



## Characterizing generative artificial intelligence applications: Text-mining-enabled technology roadmapping

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### ABSTRACT

This study aims to identify generative AI (GenAI) applications and develop a roadmap for the near, mid, and far future. Structural topic modeling (STM) is used to discover latent semantic patterns and identify the key application areas from a text corpus comprising 2,398 patents published between 2017 and 2023. The study identifies six latent topics of GenAI application, including object detection and identification; medical applications; intelligent conversational agents; image generation and processing; financial and information security applications; and cyber-physical systems. Emergent topic terms are listed for each topic, and inter-topic correlations are explored to understand the thematic structures and summarize the semantic relationships among GenAI application areas. Finally, a technology roadmap is developed for each identified application area for the near, mid, and far future. This study provides valuable insights into the evolving GenAI landscape and helps practitioners make strategic business decisions based on the GenAI roadmap.

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### Introduction

Artificial intelligence (AI) advancements, including generative AI (GenAI), have introduced myriad opportunities for both individuals and business organizations (Santana & Díaz-Fernández, 2023; Eapen et al., 2023; Spanjol & Noble, 2023). With the ability to generate texts that are similar to those written by humans (Pavlik, 2023), GenAI algorithms have a broad range of applications across different industries (Ameen et al., 2023; Hendriksen, 2023). GenAI allows chatbots and virtual assistants to have contextually relevant and human-like conversations, adding personalized details to conversations and enhancing customer service efficiency (Silard et al., 2023). Additionally, GenAI can enhance creative expressions and facilitate the creation of art, music, and literature content. For instance, ChatGPT can generate a wide variety of content based on the user command,

including essays, poetry, concise summaries, and answers to user questions (Ray, 2023).

As the technology continues to rapidly evolve, mapping the landscape of GenAI is crucial (Mariani & Dwivedi, 2024). Park et al. (2020) defined roadmapping as “a process that mobilizes structured systems thinking, visual methods (e.g., roadmap ‘canvas’) and participative approaches to address organizational challenges and opportunities, supporting communication and alignment for strategic planning and innovation management within and between organizations at firm and sector levels” (p. 2). More specifically, technology roadmapping (TRM) is “the process of creating visualizations of elements related to technologies” (Nazarko et al., 2022). TRM can help identify trends and future development opportunities across multiple sectors, enabling firms to explore new product lines and market opportunities. The insights generated can be useful for guiding strategic decisions and ensuring the future development of technologies (Carvalho et al., 2013). In addition, TRM can provide strategic direction and resource optimization by outlining the sequence of technology development (i.e., near-, mid-, and far-future), facilitate stakeholder communication by visualizing the dimensions of technology

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development (Lee et al., 2013; Ramos et al., 2022), and help firms identify inventors or patent applicants with whom to form strategic partnerships.

Although previous studies on GenAI have focused on a variety of facets, including implications for innovation management (Mariani & Dwivedi, 2024; Obreja et al., 2024), management educators (Ratten & Jones, 2023), travel decision-making (Wong et al., 2023), human resource management (Budhwar et al., 2023), innovation management (Idrees et al., 2023; Spanjol & Nobel, 2023), and information systems (Susarala et al., 2023), there has been a limited focus on roadmapping GenAI, exploring how it emerged, and identifying future prospects. This study aims to map the technological landscape of GenAI using a text-mining approach (i.e., structural topic modeling), extracting GenAI-related patents from patent datasets. Patents have been shown to be a valid proxy measure for innovation and technological developments (Noh et al., 2021; Su et al., 2023) and previous studies on the blockchain (Zhang et al., 2021), e-commerce (Singh & Vijay, 2024), and autonomous driving (Su et al., 2023) have used patent data to construct a technology roadmap. To better understand the GenAI landscape, the following research objectives are proposed:

- To conduct a comprehensive mapping of the technological clusters and applications
- To develop a technological roadmap for GenAI and foresight for the future

The findings of this study provide three contributions. First, the results contribute to studies on technological forecasting and roadmapping, integrating the current literature on AI with roadmapping practices. By analyzing patent data related to GenAI, this study presents a roadmap of GenAI advancements across various industries. Second, while traditional roadmapping methodologies have relied upon expert opinions, patent-data-driven TRM offers comprehensive application areas of the GenAI. Third, the findings of this study can assist decision-makers in AI research and development.

## Literature review

### Generative AI

GenAI is a rapidly evolving category of AI systems that develops creative content based on pre-trained data (Nguyen-Duc et al., 2023; Mariani & Dwivedi, 2024). According to Kalota (2024), GenAI is “algorithms (such as ChatGPT) that can be used to create new content, including audio, code, images, text, simulations, and videos” (p. 7). Advancements in deep learning, large language models (LLMs), generative pre-trained transformers, natural language processing (NLP), and diffusion models have accelerated the technological capabilities of GenAI (Dwivedi et al., 2023a). By automatically generating informative content based on user input, GenAI can reduce human efforts. It can be used, for example, to test and debug codes, generate new NFTs, and provide informative data to aid in decision-making. GenAI can speed up the development of creative processes, simplify business operations, foster incremental or radical innovation, and generate informative content that can enhance business performance (Amankwah-Amoah et al., 2024).

Firms can use GenAI to automate routine operations, personalize information to specific preferences, improve operational efficiency, and quickly adapt to dynamic markets. Predictive models generated through GenAI can help firms identify new market opportunities and customize products and services to meet individual customers' requirements (Fosso Wamba et al., 2023). In other words, GenAI can help simplify complex procedures, enhance creative talents, and enable cost reductions.

GenAI can enhance human creativity by boosting divergent thinking, improving understanding, and addressing knowledge bias. It can generate ideas more quickly than humans, enabling individuals to assess the viability of the ideas. GenAI can be applied to a wide range of practical business scenarios, such as enhancing customer satisfaction, improving marketing strategies, and advancing healthcare services (Wamba et al., 2024). Firms can utilize GenAI predictive modeling to predict customer preference, market trends, and competitive advantage. Medical researchers are exploring the use of GenAI techniques, such as artificial neural networks (ANN), to create antibodies. Effective, sustainable integration of GenAI technologies into existing technological systems must address ethical issues, identify constraints, and encourage human–AI association. Mariani and Dwivedi (2024) explained that “GenAI can enable the fusion and hybridization of different types of innovation – such as product, process and marketing innovation – thus paving the way for the emergence of entirely new business models” (p. 5). GenAI provides distinctive advantages across multiple industries and can easily be integrated into firms' existing technological capabilities to enhance competitive advantage.

