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# Modelling And Simulation Of Gas Stations: A Systematic Literature Review And Bibliometric Analysis

**Abdulfatai, T. A., Ganiyu, R. A. and Omidiora E. A.**

*Department of Computer Engineering, Ladoke Akintola University of Technology, Ogbomoso, Nigeria*

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***Corresponding Author:***
thaobanabdulfatai@gmail.com

**ABSTRACT**

***Gas stations play a critical role in transportation and energy distribution systems, necessitating efficient operational strategies to improve service quality and resource utilisation. This study presents a systematic literature review and bibliometric analysis of modelling and simulation approaches applied to gas station systems. The review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework. Literature published between 2010 and 2025 was retrieved from five scientific databases: Google Scholar, IEEE Xplore, ScienceDirect, SpringerLink, and Scopus. A total of 186 records were identified, 24 duplicate records were removed, and 33 studies satisfied the inclusion criteria for qualitative synthesis. The reviewed studies were categorised into queueing theory, discrete event simulation, Petri net-based models, system dynamics, and intelligent and hybrid approaches. The findings reveal a transition from conventional analytical methods towards intelligent, data-driven, and integrated modelling frameworks. Petri net-based approaches demonstrate superior capabilities for modelling concurrency and synchronisation, whereas intelligent and hybrid techniques show significant potential for enhancing operational efficiency and decision-making. The study identifies key research gaps, highlights emerging research trends, and provides practical directions for developing intelligent, integrated, and sustainable gas station systems.***

## INTRODUCTION

Gas stations constitute an essential component of transportation and energy distribution systems, providing fuel and related services that support economic and societal activities. The increasing number of vehicles and growing demand for efficient service have necessitated the development of effective operational strategies aimed at improving customer satisfaction, reducing waiting times, and enhancing resource utilisation (Farzaneh-Gord *et al.,* 2013; Masoud *et al.,* 2016). Consequently, gas station operations have attracted considerable attention from researchers seeking to analyse and optimise system performance. Modelling and simulation techniques have emerged as indispensable tools for investigating the behaviour and performance of complex systems by providing valuable insights into customer arrival patterns, service mechanisms, queue lengths, throughput, and resource allocation without disrupting actual operations (Murata, 1989; Jensen and Kristensen, 2009). These techniques also facilitate informed decision-making by enabling the evaluation of alternative configurations and operational policies under varying operating conditions.

Several modelling techniques have been employed to analyse gas station systems. Queueing theory has been widely adopted because of its strong mathematical foundation and ability to evaluate service performance (Khan and Hussain, 2013; Adele and Edeh, 2019), while discrete event simulation has become one of the most popular approaches due to its capability to represent stochastic events and dynamic interactions within gas station environments (Moazzami*et al.,* 2013;

Hawari *et al.,* 2025). Petri net-based approaches have also demonstrated significant capabilities in modelling concurrency, synchronisation, and hierarchical structures in complex systems (Jensen, 1997; David and Alla, 2005). Furthermore, emerging approaches involving intelligent systems, multi-agent systems, optimisation techniques, system dynamics, and hybrid frameworks have contributed to improving operational efficiency and decision-making (Gubbi *et al.*, 2013; Altayeb, 2025). These developments underscore the growing importance of modelling and simulation as effective tools for enhancing the performance and sustainability of gas station operations.

Despite these developments, existing studies remain fragmented and predominantly focused on isolated operational components, such as vehicle queue management, fuel dispensing, or payment processes. Most previous investigations have concentrated on individual modelling techniques without providing a comprehensive comparison of their modelling capabilities, validation approaches, application domains, strengths, and limitations. In addition, limited attention has been given to the evolution of modelling techniques and emerging trends, particularly the integration of artificial intelligence, Internet of Things technologies, digital twins, optimisation methods, and formal modelling frameworks for intelligent gas station management. Existing review studies also provide limited bibliometric evidence for identifying influential research themes, collaboration patterns, and future research directions. Consequently, researchers and practitioners lack a comprehensive reference that synthesises current knowledge while identifying emerging opportunities for the development of intelligent, integrated, and sustainable gas station systems.

