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Artificial Intelligence Applications in Natural Gas Industry: A Literature Review

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Abstract: ***One of the more controversial uses of artificial intelligence (AI) in the petroleum industry has been in technological advancement. The gas business generates data constantly from several operational procedures. The gas sector is now very concerned about recording this data and using it appropriately. Making decisions based on inferential and predictive data analytics facilitates timely and accurate decision-making. The gas industry is experiencing a significant increase in the use of data analytics for decision-making, despite numerous obstacles. Considerable progress has been made in the aforementioned field of study. With the use of artificial intelligence (AI) and machine learning (ML) techniques, many complicated issues may now be resolved with ease. This study, which examines artificial intelligence applications in the natural gas sector, collected its data from various sources between 2005 and 2023. The current work may provide a technical framework for selecting relevant technologies that enable efficient information extraction from the vast amount of data generated by the gas industry.***

Keywords: Artificial Intelligence, Applications, Gas Industry, Machine Learning Models, Natural Gas

I. INTRODUCTION

With the introduction of artificial intelligence (AI) technology, the natural gas sector—a vital part of the world's energy landscape—has seen tremendous changes in recent years [1, 2]. The optimization of several facets of the natural gas value chain, from distribution and consumption to exploration and extraction, has been greatly aided by AI technologies [3, 4]. It involves generating new ideas on how to approach research, development, production, transportation, refining, and sales, starting with the early stages of the process and ending with the end user [5, 6].

Artificial intelligence (AI), in all of its integrated forms—from fuzzy logic to neural networks to genetic optimization—has come a long way in the past few years and is starting to gain traction in the gas sector [7].

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It's becoming evident from recent advances in the gas upstream sector that the petroleum industry has grasped the enormous potential that intelligent systems present [8, 9]. Furthermore, a vast quantity of data, including critical and essential information, is now accessible due to the introduction of new sensors that are permanently installed in the wellbore [10]. To fully utilize these inventive hardware instruments, an operator must handle the software to process data in real time [11]. The only practical methods for enabling real-time analysis and decision-making capabilities on the new hardware are intelligent systems [12].

Models used in traditional petroleum extraction techniques fall into three categories: mathematical, physical, and empirical, according to Thanh et al. [3]. The empirical model is founded on experimentation and observation, while the mathematical model depends on the conservation of momentum, energy, or mass [13, 14, 22]. Due to the limitations of mathematical models under different operating conditions and the imprecision of models derived from empirical modelling, these models necessitate certain assumptions and are unable to manage complicated relationships, noise, and incomplete data [15, 16, 17]. This study examines the application of artificial intelligence (AI) in the natural gas industry, drawing on studies that support data-driven decision-making. The applications of machine learning modelling and the analytical modelling tools utilized in the gas industry [21]. This publication presents the latest research on the application of AI approaches in the gas upstream industry. This paper's primary goal is to demonstrate the benefits of AI approaches across several gas industries. Based on a methodical comprehension of this sector, the article outlines procedures that employ AI to facilitate efficient computing and decision-making. This study examines the potential collaboration between an intelligent system and the gas sector to enhance efficiency and productivity.

II. METHODOLOGY

Using the databases SpringerLink, Elsevier, PubMed, and Google Scholar, a review of relevant research publications published between 2005 and 2023 was conducted. The substantial increase in articles in the database, along with the close relationship between these articles and the gas industry sector, served as the driving forces behind choosing this bibliographic system as the primary source of data. The search terms "machine learning," "AI," "natural gas," and "gas industry" were among them. Boolean operators (AND, OR) were used to carefully combine these phrases, generating a highly focused and thorough search strategy.

After that, an objective dataset of articles was created by combining the individual datasets. Every reference mentioned in the datasets was thoroughly examined. Lastly, a thorough search of the reviewed articles' bibliographies was conducted to identify titles relevant to the study's primary topic.

The inclusion criterion—which required that papers be published in English—emphasized the review's dedication to accessibility and comprehensiveness. By considering articles published between 2005 and 2023, the systematic review was able to incorporate the most current and relevant research in the field. To aid in the classification of research based on its common and unique qualities, the final collection of papers was divided into multiple categories. The subcategories were combined and adjusted during the systematic review process to allow for the integration of data. After the relevant articles have been retrieved from the databases. The titles, abstracts, and full-text reads were used to evaluate the papers. Ultimately, 15 papers were selected for additional screening and quality assessment.