Although GenAI can improve customer experiences by providing responses, there is the risk of dissatisfaction if GenAI does not meet user expectations in domains such as accuracy or responsiveness. Aydın and Karaarslan (2022) highlighted the possibility of error or inadequate content creation when employing GenAI, explaining that it can reduce consumer trust. Additionally, there is a security risk that GenAI-generated content will reveal confidential information about customers or firms. Despite these challenges, GenAI provides businesses with the opportunity to streamline processes, improve consumer engagement, and foster innovation (Rubel et al., 2022).

### Roadmapping

Corporate foresight is the “application of futures and foresight practices by an organization to advance itself” (Gordon et al., 2020). It involves analyzing trends, identifying signals, and formulating corporate strategies to plan for an uncertain future (Gershman et al., 2016). Corporate foresight contributes to innovation by providing strategic guidance, assisting innovation initiatives, and challenging assumptions (Gordon et al., 2020). Multiple approaches can be applied to corporate foresight, including competitive intelligence (Hakmaoui, Oubrich, Calof, & Ghazi, 2022), benchmarking (Calof et al., 2020), scenario analysis (Fink & Schlake, 2000), and roadmapping analysis, also referred to as TRM (Gordon et al., 2020). Roadmapping analysis, in particular, is an integral method of corporate foresight (Ozcan, Homayounfard, Simms, & Wasim, 2021).

TRM integrates technology and market-oriented elements into a cohesive multi-tier roadmap to provide a systematic view of advancement within a technological domain (Nazarenko et al., 2022). It can be used to map a broad range of technologies to achieve diverse purposes, including the acquisition of competitive intelligence, forecasting, portfolio management, strategic planning, technology management, and technology planning (Ding & Hernández, 2023; Lee & Park, 2005; Lee et al., 2007; Vasconcellos et al., 2014). Previous studies have documented the successful application of TRM (Chakraborty et al., 2022; Letaba & Pretorius, 2022; Nazarenko et al., 2022; Ozcan et al., 2021; Watanabe et al., 2020). Within a technology roadmap, essential components include time frame, know-why (i.e., factors contributing to value creation), know-how (i.e., encompassing technological developments), and linkages (Aström et al., 2022; Ding & Hernández, 2023). Phaal et al. (2004) highlighted eight primary purposes for TRM: strategic planning, product planning, knowledge asset planning, capability planning, integration planning, long-range planning, program planning, and process.

De Alcantara and Martens (2019) explained that TRM “has the ability to show the interrelationship between market, product, and

technology and has been applied in a large number of industries” (p. 128). TRM is an important step in the strategic planning process that should be initiated before articulating the project portfolio and develops over multiple iterations and refinements, in alignment with the organization’s technology strategy. TRM utilizes a time-based orchestrated framework to create, demonstrate, and disseminate strategic plans for developing technology, products, services, or markets. The TRM technique is highly adaptable, so it may be used to address various organizational objectives. TRM helps firms achieve a competitive advantage by developing and utilizing input, transformation, and output-based capabilities.

In TRM, the “focus should be on strategic planning, with roadmapping providing a mechanism, catalyst, and common language to carry the strategic planning process forward” (Phaal et al., 2005). TRM enables the firm to achieve strategic transformation by identifying strategic opportunities in the emerging industry, developing a technical roadmap, and providing recommendations on where the firm can enhance its technological competencies.

## Methodology

Prior studies on TRM have utilized a variety of methods, such as text mining (Liu et al., 2023; Ozcan et al., 2021); text clustering (Zhang et al., 2016); semantic analysis (Miao, Wang, Li, & Wu, 2020); keyword network analysis and link prediction (Kim & Geum, 2021); Bayesian networks (Jeong, Jang, & Yoon, 2021); the Delphi technique (Park et al., 2020); morphological analysis (Bloem da Silveira et al., 2018); and topic modeling based on latent Dirichlet allocation (Zhang, Daim, & Zhang, 2021).

This study adapts the structural topic model (STM) by Roberts et al. (2016) to extract latent topics from an extensive collection of patent text documents and understand related trends. STM is an unsupervised statistical machine-learning method that identifies a topic as a probabilistic distribution of semantically associated terms (Roberts, Stewart, & Airolidi, 2016; Sánchez-Franco & Aramendia-Muneta, 2023). In other words, STM clusters frequently co-occurring and semantically related terms in a text corpus, and these clusters are defined as latent topics (Kraus et al., 2023). STM is preferable to traditional topic modeling approaches because the topic modeling process incorporates document-level covariates that improve the causal inference and qualitative interpretability of the latent thematic structures (Sharma, Rana, & Nunkoo, 2021). STM enables researchers to approximate the relationship between metadata covariates and topical prevalence, facilitating the analysis of how topic content and prevalence vary as per document-level covariates (Dwivedi et al., 2023b).

The data-generating process under STM is depicted in Fig. 1. Each node has a separate role; the observed variables are shown in shaded nodes and latent variables are represented as unshaded nodes. The rectangles characterize replication as the text corpus has  $D$ -indexed documents, and each document,  $d$ , has terms indexed by  $N_d$ . The number of topics ( $K$ ) is selected empirically by the researchers. The topic-term distribution and per-document topic proportions are two key latent variables that capture the mixture of topics within the documents and the probability distribution of each topic over terms. The core language model generates topic proportions for each document and then estimates per-term topic assignment and topic-word distribution for each word in the document.