To address these limitations, this study integrates a systematic literature review with bibliometric analysis to comprehensively evaluate modelling and simulation techniques applied to gas station systems. Unlike previous review studies that primarily provide descriptive summaries of modelling approaches, this study comparatively analyses queueing theory, discrete event simulation, Petri net-based models, system dynamics, and intelligent and hybrid approaches based on their modelling characteristics, application domains, strengths, limitations, and research trends. The study also identifies emerging research directions and proposes future opportunities for integrating intelligent technologies with formal modelling techniques to support the development of next-generation gas station systems.

Accordingly, the main objective of this study is to systematically review and critically evaluate modelling and simulation techniques applied to gas station systems. Specifically, the study seeks to identify and classify modelling and simulation techniques used in gas station operations, compare their characteristics, strengths, limitations, and application domains, examine research trends and emerging developments through bibliometric analysis, identify existing research gaps and future research opportunities, and provide recommendations for the development of intelligent, integrated, and sustainable gas station modelling frameworks. To achieve these objectives, the study addresses the following research questions: What modelling and simulation techniques have been applied to gas station systems? What are the strengths, limitations, and application domains of the identified modelling approaches? What research trends and emerging themes characterise modelling and simulation studies on gas station systems? What research gaps remain, and what future directions should guide the development of intelligent gas station modelling frameworks?

By addressing these questions, this study provides a comprehensive systematic review of modelling and simulation techniques applied to gas station systems, presents a comparative evaluation of queueing theory, discrete event simulation, Petri net-based models, system dynamics, and intelligent and hybrid approaches using clearly defined analytical criteria, identifies research trends, emerging themes, and existing knowledge gaps through bibliometric analysis, and proposes future research directions for integrating artificial intelligence, Internet of Things technologies, digital twins, optimisation techniques, and formal modelling approaches to support intelligent gas station operations. The findings are expected to serve as a valuable reference for researchers, practitioners, and policymakers involved in the design, optimisation, and management of gas station systems.

## REVIEW OF RELATED WORKS

This section presents a critical review of existing studies on modelling and simulation of gas station systems. The reviewed literature was categorised into five major modelling approaches: queueing theory, discrete event simulation (DES), Petri net-based models, system dynamics, and intelligent and hybrid approaches. The approaches differ in their ability to represent customer queues, stochastic events, concurrency, resource sharing, feedback relationships, optimisation and intelligent decision-making. Therefore, the studies are comparatively evaluated based on their modelling techniques, application domains, strengths, limitations and identified research gaps in Table 1.

### Comparative Analysis of Modelling Approaches

**Table 1:** Comparative summary of the major modelling approaches identified in the reviewed literature.

| **Modelling approach** | **Representative authors** | **Modelling technique** | **Application domain** | **Strengths** | **Limitations** | **Research gaps** |
|---|---|---|---|---|---|---|
| **Queueing Theory** | Khan and Hussain (2013); Balaji (2017); Adeke *et al.,* (2019) | Queueing models for customer arrivals, waiting lines, service rates and service channels | Petrol/filling station operations, customer queues, fuel dispensing and service capacity | Provides quantitative analysis of waiting time, queue length, service rate and server utilisation; mathematically rigorous and relatively efficient for capacity planning | Relies on simplifying assumptions concerning arrival and service processes; limited representation of complex customer behaviour, concurrent activities, multiple service stages and interactions | Need for integrated models capable of representing stochastic, multi-stage and concurrent gas station processes |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | among shared resources | |
| **Discrete Event Simulation (DES)** | Khan and Hussain (2013); Moazzami *et al.,* (2013); Chaorui and Yuwen (2014); Masoud *et al.,* (2016); Monakhov (2016); Aksyonov *et al.,* (2020); Hawari *et al.,* (2025) | Discrete-event simulation of stochastic arrivals, service processes, resource allocation and operational scenarios | Petrol/gas station operations, fuel dispensing, customer flow, station layout, resource allocation and petroleum logistics | Flexible representation of stochastic events, dynamic interactions, resource constraints and alternative operating scenarios | Requires appropriate operational data and computational effort; model development, verification and validation can be demanding; limited formal analysis of system properties such as reachability and deadlocks | Need for integration with formal modelling, optimisation and intelligent technologies for complex and adaptive gas station operations |
| **Petri Net-Based Modelling** | Al-Hajri and Rossiter (2010); Mendes *et al.,* (2010); Liu *et al.,* (2022); Kang *et al.,* (2022); Li *et al.,* (2023); Abdulfatai *et al.,* (2025) | Petri Nets and extensions including Timed, Stochastic, Fuzzy, Coloured and Hierarchical Petri Nets | Industrial oil systems, gas leakage and emergency processes, hydrogen refuelling, natural gas systems and gas station operations | Represents concurrency, synchronisation, resource sharing and system states; supports formal behavioural analysis; extensions allow time, uncertainty, stochastic behaviour and hierarchical decomposition | Model construction can become complex as system size and interactions increase; specialised modelling knowledge and tools may be required | Need for more comprehensive models of complete gas station operations and greater integration with AI, optimisation, IoT and digital-twin technologies |
| **System Dynamics** | Rodrigues and Bowers (2011); | System Dynamics based on | Petroleum systems, fuel | Effective for analysing feedback | Relatively high-level representation | Need to link strategic/system-level |