III. RESULT

Fifteen papers in total were included in the review (Table I). Numerous crucial management concerns have been examined regarding the deployment of AI approaches in the gas sector. To summarise the most recent contributions and the outcomes detailed in the reviewed publications, apply the following suggested AI strategies in the gas business in this section.

Table I: Summary of the Studies

No.	Author and Years	Aim	Model	Key Findings
1	(Ghahfarokhi et al., 2018)	Gas production using DTS data	Machine learning, fiber-optic system	▪ Neural network accuracy is less affected by stages with more fluctuation in DAS energy, which indicates less efficient stimulation.
2	(Ali, 2021)	Novel deliverability prediction models for underground natural gas storage	Machine learning algorithms	▪ The study's machine learning models can be valuable instruments for forecasting UNGS deliverability in salt caves with varying capacities.
3	(Aramesh et al., 2014)	Predict the transmission of natural gas (NG)	Neural and fuzzy-neural algorithm	▪ Technique reduces the expense of building a new prediction model for every station
4	(Bai & Li, 2016)	Forecast of natural gas (NG) consumption	Support vector regression approach	▪ The SC-SVR approach can increase forecast accuracy for daily NG consumption due to the nonlinear mapping capabilities of SVR and the dynamic nature of online calibration for the model structure.
5	(Curin et al., 2021)	Operation plans of underground natural gas storage facilities	Deep learning	▪ Intrinsic complexity resulting from the high-dimensional forward market and several limitations
6	(Demirel et al., 2012)	Natural gas consumption forecasting	Neural networks	▪ Since most purchasing agreements are based on predictions, accurate forecasting of natural gas consumption is vital.
7	(Khosravi et al., 2018)	to predict the natural gas density at natural gas pressure	Artificial intelligence	▪ ANFIS-GA and GMDH models performed better than the FIS, MLFFNN and ANFIS models.
8	(Manan et al., 2021)	Failure classification in natural gas	Artificial Neural Networks, Support Vector Machine	▪ The training models are used to predict the testing dataset, and their performance is evaluated.
9	(Mann & Ayala, 2009)	Underground natural gas storage facilities	ANN technology	▪ ANN technology intelligent system is capable of understanding the intricate relationships between input parameters and output responses.
10	(Sanjari & lay, 2012)	Prediction of the compressibility factor of natural gas	Artificial neural network (ANN)	▪ Artificial neural network's correctness has been compared with the most widely used empirical models, Peng-Robinson equations of state, and statistical association fluid theory.
11	(Soldo, 2012)	The area of forecasting natural gas consumption	Artificial intelligence (AI)	▪ Yearly data on the production of fossil fuels, and following the plotting of production over time curves.
12	(Soldo et al., 2014)	Natural gas is supplied in distribution systems	Solar radiation	▪ Solar radiation affects natural gas consumption, and the forecasting model performs better when it takes solar radiation into account as an input variable.
13	(Szoplik, 2015)	Forecasting of the gas demand	Artificial neural networks	▪ predictions made using MLP models that varied in the quantity of the training dataset.
14	(Taşpınar et al., 2013)	Forecast short-term natural gas consumption	ANN	▪ The algorithm generates positive and significant results when used to forecast short-term natural gas usage.
15	(Thanh et al., 2022)	To predict underground natural gas storage deliverability	Hybrid artificial intelligence models	▪ Utilise nature-inspired strategies to predict the deliverability of storage sites.

A. Artificial Intelligence (AI) in the Gas Industry

Algorithms used in machine learning and deep learning are black boxes because it is difficult to determine why or how they operate in systems that depend on them [1, 7]. There are incredibly intricate multi-dimensional algebraic expressions in these methods [6, 9, and 10]. The definition of the coefficients in these expressions fits the input and output data that describe the object, system, or process [3].

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The algorithms can produce original insights based on fresh inputs once they have been trained on known data [4]. Furthermore, there are industrial uses for hybrid modelling, which combines the use of machine learning techniques with physics-driven models.