## Data and data pre-processing

This study began with the identification of search query keywords. Based on keywords in the previous literature (e.g., Kraus et al., 2022; Sauer and Seuring, 2023), the following search string was used to search the patents: “large language models” OR “LLMs” OR “Conversational Agents” OR GPT\* OR \*GPT OR “Dall-E” OR BARD OR LaMDA OR “Generative Pre-trained Transformer” OR “Generative Models” OR “Pre-trained Generative Models” OR “Generative Adversarial Network.” Using these keywords, 2,985 patents were identified between 2017 and 2023. The year 2017 was chosen as the starting point for this roadmapping study as it marks the beginning of a significant period of advancements in the field of GenAI, including Progressive GAN (2017), GPT-2 and GPT-3 (2019, 2020), DALL-E 2 (2023), ChatGPT (2022), and GPT-4 (2023) (Bengesi et al., 2024). After filtration for relevancy, 2,398 patents were retained for final analysis. The patents were listed in various patent offices, including the U.S. Patent and Trademark Office, the European Patent Office, and the Japan Patent Office. The top countries that have filed patents include in the United States, South Korea, China, Japan, India, Great Britain, Taiwan, Germany, Canada, and Australia.

The text corpus for this study was prepared by concatenating the title and abstract of patent documents, which is a standard procedure in topic modeling (Madzik, Falat, Yadav, Lizarelli, & Carnogursky, 2024). Text pre-processing involved the removal of non-English characters, basic English stop words, punctuation marks, and country names (Gao, Wang, & Wu, 2023; Singh et al., 2020; Singh et al., 2023). An n-gram tokenizer was implemented in the R language to identify the most frequent bigrams and trigrams, which were then converted into unigrams to preserve the semantics of these words (Goodell, Kumar, Li, Pattnaik, & Sharma, 2022). Topic models with varying numbers of topics were tested to empirically select the optimal number of topics. Past studies have confirmed that the optimal number of topics can be chosen based on exclusivity scores, semantic

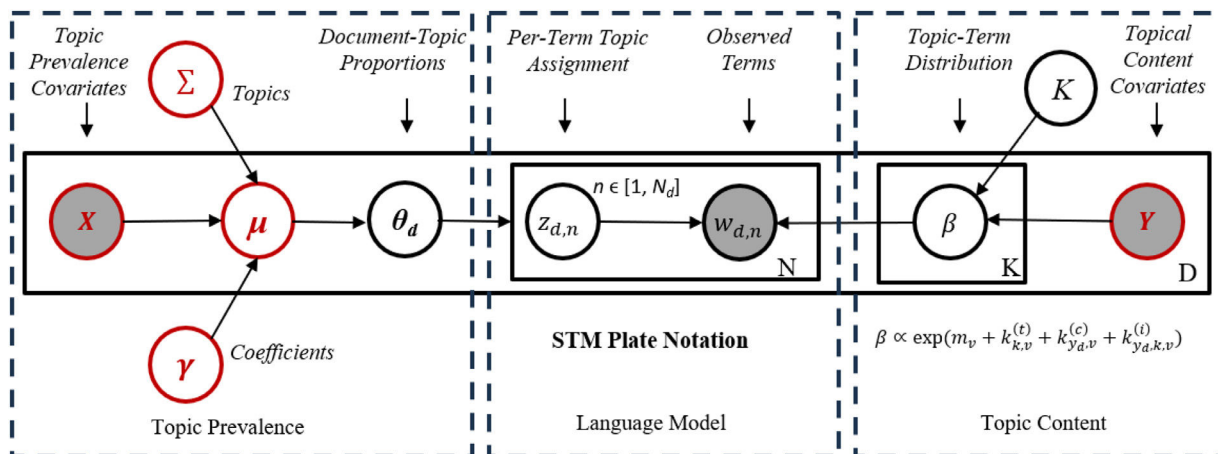


Fig. 1. Plate Notation of STM (adapted from Roberts et al. (2016)).

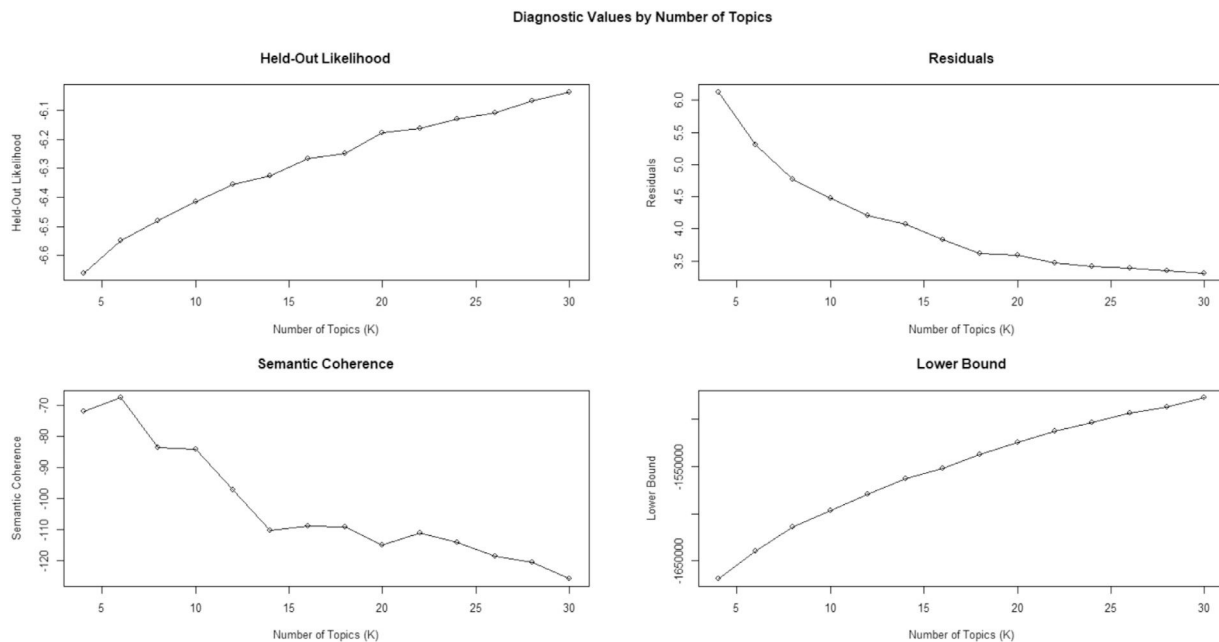


Fig. 2. Estimating the optimal number of topics within the model.

coherence, and held-out likelihood (Sharma, Koohang, Rana, Abed, & Dwivedi, 2023; Sharma et al., 2021; Singh, Singh, Koohang, Sharma, & Dhir, 2023). Fig. 2 illustrates that semantic coherence drops sharply when the number of topics is greater than six, thus, a model with six topics was used.

