified goals, such as optimizing material distribution for strength and reducing unnecessary bulk **Runway ML (GAN model)** Generates new design variations and optimized product output shapes based on input parameters (e.g. dimensions, material types, functional goals)	*Manufacturing Design; Advanced Product Design*
Quality: A company producing high-end consumer goods, such as luxury watches, wants to automate the visual inspection process to identify defects in product finishing, like scratches, cracks, or misalignments. Traditional methods of visual inspection are slow and prone to human error.	• Automatically detect quality defects in real-time. • Improve the precision and speed of quality inspections.	Generate predictions about possible defects. **DeepAI Image Generator (GAN model)** Generate realistic defect images based on textual descriptions (e.g., "micro-crack in semiconductor component," "misalignment in a circuit board")	*Quality Control and Assurance; Advanced Manufacturing Processes*

Conclusion

This study aims to identify the areas driving the adoption of GAI in IE fields and explores its applications and expected benefits. A literature review was conducted to map the specific domains where GAI is being utilized. The findings were then used to examine opportunities for reshaping instructional approaches in IE education. The most prominent domains where GAI is increasingly applied include supply chain and operations, education and research, manufacturing, and quality.

To enhance the curriculum, integrating use case practices and providing training on relevant GAI tools is recommended. Additionally, an overview of basic GAI concepts and applications is included. Conducting a literature review for a field as broad as IE presents inherent challenges, leading to the need for narrowed search terms. This, combined with the rapid pace of GAI advancement, may have resulted in a list that is not entirely comprehensive for GAI within IE. Despite this limitation, the study's findings offer valuable insights and practical takeaways. Future work may focus on each of the application domains identified in this study to gain more in-depth understanding on how GAI is shaping these areas.

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