There are two types of hybrid models: physics-dominated and data-dominated [13]. In hybrid models dominated by physics, machine learning is used to adapt the equation's coefficients to the actual data generated by an item of interest. On the other hand, with data-dominated hybrid models, the physics-driven model produces a large amount of training data that the machine learning model uses to comprehend the physics of the issue and help resolve it [15]. Ultimately, AI planning is being used for the first time in the gas industry [2]. AI planning is the process of organising specific actions to achieve a goal using a combination of machine learning and optimisation techniques. Intelligent agents, autonomous robots, and crewless vehicles usually carry out these actions [10].

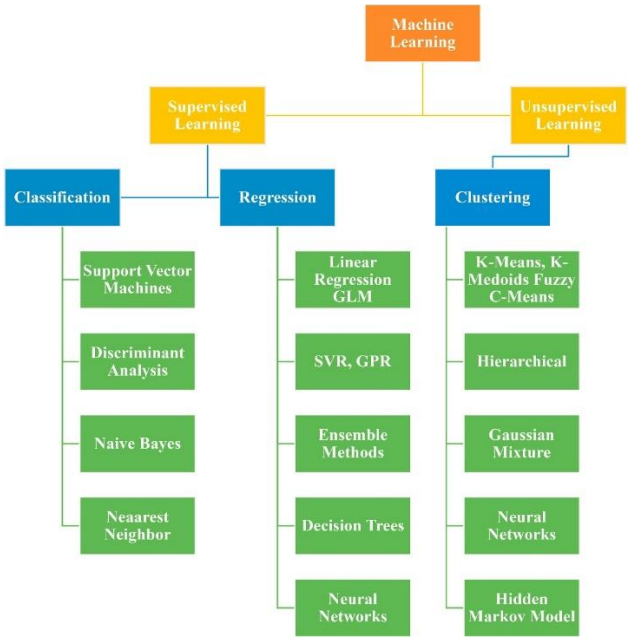

Fig. 1. AI in Gas Industry [7]

B. Forecasting Gas Consumption

To simulate the gas network and control the flow of gas through it, it is essential to know the quantity of natural gas consumed, also known as the load on the gas network [6]. Approximately 28% of Poland's gas consumption structure is shaped by municipal users. It appears that regression models are a more sophisticated and precise method of estimating gas consumption [7]. Geem put into practice a linear regression model based on GDP, population size, import and export values, and four other economic variables [15]. The system of points is only partially linear, as Figure 2 illustrates [10]. Gas consumption is constant at around 15 °C and decreases with decreasing temperature below approximately. 15 °C, at which point the value of gas consumption increases directly proportionately. Even though the temperature continues to drop, consumption does not grow after reaching a certain maximum [13].

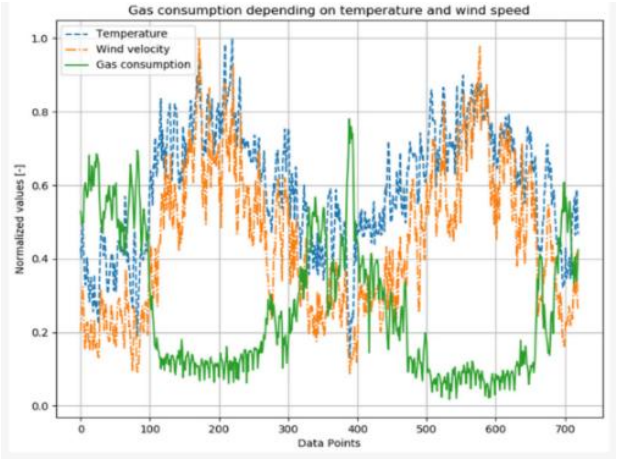

Fig. 2. Natural Gas Consumption [10]

C. Predicting Gas Production

A model was developed to predict the density of natural gas as a function of temperature, pseudo-reduced pressure, and the gas's apparent molecular weight [1]. Their findings showed that the created model can accurately forecast natural gas density across a broad temperature and pressure range [9].