| | | | | | | |
|---|---|---|---|---|---|---|
| | Farzaneh-Gord *et al.,* (2013); Fernandes *et al.,* (2013); Androutsopoulos and Zografos (2024) | feedback relationships, stocks, flows and dynamic interactions | distribution, supply chains, resource management and strategic planning | mechanisms, accumulations, resource flows and long-term system behaviour; useful for strategic and policy analysis | ; less suited to detailed discrete events, individual customer activities, service stages and concurrent operational processes | analysis with detailed operational modelling of stochastic and concurrent gas station activities |
| **Intelligent and Hybrid Approaches** | Gehlot and Nigro (2010); Aksyonov *et al.,* (2020); Choubey and Karmakar (2021); Okta *et al.,* (2023); Androutsopoulos and Zografos (2024); Talukdar (2025); Li *et al.,* (2025); Muhammad *et al.,* (2025) | Artificial intelligence, machine learning, optimisation, multi-agent systems, IoT, digital twins and hybrid modelling | Petroleum logistics, fuel distribution, gas station operations, intelligent transportation, predictive maintenance and data-driven decision support | Supports prediction, optimisation, adaptive decision-making and integration of data-driven information; hybridisation combines complementary modelling capabilities | Often data-intensive and computationally demanding; integration, interpretability and real-time implementation can be challenging | Need for integrated frameworks combining intelligent technologies with formal and operational modelling to provide comprehensive and adaptive gas station models |

**Critical Synthesis of the Modelling Approaches**

The comparison in Table 1 shows that the five approaches provide complementary capabilities rather than a universally applicable solution. Queueing theory is particularly suitable for quantitative analysis of waiting times, queue lengths, service rates and server utilisation, but its simplifying assumptions make it less effective for representing complex interactions, concurrent activities and multiple service stages. DES provides greater flexibility by representing stochastic events, customer arrivals, service processes, resource utilisation and interactions among system components. Studies have applied DES and related simulation techniques to customer flow, service processes, resource allocation, station layout and operational optimisation. However, DES generally requires substantial input data and careful verification and validation, while its conventional form provides limited support for formal analysis of properties such as concurrency, synchronisation, deadlock and state-space behaviour.

Petri net-based models provide a stronger formal representation of discrete-event systems involving concurrency, synchronisation, resource sharing and interacting components. The use of stochastic, fuzzy and hierarchical extensions has increased their capabilities to represent uncertainty, timing and complex system structures. In particular, Abdulfatai *et al.,* (2025) demonstrated the application of a Hierarchical Timed Coloured Petri Net to gas station processes, including customer flow, service operations and resource utilisation. Nevertheless, Petri-net model construction can become increasingly complex as the number of system components and interactions grows, while their integration with artificial intelligence, optimisation, IoT and digital twins remains relatively limited.

System Dynamics provides a different modelling perspective by concentrating on feedback relationships, accumulations and long-term system behaviour. It is therefore appropriate for strategic decision-making, resource management and supply-chain analysis. However, its relatively high level of abstraction limits its ability to represent detailed operational activities, individual customer movements and concurrent events within gas station systems.

Intelligent and hybrid approaches represent a more recent development in the literature. These approaches combine techniques such as artificial intelligence, machine learning, optimisation, multi-agent systems, Petri nets, IoT and digital twins to improve prediction, adaptability and decision-making. Recent studies demonstrate growing interest in AI- and IoT-driven intelligent gas stations and hybrid digital-twin frameworks. However, practical challenges remain concerning data availability, computational complexity, model interpretability and real-time implementation.