The study adapted its approach to developing a technology roadmap from previous studies, including Ozcan et al. (2021) and Lee et al. (2008). The layers of the technology roadmap, i.e., market drivers and processes, were identified and the time lag was adjusted based on the patent application date to classify it as in the near-, mid-, or far-future. The processes were identified from the patent dataset and linked to the market drivers. Based on the identified layers and time lag of patents, the GenAI roadmap was prepared.

## Results

A keyword analysis was performed on the title and details of each patent to understand the trends and concepts. A total of 5,102 keywords were identified. The keywords with the highest frequency included “network” (9,135 instances), “data” (6,995), “adversarial” (5,565), “learning” (2,577), “input” (2,454), “neural” (2,283), “discriminator” (2,006), “plurality” (1,936), “generation” (1,402), and “apparatus” (1,114). Various neural network architectures are used in GenAI models, including convolutional neural networks (CNNs), recurrent neural networks (RNNs), and generative adversarial networks (GANs). Further, datasets are required to train these GenAI models. “Adversarial” denotes an adversarial training technique used in GANs. “Learning” is related to supervised and unsupervised learning techniques. The input data can exist in a variety of formats, including text, audio, and image. Further, the “discriminator” is a component in GANs that distinguishes between real and generated data. “Plurality” denotes the multiplicity of generated outputs. “Apparatus” refers to the frameworks, tools, or platforms used to develop and deploy GenAI models.

STM associates documents with key topics that can be expressed using the top emergent terms. Table 1 summarizes the key topics and the associated top terms based on the probability of occurrence. A few exemplary patent documents are also provided to help further exploration and analysis. The proposed topic labels and definitions are based on the top terms and associated patent documents for each

topic (Ammirato, Felicetti, Linzalone, Corvello, & Kumar, 2023). Most patents within the corpus have been registered under financial and information security applications (22.8%), although image generation and processing (21.7%) has also attracted significant attention from GenAI inventors and researchers.

### Topic 1: object detection and identification

Topic 1, Object Detection and Identification, represents the dominant research related to the detection of objects, locations, patterns, and outliers from digital images and videos. The wide-ranging applications of GAN models in detecting street objects, finding anomalies in medical images, and gesture control in human–robot interaction (Brophy et al., 2023; Hoffman et al., 2023; Wu et al., 2022) are well-addressed in patent documents. Contemporary computer vision techniques heavily exploit deep generative models for a wide range of object detection and identification applications.

### Topic 2: medical applications

Topic 2, Medical Applications, mainly focuses on applications of GenAI in the healthcare industry, including medical imaging technologies, drug discovery and development, and medical research and data analysis (Chen & Esmailzadeh, 2024; Hazra & Byun, 2020; Yi et al., 2019). Several patents have been registered that use ensemble GANs to simulate biomedical signals related to cardiovascular disease. GANs are also used to generate protein sequences and detect real or counterfeit chemicals in medical drugs.

### Topic 3: intelligent conversational agents

Topic 3, Intelligent Conversational Agents, encompasses patents related to the application of AI-based conversational agents like chatbots or virtual agents that can interact with humans over text or voice interfaces (Mekni, 2021). Multipurpose conversational agents based on deep learning techniques for processing natural language queries have been proposed and deployed for various business applications (Allouch et al., 2021). Filed patents for intelligent conversational agents propose systems and methods for integrating these

**Table 1**  
Topics proportion and emergent topic terms.

Topic and Topic Proportion	Definition	Emergent Topic Terms	Sample Patents
Object Detection and Identification (12.7%)	Systems and methods for detecting objects, locations, and Abnormalities	Image, Resolution, Vehicle, Embodiment, Generative Adversarial Network, Product, Component, Damage, Roadway, Detector	<ol style="list-style-type: none"> <li>1. Generative adversarial network models for detecting small street objects</li> <li>2. System and method for utilizing weak supervision and a generative adversarial network to identify a location</li> </ol>
Medical Applications (14.6%)	Computer-aided diagnosis, disease prediction, and physiological interpretation	Electrocardiogram, Antibody, Cellular Image, Amino Acid Sequence, Prediction, Abnormal Flow Detection, Frame, Sequence, Reflection, Composition	<ol style="list-style-type: none"> <li>1. Ensemble generative adversarial network-based simulation of cardiovascular disease-specific biomedical signals</li> <li>2. Electrocardiogram generation device based on generative adversarial network algorithm and method thereof</li> </ol>
Intelligent Conversational Agents (13.9%)	Systems and methods for development, deployment, integration, and monitoring of conversational agents such as chatbots	Conversational Agent, Response, Natural Language Query, Detection, Verification, Deep Learning Technique, Chatbot, Merchant, Self-Disclosure, Support	<ol style="list-style-type: none"> <li>1. Method and system for switching and handover between one or more intelligent conversational agents</li> <li>2. System for monitoring and integration of one or more intelligent conversational agents</li> </ol>
Image Generation and Processing (21.7%)	Processing, generating, editing, and restoring digital images	Image, Synthetic, Image Processing, Output, Information, Image Generation, Learning, Feature, Discriminator, Segmentation	<ol style="list-style-type: none"> <li>1. Generative adversarial network for processing and generating images and label maps</li> <li>2. Method for generating image generation model based on generative adversarial network</li> </ol>
Financial and Information Security Applications (22.8%)	Classification and prediction systems for finance and data security-related tasks	Data, Training, Model, Covariance, Generative Adversarial Network, Loan, Borrower, Time-Series, Behavior Inference Model, Semi-Supervised	<ol style="list-style-type: none"> <li>1. Method and apparatus for examination of financial credit using artificial neural network, generative adversarial network, and reinforcement learning</li> <li>2. Method for performing continual learning on credit scoring without reject inference and recording medium recording computer readable program for executing the method</li> </ol>
Cyber-Physical Systems (14.3%)	Intelligent systems for sensing, computation, controlling, monitoring, optimizing, and communicating with other systems	Model, Device, Controller, Generative Adversarial Network, Information, Target, Signal, Process, Generative-AI, Cyber-Physical System	<ol style="list-style-type: none"> <li>1. System and Method for Abstracting Characteristics of Cyber-Physical Systems</li> <li>2. Method for Controlling a Home Appliance</li> </ol>



techniques in different sectors. Although the research in this area is still emerging, it has significant potential to evolve in the future.