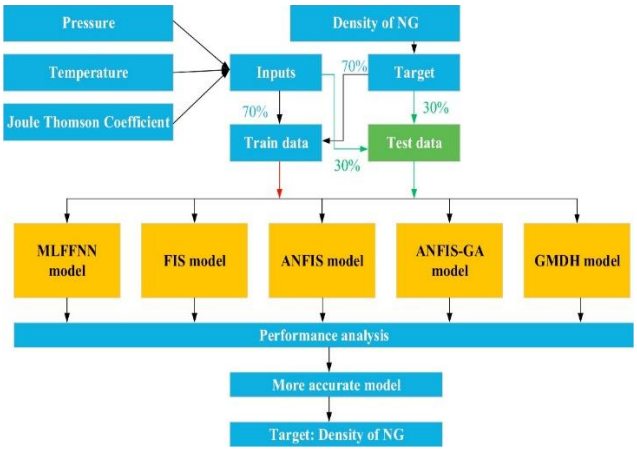

Fig. 3. Prediction of Natural Gas Density [7]

The ability of artificial neural networks (ANN) to effectively identify incredibly complex patterns without assuming anything about the data being investigated has led to an increase in ANN popularity [3]. Without clearly specifying the link between input and output parameters, ANNs offer a flexible solution for regression and classification problems (Table II). Because neural networks have been applied to many different disciplines of research, they provide a wide range of uses [14, 23]. The proposed model for determining the mass flow rate of natural gas is schematically shown in Fig. 4. As seen in the figure, the mass flow rate of natural gas is calculated by the volume corrector using the density of natural gas, which is ascertained by the optimal model of the proposed artificial intelligence techniques, along with the volume flow rate value received from the volume flow meter [7].

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The temperature and pressure recorded before and after the throttle valve are compared to determine the standard deviation of the temperature, strain, and JT coefficient of determination [15].

Table II: Dynamic Inputs for the Neural Network [8]

Inputs	Outputs
Upscaled DTS (t-1) for stages 1 to 28	Gas production (t)
Flowing time (t-1)	

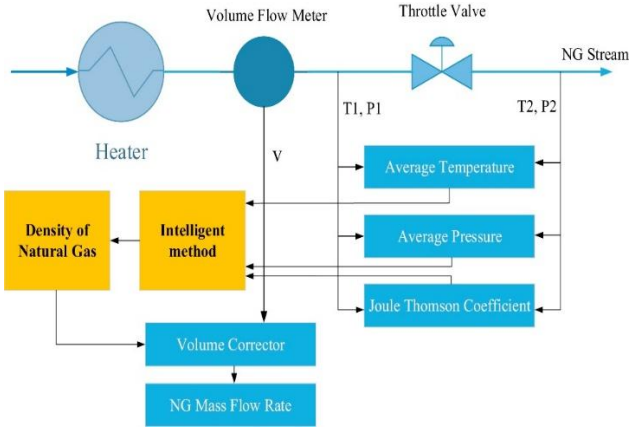

Fig. 4. Predict the Density of Natural Gas [7]

In particular, it has been demonstrated that they can enhance sparse data in engineering and geology to improve reservoir modelling performance. Data mining methods for assessing production from shale [9]. A more recent work [5] demonstrated the use of machine learning in the Marcellus Shale to categorise hydraulic cracks. The estimate for reservoir output has also been applied to several non-traditional Shales. The study demonstrates that gas production from an unconventional shale resource can be predicted using a continuous stream of fibre optic data (DTS). Downhole temperature is a dynamic metric that varies with production at every stage, as demonstrated by Ghahfarokhi [1]. A production log for a single day does not represent stages of production in the modern sense.

Stage number	Sensitivity analysis error difference	DAS variance	Production log (MCF/d)
28	33.2344	0.084507042	50
27	29.4075	0.481690141	84
26	28.782	0.430985915	67
25	22.5155	0.346478873	158
24	27.5071	0.295774648	192
23	24.355	0.43943662	272
22	26.774	0.346478873	389
21	27.304	0.194366197	198
20	32.8965	0.566197183	99
19	32.5699	0.21971831	119
18	30.7536	0.109859155	231
17	34.4187	0.016901408	250
16	21.8756	0.38028169	378
15	18.7224	0.464788732	59
14	23.611	0.236619718	203
13	23.4141	0.185915493	268
12	17.5225	0.785915493	242
11	23.0408	0.549295775	316
10	13.6376	0.667605634	190
9	16.8706	0.228169014	167
8	24.5391	0.684507042	153
7	23.6815	0.473239437	142
6	26.5018	0.718309859	256
5	17.5871	0.709859155	310
4	16.3985	0.709859155	75
3	25.8073	0.43943662	58
2	21.2219	0.532394366	256
1	-10.5889	0.701408451	251