**Overall Research Gap**

The comparative analysis indicates that no single modelling approach simultaneously provides detailed operational representation, formal behavioural analysis, hierarchical decomposition and intelligent decision support. Queueing theory provides efficient analytical performance measures but has limited capacity for representing complex operational interactions. DES offers greater flexibility in representing stochastic and dynamic processes but provides less formal analysis of system behaviour. Petri nets provide strong capabilities for modelling concurrency, synchronisation, resource sharing and system states, although model complexity increases with system detail. System Dynamics is effective for strategic and long-term analysis but provides a relatively aggregated representation of operational processes. Intelligent and hybrid approaches provide opportunities for prediction, optimisation and adaptive decision-making, but their application is constrained by data, computational and integration requirements.

The reviewed literature also shows that many existing studies focus on isolated operational components, such as queue management, fuel dispensing, service optimisation or resource allocation, rather than providing comprehensive representations of gas station processes. Furthermore, the integration of stochastic behaviour, formal modelling, intelligent decision-making and real-time data analytics remains limited.

Consequently, there is a need for integrated modelling frameworks capable of representing the complete operational behaviour of gas station systems while capturing stochasticity, timing, concurrency, synchronisation, resource sharing and interactions among system components. Future modelling efforts should therefore explore the integration of formal approaches such as Petri nets with discrete-event simulation, optimisation, artificial intelligence, IoT and digital-twin technologies to achieve more comprehensive and adaptive representations of gas station operations.

## METHODOLOGY

The methodology adopted in this study comprised six major stages, namely research design, literature search, application of inclusion and exclusion criteria, screening and selection of studies, data extraction, and qualitative and bibliometric analyses. The overall procedure was designed to ensure transparency, reproducibility, and reliability in the synthesis of existing literature on modelling and simulation of gas station systems. Furthermore, the study selection process was guided by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework.

### Research Design

This study adopts a Systematic Literature Review (SLR) approach to provide a comprehensive and structured synthesis of existing studies on modelling and simulation of gas station systems. Unlike conventional narrative reviews, systematic literature reviews employ explicit and reproducible procedures for identifying, selecting, and analysing relevant studies, thereby minimising bias and improving the reliability of the findings (Kitchenham and Charters, 2007). In addition, bibliometric analysis was employed to identify prevailing research trends and the evolution of modelling approaches within the domain.

### Search Strategy

Relevant literature was retrieved from five major scientific databases, namely Google Scholar, IEEE Xplore, ScienceDirect, SpringerLink, and Scopus. These databases were selected for their extensive coverage of engineering, computer science, and operations research publications.

A combination of keywords and Boolean operators was employed to maximise the coverage of relevant studies. The search terms included:

- "Gas station simulation";
- "Petrol station modelling";
- "Fuel station simulation";
- "Gas station queueing system";
- "Discrete event simulation of gas stations";
- "Petri nets in service systems";
- "Gas station optimisation";
- "Simulation and performance analysis of petrol stations".

Studies published between 2010 and 2025 were considered to capture both foundational and recent developments in modelling and simulation techniques.

### Inclusion Criteria

Studies were included in the review based on the following criteria:

i. articles published in peer-reviewed journals or conference proceedings;
ii. studies written in English;
iii. publications between 2010 and 2025;
iv. studies focusing on modelling, simulation, optimisation, or performance evaluation of gas station systems; and
v. studies employing analytical, simulation-based, or hybrid approaches.

### Exclusion Criteria

Studies were excluded from the review if they:

i. were duplicate records obtained from multiple databases;
ii. were not written in English;
iii. consisted of editorials, books, theses, or unpublished manuscripts;
iv. addressed domains unrelated to gas station operations; or
v. lacked sufficient methodological information.