Topic 4: image generation and processing

Topic 4, Image Generation and Processing, represents the use of GenAI and deep learning techniques to generate digital images and apply different effects to images. Text-to-image synthesis, the manipulation of image effects, and the restoration of images are the most common use cases of GenAI in relation to digital images (Gu et al., 2022; Liu et al., 2021). The recent patents filed and granted within this topic propose the application of transformers and GANs in image processing and digital image generation.

Topic 5: financial and information security applications

Topic 5, Financial and Information Security Applications, includes patents related to financial credit analysis, anomaly detection in financial data, financial forecasting, risk assessment, and credit scoring. GenAI's substantial productivity and operational efficiency has the potential to revolutionize the financial industry and related sectors (Kanbach, Heiduk, Blueher, Schreiter, & Lahmann, 2024; Zheng et al., 2024). GenAI is revolutionizing the finance sector by analyzing data variances to support fraud detection (Rane, 2023). Similarly, applications of GenAI in information security and data privacy focus on identifying potential breaches and vulnerabilities, generating cyberattack simulations, prioritizing risk modeling, and automating security tasks.

Topic 6: cyber-physical systems

Topic 6, Cyber-Physical Systems, focuses on intelligent, computer-based systems (Proven et al., 2021) that can process substantial amounts of data and integrate sensing, monitoring, control, and networking into physical processes in a digital environment (Nayak, Naik, Vimal, & Favorskaya, 2024). Most patents within this topic apply to cyber-physical systems such as vehicle controllers, cabin monitoring systems, smart home devices, secure private networks, and industrial automation. Cyber-physical systems primarily emphasize the need to develop interfaces and processes for facilitating

device-level interaction to monitor and control internet-of-things-based systems within cyberspace.

Discussion

A correlation analysis utilizing an estimated marginal topic proportion correlation matrix was performed to further investigate and quantify the associations between the identified topics. Fig. 3 presents the correlations among the six topics, the values of which are all less than 0.3. The negative values confirm no documents within the corpus contain equal references to any two topics.

One of the main advantages of STM is that it can be used to investigate the interactions between covariates and topics. The topic proportion is estimated as a function of the publication year. The temporal dynamics in topic proportions indicate changes in the popularity of each topic over time and can be used to identify emergent themes based on increasing trends in topic proportion. Fig. 4 depicts the trends for each of the six topics over the study period. Topic 2 (Medical Applications), Topic 3 (Intelligent Conversational Agents), and Topic 6 (Cyber-Physical Systems) all show a rising trend. Topic 4 (Image Generation and Processing) shows a slight decline after 2022, though it continues to attract a significant amount of scholarly focus. Finally, Topic 1 (Object Detection and Identification) and Topic 5 (Financial and Information Security Applications) show a gradually declining trend.

Roadmapping (near-future, mid-future, and far-future)

Based on the identified topics, a technology roadmap was generated for GenAI for the near, mid, and far future, mapping market drivers and processes for each cluster. The near-future advancements are those that are expected in the next 0–2 years; the mid-future advancements are anticipated in 2–5 years; and far-future developments are anticipated in 5–10 years (Table 2).

In the near future, object detection and identification advancements can focus on leveraging deep learning models to generate novel chemical compounds for drug design, enhancing road safety by integrating advanced driving assistance systems, and implementing predictive maintenance solutions that forecast equipment damage and optimize maintenance schedules to minimize downtime in

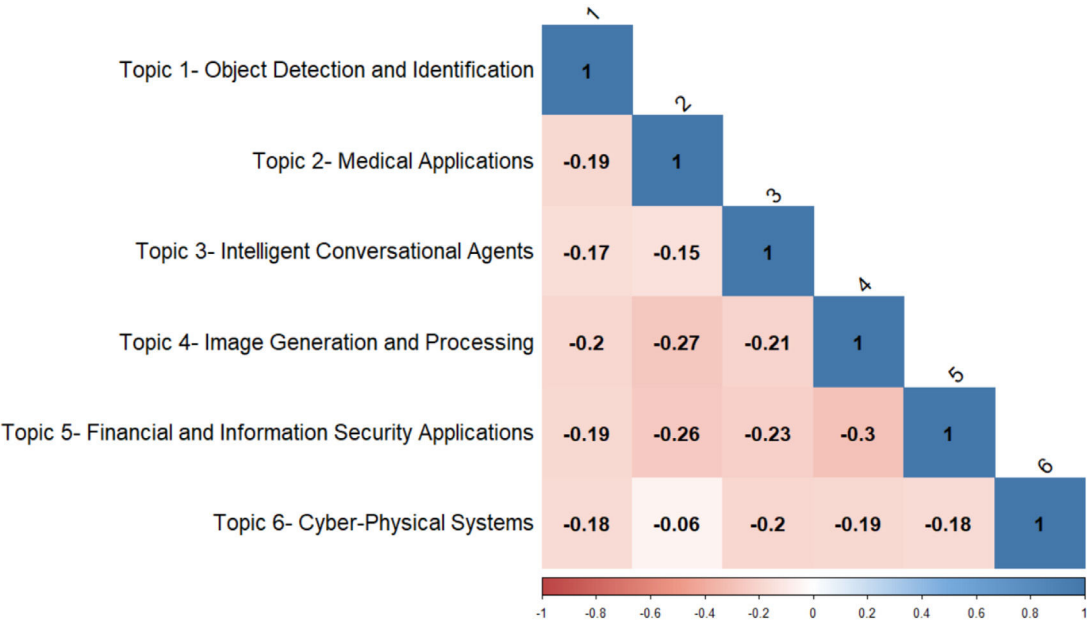


Fig. 3. Correlation among topics.