Fig. 5. DAS Variance and Production

D. Artificial Intelligence in Natural Gas Industry Advantages

By analysing sensor and equipment data, artificial intelligence (AI) can forecast when maintenance is required, saving downtime and averting expensive equipment breakdowns [7]. Ensuring the integrity of natural gas infrastructure is imperative. From production to distribution, natural gas plants can operate more efficiently thanks to the use of AI algorithms. This entails controlling storage, optimizing supply chain logistics, and raising general operational effectiveness [14]. Through real-time equipment status monitoring, possible hazard identification, and early warning of safety issues, artificial intelligence (AI) can improve safety. This can guarantee worker safety and help prevent accidents [12]. AI systems can optimize energy trading and pricing methods by analyzing geopolitical issues, market trends, and demand-supply dynamics [1]. Businesses in the natural gas industry may benefit from better decision-making and increased profitability as a result [4]. AI can be utilised to optimise natural gas resource discovery and production by analysing seismic data, modelling reservoirs, and enhancing drilling operations. This can lower exploration expenses and improve resource recovery [9, 24]. AI can help in managing and monitoring the environmental impacts of natural gas production. This includes monitoring emissions, making sure environmental laws are followed, and putting sustainable policies into action [5].

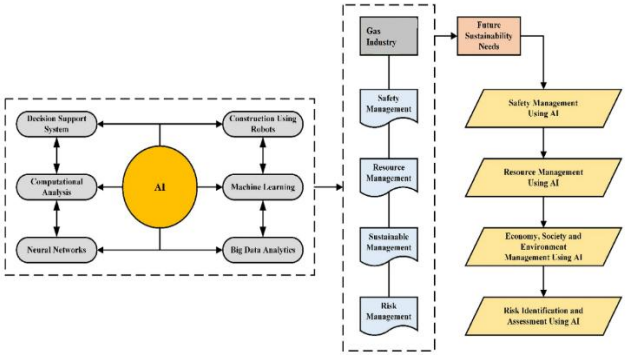

Fig. 6. DAS Variance and Production [2, 5, 9, 11, and 13]

E. Challenges

Reliable and precise data are essential for training and making decisions in AI algorithms. Integrating data from several sources, guaranteeing its accuracy, and managing legacy systems might present difficulties for the natural gas sector [1, 4]. When implementing AI solutions, compliance concerns must be carefully considered, and AI applications must ensure they abide by industry rules and laws. The growing prevalence of AI applications necessitates that the sector tackle the heightened danger of cyber risks [8]. Ensuring the security and integrity of natural gas operations requires safeguarding AI models and sensitive data against cyberattacks [10]. The up-front costs associated with implementing AI technologies may be high for infrastructure, development, and training.

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Artificial intelligence (AI) in the natural gas sector may give rise to ethical questions, especially about employment displacement, privacy concerns, and responsible technology use [11, 25]. The processes involved in natural gas operations are complex, and they require specialist knowledge to design AI systems that can effectively handle their complexity. Acquiring and maintaining proficient AI experts could be difficult [13].

IV. RECOMMENDATIONS AND LIMITATIONS

The suggestions presented in this study, based on the theoretical framework, are highly beneficial in guiding and resolving potential issues in subsequent research. From the perspective of addressing the research gap, the study contributes by providing upcoming scholars with the theoretical knowledge required to implement a robust technique for advancing artificial intelligence technology in environmentally friendly gas project development. Artificial intelligence technologies hold considerable promise for shaping a safer, more sustainable, and productive future when integrated into the natural gas sector. Businesses in the natural gas industry need to adopt these advances as technology develops further in order to remain competitive and meet the demands of a fast-shifting energy market [16, 17, and 18]. Through the application of artificial intelligence (AI) in the areas of supply chain optimization, smart grids, safety, improved exploration, and predictive maintenance, the natural gas sector may more adeptly and resiliently manage the challenges posed by future energy requirements [19, 20].

An analysis of the literature shows that the gas industry is well-positioned to benefit from machine learning, given its ability to process massive amounts of data quickly and efficiently. This research has identified and examined a wide range of monitored learning strategies. Machine learning can significantly impact the critical decisions that engineers and administrators in the gas industry make on a daily basis. Information can be beneficial in the future if appropriate techniques are used to combine different data types or structures and convert them into insightful knowledge that aids in making informed decisions. The study has helped establish a theoretical framework, based on a comprehensive review of the existing research on artificial intelligence and its implications for the sustainable development of gas projects. From the standpoint of constraints, it is clear that there are fewer publications in the databases used for research evaluation than in the total amount of research on gas and AI projects. In the long run, a variety of databases will be necessary to enhance both the qualitative and quantitative understanding of AI's impact on sustainable development. Though it does not fully represent the body of literature involving research on AI and gas projects, the study is also pertinent to the journal articles. Future researchers will find these constraints to be great opportunities to concentrate their efforts on refining the research findings and increasing the sustainability of oil and gas operations.