### Screening and Selection Process

The selection of studies was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework. Initially, 186 records were identified from the selected databases. After the removal of duplicate records, 162 studies remained for title and abstract screening. Subsequently, 56 articles were subjected to full-text assessment. Following the application of the inclusion and exclusion criteria, 33 studies were selected for detailed analysis and synthesis. Figure 1 presents the PRISMA-based procedure adopted for the identification, screening, eligibility assessment, and selection of relevant studies. A total of 186 records were initially obtained from database searches and other sources. After removing duplicate records and applying the inclusion and exclusion criteria, 56 articles were subjected to full-text assessment. Subsequently, 23 studies were excluded due to irrelevance, incomplete information, or methodological redundancy. Consequently, 33 primary studies were finally included in the qualitative synthesis and formed the basis of the review.

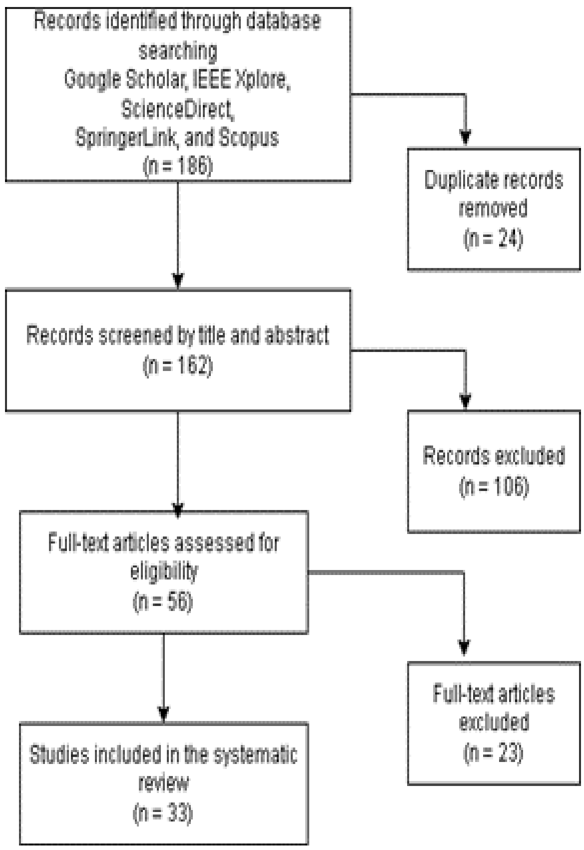


**Figure 1:** PRISMA flow diagram illustrating the study selection process

**Data Extraction and Analysis**

Information extracted from each selected study included the modelling technique employed, simulation tools used, study objectives, performance measures considered, strengths, limitations, and key findings. Comparative and bibliometric analyses were then performed to identify dominant research themes, methodological trends, strengths, limitations, and existing research gaps.

**RESULT AND DISCUSSION**

**Distribution of Reviewed Studies by Modelling Approach**

The systematic review identified 33 studies that satisfied the predefined inclusion and exclusion criteria. The selected studies were analysed based on modelling approaches, application domains, modelling techniques, performance measures, and major research themes. The analysis shows that the literature covers five principal modelling categories: queueing theory, discrete event simulation, Petri net-based modelling, system dynamics, and intelligent and hybrid approaches.

The distribution of the reviewed studies across these categories indicates a gradual evolution in gas station modelling. Earlier studies were predominantly concerned with queueing and simulation-based approaches, reflecting the importance of customer waiting, service capacity, resource utilisation and operational efficiency. More recent studies increasingly consider Petri nets, optimisation, artificial intelligence, Internet of Things (IoT), multi-agent systems and digital twins, indicating a shift towards more integrated and adaptive modelling frameworks.

**Evolution of Modelling Approaches**

The reviewed literature demonstrates an evolution from relatively simple analytical models towards more flexible, formal and intelligent approaches. Queueing theory provides an analytical foundation for evaluating customer waiting times, queue lengths and server utilisation, while DES extends the analysis by allowing stochastic events, resource constraints and alternative operational scenarios to be represented. Petri-net-based approaches provide additional capabilities for modelling concurrency, synchronisation, resource sharing and system states. The emergence of timed, stochastic, fuzzy and hierarchical extensions has further expanded their applicability to complex engineering and gas station systems. In particular, the application of HTCPN by Abdulfatai *et al.,* (2025) demonstrates the applicability of hierarchical timed coloured Petri nets to customer flow, service operations and resource utilisation in gas station processes. More recent research has increasingly incorporated intelligent and data-driven technologies. Multi-agent simulation, artificial intelligence, IoT and digital twins have been explored to improve prediction, optimisation, monitoring and decision-making. These developments suggest that gas station modelling is moving towards more adaptive and interconnected systems rather than models that focus exclusively on isolated service activities.