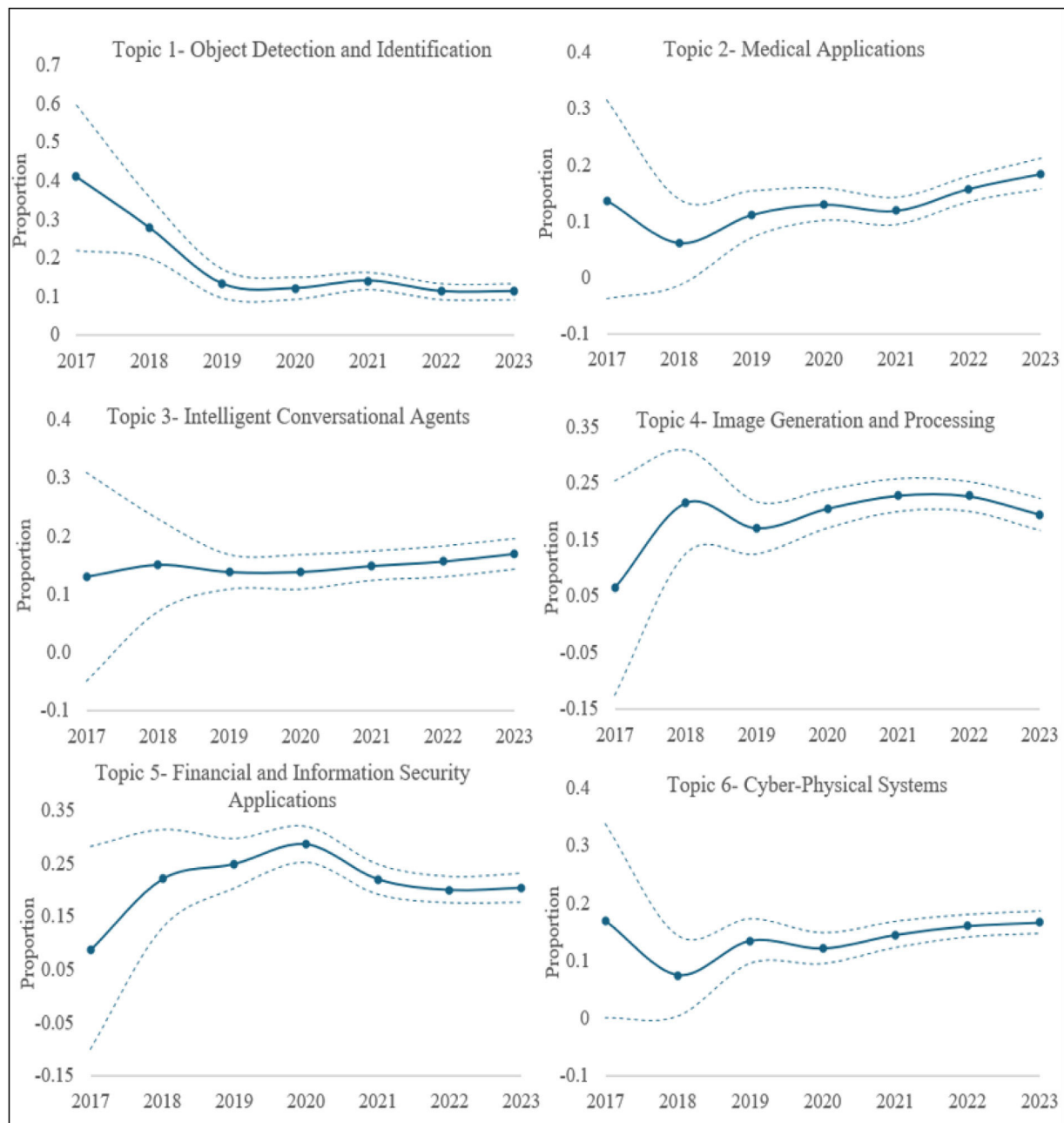


Fig. 4. Evolution of emergent topics.

industrial operations. Medical developments from GenAI revolve around enhancing diagnostic capabilities and treatment planning through medical image synthesis, streamlining documentation tasks to generate accurate and relevant medical reports, and facilitating personalized interaction experiences. By improving the accuracy and efficiency of medical processes and clinical workflows, these developments are poised to significantly enhance patient care.

In the short term, the anthropomorphic nature of intelligent conversational agents and their contextual responses are expected to improve, enhancing user engagement. These developments include the generation of dialogue responses, query-keyword matching, and the generation of customized content. Using GenAI techniques, conversational agents will be able to cater to individual user needs, enhancing user satisfaction, fostering query understanding, and creating more relevant and personalized content. At the same time, image generation and processing

capabilities will focus on enhancing preventive maintenance practices through a visual anomaly detection system, improving the accuracy of healthcare diagnostics through medical image noise reduction, and advancing immersive experiences through virtual feature maps. Through the use of GenAI techniques, firms can make significant improvements in operational efficiency, diagnostics capabilities, and user satisfaction.

Near-term advancements in financial and information security applications can focus on enhancing and optimizing performance through pre-training systems for self-learning agents, predictive maintenance and fault prediction to avoid device failures and mitigate risks, and network optimization to enhance application performance, reliability, and security. GenAI developments in cyber-physical systems include cyber-security measures to tackle evolving risks. Further, GenAI can also be leveraged to improve the clarity and resolution of monitoring systems.

Table 2  
Technology roadmap.