V. CONCLUSION

As the idea spreads throughout the gas industry, the use of artificial intelligence (AI) is currently accelerating. This includes intelligent drilling, intelligent improvement, intelligent pipelines, smart processing, and so forth. It will eventually be a fruitful field of study as well. Developers have created a wide range of practical application capabilities in both development and manufacturing by utilizing artificial intelligence algorithms. Developers have created a wide range of practical application innovations in both studies and manufacturing by using artificial intelligence algorithms. Exploration risks have already decreased, and well success rates have increased as a result of implementing the ANN technique. These are positive results.

DECLARATION STATEMENT

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Conflicts of Interest	No conflicts of interest to the best of our knowledge.
Ethical Approval and Consent to Participate	No, the article does not require ethical approval or consent to participate, as it presents evidence that is not subject to interpretation.
Availability of Data and Material/ Data Access Statement	Not relevant.
Authors Contributions	All authors have equal participation in this article.

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AUTHORS PROFILE

Siddhartha Nuthakki is an Azure and IBM-certified data scientist with over 7 years of experience in building and delivering cutting-edge AI/ML solutions. Proficient in programming languages such as Python, R, and Scala, he specialises in big data technologies, including Azure, Databricks, and AWS. With expertise in machine learning algorithms, NLP, deep learning, and graph technologies, Siddhartha has a proven track record of developing innovative solutions for healthcare and client industries. He holds a Master's in Applied Data Science and Health Informatics, complementing his Doctor of Pharmacy degree, and is recognized for his contributions with multiple awards and certifications.

Chinmay Shripad Kulkarni is a data science professional with a strong foundation in deploying distributed and scalable machine learning solutions across cloud platforms, including AWS and GCP. His experience spans over five years, including impactful roles at DocuSign and Waymo. He has engineered pivotal models and tools to enhance operational efficiencies—from customer health scoring to collision evaluation and ROI tools for agricultural applications. My academic journey in Data Science and Business Analytics, which I undertook at the University of Cumberlands and Fordham University, has equipped me with the theoretical knowledge and practical skills necessary to excel in this dynamic field.

Suraj Kumar is a Lead Data Scientist, where my passion for data science powers product innovation and impactful outcomes. His journey has taken him through roles at Walmart, Intuit, and Realtor.com, where he has specialised in experimentation and product analytics. At Walmart, he explored consumer behaviours to refine shopping experiences, thereby boosting engagement and sales. At Intuit, he used data to tailor financial tools, making complex decisions more straightforward for users. Realtor.com noted that he was merging real estate trends with digital preferences to enhance property searches. His mantra is simple: listen to the data, iterate based on insights, and always aim for products that are not just better, but are also more intuitive and aligned with user needs.

Satish Kathiriya is a seasoned software engineer with a robust 9-year tenure in the tech industry, currently enhancing the technological landscape at Amazon. His expertise spans AI, machine learning, and large-scale distributed systems, reflecting a career marked by significant contributions to leading corporations, including Walmart and J.P. Morgan & Chase. Presently, Satish delves into the groundbreaking domain of generative AI, where his innovative work continues to push the boundaries of technology. His diverse experience across various domains showcases his adaptability and commitment to driving advancements in the ever-evolving field of software engineering.

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Yudhisthir Nuthakki is a seasoned Software Engineer and Technical Lead/CRMA Architect with over 8 years of experience in designing and implementing advanced analytics solutions using Salesforce CRM Analytics. Specialising in the entire CRM Analytics development lifecycle, Yudhisthir has a proven track record of creating data-driven solutions that empower organisations to make informed decisions, optimise processes, and drive business growth. Proficient in data modeling, integration, and the deployment of Einstein Discovery for predictive analytics, Yudhisthir has successfully led CRM Analytics implementations, ensuring seamless integration and customization to meet specific business requirements.

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