**Comparative Findings**

The review indicates that the suitability of a modelling approach depends strongly on the objective and level of detail required. Queueing theory is appropriate when the primary objective is quantitative analysis of waiting and service performance. DES is more suitable when stochastic events and operational scenarios need to be examined. Petri nets provide stronger representation of concurrent and synchronised activities, while System Dynamics is more appropriate for strategic and long-term system behaviour. Intelligent and hybrid approaches provide opportunities for prediction, optimisation and adaptive decision-making. However, the review also reveals a common limitation across the literature: many studies concentrate on individual operational aspects rather than modelling the complete gas station process. Examples include queue management, service optimisation, fuel dispensing, resource allocation and logistics. Consequently, interactions among different stages of gas station operations are not consistently represented within a single modelling framework.

**Emerging Research Trends**

A major trend identified from the reviewed studies is the increasing integration of formal modelling with intelligent and data-driven technologies. AI and machine learning are being explored for predictive analysis and operational optimisation, while multi-agent systems provide mechanisms for representing autonomous interactions and distributed decision-making. IoT and digital-twin technologies further provide opportunities for real-time monitoring, predictive maintenance and intelligent control. Another emerging trend is the expansion of modelling beyond conventional petrol stations to include hydrogen refuelling stations and other sustainable energy infrastructures. This broadens the scope of gas station modelling and introduces additional requirements for handling heterogeneous resources, uncertainty and increasingly complex operational interactions.

**Identified Research Gaps**

Despite these developments, the review identifies several areas requiring further investigation. First, relatively few studies provide comprehensive representations of gas station processes, with many concentrating on isolated operational activities. Second, although Petri nets possess inherent capabilities for representing concurrency, synchronisation and resource sharing, their application to complete gas station systems remains limited. Third, the integration of stochastic behaviour, intelligent decision-making and real-time data analytics remains insufficiently explored.

The findings therefore suggest that future research should investigate integrated modelling frameworks that combine the formal capabilities of

Petri nets with simulation, optimisation, artificial intelligence, IoT and digital-twin technologies. Such integration could provide a more comprehensive representation of gas station operations while supporting performance evaluation, adaptive decision-making and real-time operational management.

**Bibliometric Analysis**

Bibliometric analysis was performed to examine the publication patterns, evolution of modelling approaches, and emerging research directions in gas station modelling and simulation. The analysis provides quantitative insights into the temporal distribution of studies, the progression of modelling paradigms, and the relative prominence of various research themes. Furthermore, it facilitates the identification of emerging trends and potential areas requiring further investigation.

**Publication Trends**

The annual distribution of publications demonstrates the progressive development of research on gas station modelling and simulation between 2010 and 2025. The publication trend indicates relatively limited research activity during the early years, followed by a gradual increase in the number of studies after 2018. This growth reflects increasing academic and industrial interest in improving operational efficiency, customer service, and intelligent resource management within fuel station systems. The upward trend further suggests that modelling and simulation have become recognised as effective decision-support tools for analysing increasingly complex gas station operations. The recent increase in publications also coincides with the emergence of intelligent technologies, including artificial intelligence, Internet of Things (IoT), optimisation algorithms, and digital twins, which are expanding the scope of modelling and simulation research in this domain.

The temporal distribution of publications was examined to determine how research interest in gas station modelling and simulation has developed over the review period. The publication record shows relatively limited research activity during the earlier years, followed by a gradual increase after 2018. This pattern indicates growing interest in modelling and simulation as tools for analysing operational efficiency, customer service and resource management. The recent increase also coincides with the emergence of intelligent technologies, including artificial intelligence, optimisation, Internet of Things (IoT) and digital-twin applications. The annual publication trend is presented in Figure 2.