Object Detection and Identification	Processes	Drug design	Driving assistance system	Equipment damage prediction system	Machine translations using LLMs	Collision avoidance and micro navigation	Resolving time delays	Automated visual inspection	Synthetic human fingerprints	Service-robot
	Market-driver	Generate chemical compounds with desired characteristics	Safety enhancement Optimization	Risk-mitigation Data-driven decision making	Integration with business workflows	Autonomous navigation	Customer experience enhancement	Quality assurance	Biometric security solutions	Aging population Human-robot interaction
Medical Applications	Processes	Medical image synthesis	Medical text generation	Opinion expression based on consistent style or personality	Electronic medical record entity recognition	Depression diagnosis interview	Speech recognition (unspoken text and speech synthesis)	Generation of protein sequence	Prognosis evaluation of breast cancer	Disease early warning
	Market-driver	Diagnosis and treatment planning	Generating accurate and contextually relevant medical reports	Personalized interaction styles	Automation of data entry	Scalability of mental health services	Accessibility improvements (speech impairments)	Application in pharmaceutical research and	Treatment planning	Disease prevention
Intelligent Conversational Agents	Processes	Generation of dialogue responses	Query-keyword matching	Generation of customized content	Efficient data co-clustering	Persona-based dialogue modeling	Generating facial expressions in a user interface	Conversational interface for APIs	Switching and handover between one or more intelligent conversational agents	
	Market-driver	Natural and contextually relevant responses	Accurate query understanding	Personalized content creation	Collaborative filtering	Enhance user engagement	Virtual reality Augmented reality	Simplify API interaction	Agent coordination Multi-agent systems	
Image Generation and Processing	Processes	Visual anomaly detection system	Medical image noise reduction method	Virtual feature maps	Pose-invariant face recognition	Medical image segmentation	Target identification	De-identification of personal information	Turning a 2-D image into a Skybox	System for forming fetal affection
	Market-driver	Preventive maintenance Risk mitigation	Diagnosis and treatment planning	VR, AR Immersive experiences	Invariant feature extraction	Disease diagnosis Treatment planning	Automated target identification	Anonymize personal information	Immersive media experiences	Enhance parental bonding
Financial and Information Security Applications	Processes	Pre-training system for self-learning agent	Predicting failure in devices	Network optimization	Examination of financial credit using artificial neural network	Developing and deploying anomaly detection systems	Communication efficient machine learning of data	Robust deep generative models	Generating synthetic point cloud data	Detecting undetected network intrusion types
	Market-driver	Adapt and optimize performance	Predictive maintenance Fault prediction	Improve performance, reliability, and security	Evaluate creditworthiness Mitigate financial risks	Cybersecurity threats	Efficient communication protocols	Integration of robustness techniques	Risk assessment Asset valuation	Cyber threats Malware attacks
Cyber-Physical Systems	Processes	Fine-tuning AI models	Enhancing images	Modifying responses to improve accuracy	Abstracting characteristics of cyber-physical systems	Reading computer files	Directional recommendations (activity tracking)	Predicting device maintenance	Generating synthetic data	Conversation curator system for structured interactions
	Market-driver	Cybersecurity threats	Improve clarity and resolution	Enhancing system performance Enhancing user satisfaction	Optimization Fault detection	Automated data analysis	Personalized recommendations Navigation assistance	Forecast device failures Schedule maintenance	Robust training Validation of AI models	Structured interactions Dialogue management
		Near Future (0-2 years)			Mid-Future (2-5 Years)			Far-Future (5-10 years)		



In the mid-future (2–5 years), object detection and identification using GenAI can focus on developing a robust platform by utilizing LLMs to integrate business workflows. GenAI algorithms can also predict and preempt time delays, leading to faster response rates. The medical advancements leveraging GenAI can prioritize scalability and efficiency, transforming various aspects of healthcare delivery. GenAI advancements, including depression diagnosis interviews, electronic medical record-entity recognition, and speech recognition, will also drive improvements in mental health screening. In the mid-future, developments in intelligent, GenAI conversational agents will focus on data co-clustering and persona-based dialogue modeling. User interfaces that generate facial expressions can make interactions with conversation agents more insightful and immersive.

In image generation and processing, the focus is likely to be on overcoming key challenges and meeting user requirements. Enhancing facial recognition to identify exact facial orientations will improve security and user authentication systems. Advancements in medical image segmentation can help in the precise delimitation of functional structures for disease identification and treatment planning. Additionally, the development of an automated target identification system can enhance situational awareness, which has applications in various industries, including defense and surveillance. Mid-future advancements in financial and information security applications include processes such as credit examination, variance detection, and communication-efficient machine learning. Financial credit investigation using ANNs can streamline lending decisions and mitigate financial risk. Communication-efficient machine learning techniques can further facilitate collaborative data analysis and decision-making to enhance the security and efficiency of the financial and information systems in the mid-future.

Mid-future developments in the cyber-physical system can focus on reading computer files and providing directional recommendations based on activity tracking. Using GenAI to read computer files will automate data analysis, streamline information processing tasks, and accelerate decision-making processes. Abstracting characteristics of cyber-physical systems can enable optimization and fault detection. In addition, directional recommendations based on activity tracking will offer personalized guidance and navigation assistance. These advancements can enhance the functionality, efficiency, and user-friendliness of cyber-physical systems.

In the far future (5–10 years), developments in object detection and identification using GenAI can focus on achieving enhanced levels of accuracy and reliability. Automated visual inspection will enable the detection of defects and variances, improving quality assurance efficiency. Synthetic human fingerprints will transform biometric security solutions, offering more secure authentication mechanisms in both physical and digital spaces. Additionally, the development of service robots based on advanced object identification and detection capabilities can redefine human–robot interaction with potential applications across a variety of industries, including healthcare and elder care. Other medical applications of GenAI will focus on achieving precision, personalization, and proactive healthcare management. The generation of protein sequences, disease prognosis evaluation, and early warning prediction of diseases, can drive innovation in diagnosis, treatment planning, and preventive medicine. Additionally, the systems enabling the formation of fetal care will reshape prenatal care, enhance bonding, and increase emotional connections during pregnancy.

Far-future developments in intelligent conversational agents that leverage GenAI can help develop a system capable of seamless task switching and handover between multiple conversational agents. This enhanced interoperability and coordination will enable the agents to address complex user queries more efficiently. Further, conversational interfaces for application programming interfaces (APIs) can redefine how users interact with the system, simplifying API interactions. GenAI techniques will bring rapid advancements in

visual data interpretation and manipulation to image generation and processing. The de-identification of personal information will place a focus on maintaining privacy and maximizing the utility of images. Further, transforming 2-D images into an immersive Skybox environment can redefine the virtual and augmented reality (VR/AR) experiences, fostering greater engagement and interactivity.

Advancements in financial and information security applications in the far future will focus on robust deep-generative models, detecting previously undetectable types of network intrusion, and generating synthetic point cloud data. Developments in detecting network intrusion types will be crucial in identifying and mitigating cybersecurity threats and malware attacks. Further, the generation of synthetic point cloud data can serve as a risk evaluation tool, defending against financial losses. Finally, the cyber-physical system advancements in the far future can focus on predictive device maintenance, synthetic data generation, and the implementation of conversation systems for structured interactions. Predictive device maintenance through advanced algorithms can predict device failures and schedule routine maintenance tasks, improving operational efficiency and reducing equipment downtime. The generation of synthetic data can facilitate the robust training and validation of developed models, ensuring accuracy and reliability. Conversation curator systems can facilitate structured interaction between users and cyber-physical systems, leading to more efficient dialogue management and fostering collaboration between users and systems.

### Implications

Understanding the practical implications of GenAI applications is important for all stakeholders, including developers and industry practitioners. Stakeholders should optimize resource allocation, foster industry adoption, and enhance decision-making. By understanding the key GenAI topics identified in this study, practitioners can recognize potential applications for exploration in the near, mid, and far future. Integrating the development and advancements of new GenAI-based services and products can help firms gain a competitive advantage.

Object detection and identification systems can be implemented across myriad sectors, including manufacturing, transportation, and security. These systems can help streamline processes, enhance safety, and improve efficiency in tasks related to inventory management, autonomous driving, and surveillance. Medical practitioners interested in GenAI should focus on personalized medicine, early disease detection, and effective healthcare management. AI-driven advancements in healthcare and medicine can enhance diagnostic accuracy and treatment efficacy, benefiting both patients and healthcare practitioners.

In addition, practitioners can focus on developing intelligent conversational agents that can generate human-like responses, generate customized content, and are capable of switching between multiple conversational agents. Image generation and processing advancements have the potential to improve content creation, medical imaging, and AR/VR experiences. Practitioners in the field of financial and information security can focus on the development of systems that detect intrusions and anomalies and safeguard sensitive data. Finally, cyber-physical-system practitioners can focus on device maintenance, generating synthetic data, and implementing conversation curator systems for structured interactions.

The study provides insights into the interdisciplinary nature of GenAI applications, enriches scholarly discussion, and shapes the trajectory of GenAI research (Cook et al., 2024; Eapen et al., 2023; Roppelt et al., 2024a). By refining the GenAI model for feature extraction, anomaly detection, and domain adaptation techniques, scholars can deepen their understanding of object recognition in various contexts. Further, the implications of GenAI in medicine are multifaceted, including decision-making and ethical considerations (Roppelt et al.,

2024b). Theoretical advancements include the integration of AI into medical health records while maintaining patient privacy, as well as AI-powered therapies (Kanbach et al., 2024). Scholars can integrate emotional intelligence into conversational interfaces to provide empathetic interactions with users (Haupt et al., 2024). Researchers can refine GenAI models for realistic image synthesis and manipulation and study the societal implications of immersive technologies. Finally, researchers can contribute to the development of resilient cybersecurity measures and ethical considerations surrounding financial security and data privacy.

## Conclusion

The study has generated a roadmap of developments in GenAI applications through a patent-based text-mining approach, identifying six key application areas (and their relative proportions), including object detection and identification (12.7 %); medical applications (14.6 %); intelligent conversational agents (13.9 %); image generation and processing (21.7 %); financial and information security applications (22.8 %); and cyber-physical systems (14.3 %). The study listed emergent topic terms for each identified application area. For object detection and identification, for instance, emergent topic terms included “image,” “resolution,” “vehicle,” “embodiment,” “generative adversarial network,” “product,” “component,” “damage,” “roadway,” and “detector.” Similarly, the emergent topic terms for cyber-physical systems included “model,” “device,” “controller,” “generative adversarial network,” “information,” “target,” “signal,” and “process.”

All inter-topic correlations were negative, indicating that none of the documents in the corpus contained equal references to any two topics. The topics of medical applications, intelligent conversational agents, and cyber-physical systems were identified as emerging topics with increasing patent trends. Finally, a technology roadmap was prepared for the identified application areas (i.e., topics) in the near (0–2 years), mid (2–5 years), and far future (5–10 years). The findings of this study underscore the transformative potential of GenAI across various industries and sectors. The implications for theory and practice are enormous, from revolutionizing healthcare delivery to enhancing cybersecurity measures to improving user experience through intelligent conversational interfaces.

The study contributes to the existing literature in three ways. First, the results add to studies on technological forecasting and roadmapping. By analyzing patent data, this study presents a roadmap of GenAI advancements across a variety of sectors. Furthermore, the study extends the current literature on AI by integrating it with roadmapping practices. Second, while traditional roadmapping methodologies rely heavily on expert opinions, this comprehensive overview of the GenAI landscape is data-driven. Third, the findings of this study can assist decision-makers in AI research and development to allocate resources in promising directions.

Although this study provides valuable insights for the characterization of GenAI applications, it has a few limitations. First, the study used the text-mining approach to classify the patent data, which might introduce some biases in the results. Incorporating qualitative methods such as expert interviews and case studies into future studies can provide deeper insights into the practical implications and theoretical underpinnings of GenAI applications. Second, the study only utilized patent data and thus did not include GenAI enhancements that have not been patented by a firm or individual. Future researchers can use a wider variety of data sources, such as prior research, industry reports, academic publications, and market studies, to validate the findings of the study. Overall, this study has highlighted the application of GenAI across different sectors and provides a roadmap for the near, mid, and far future. This study offers valuable insights that can shape the future trajectory of GenAI-based technologies.

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## CRediT authorship contribution statement

**Shiwangi Singh:** Writing – review & editing, Writing – original draft. **Surabhi Singh:** Writing – review & editing, Writing – original draft. **Sascha Kraus:** Writing – review & editing, Writing – original draft. **Anuj Sharma:** Writing – review & editing, Writing – original draft. **Sanjay Dhir:** Writing – review & editing, Writing – original draft.

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