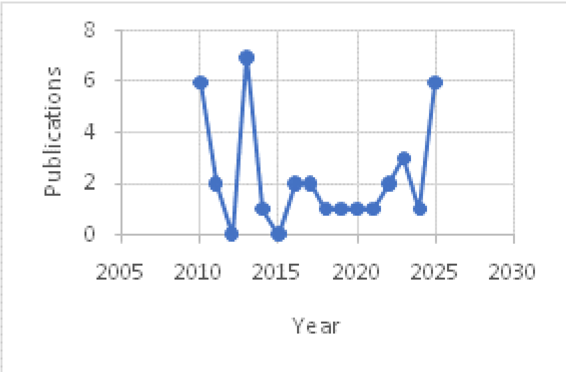


**Figure 2:** Publication trend of modelling and simulation studies on gas station systems from 2010 to 2025.

Figure 2 indicates an overall upward trend in research activity, particularly in the later years of the review period. This growth suggests that gas station modelling has progressively expanded from conventional operational analysis towards more technologically advanced approaches. The increasing attention to intelligent and data-driven technologies further indicates a shift towards adaptive decision-support systems.

**Evolution of Modelling Techniques**

The reviewed literature reveals a clear evolution in modelling approaches. Earlier studies predominantly employed analytical techniques, particularly queueing theory, to evaluate customer waiting times and service efficiency under simplified operational assumptions. As computational capabilities improved, discrete event simulation became increasingly adopted because of its ability to represent stochastic system behaviour and evaluate alternative operational scenarios. More recent studies demonstrate growing interest in Petri net-based models owing to their capability to represent concurrency, synchronisation, and resource interactions. The latest research trend indicates a transition towards intelligent and hybrid approaches that integrate simulation models with artificial intelligence, optimisation techniques, Internet of Things technologies, and digital twins to support adaptive and data-driven decision-making.

**Evolution of Modelling Approaches**

Figure 3 illustrates the chronological evolution of the major modelling approaches employed in gas station studies. Queueing theory dominated the earlier studies owing to its analytical simplicity and ease of implementation. Subsequently, discrete event simulation gained popularity due to its flexibility in modelling stochastic and dynamic processes. More recently, Petri nets and intelligent hybrid approaches have attracted increasing attention because of their capabilities in modelling concurrency, synchronisation, fault diagnosis, and intelligent decision-making. This progression demonstrates the transition from conventional analytical techniques to more advanced and integrated modelling frameworks.

The reviewed studies also reveal a methodological progression from conventional analytical approaches towards more flexible, formal and intelligent modelling techniques. Earlier studies predominantly employed queueing theory because of its analytical simplicity and suitability for evaluating waiting times and service efficiency. The subsequent adoption of DES provided greater flexibility for representing stochastic behaviour and alternative operational scenarios. More recent studies increasingly employ Petri-net-based approaches to represent concurrency, synchronisation and resource interactions, while intelligent and hybrid approaches incorporate artificial intelligence, optimisation, IoT and digital twins. The chronological evolution of the major modelling approaches is illustrated in Figure 3.

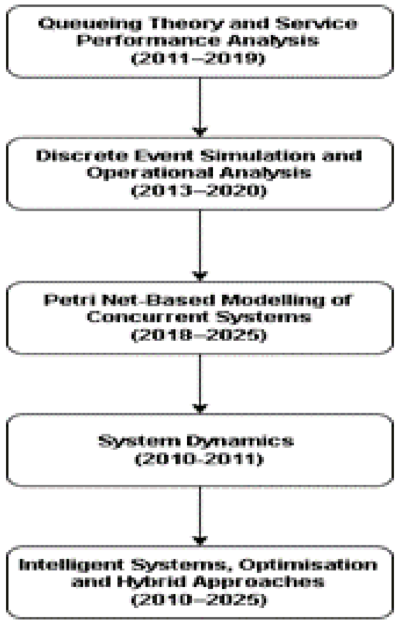


**Figure 3:** Evolution of modelling approaches in gas station modelling and simulation.

Figure 3 demonstrates a transition from relatively simple analytical models towards more comprehensive and adaptive modelling frameworks. The progression reflects the increasing complexity of gas station operations and the growing need for models capable of representing stochastic behaviour, concurrent activities, resource interactions and intelligent decision-making. This evolution also supports the need for comparative assessment of the modelling approaches based on their respective capabilities and limitations.

**Distribution of Reviewed Studies**

To quantify the relative representation of the identified modelling approaches, the 33 reviewed studies were classified according to their primary modelling approach. This classification provides a basis for identifying which techniques currently receive greater attention within the literature. The distribution of the reviewed studies across the five modelling categories is presented in Table 2.

**Table 2:** Distribution of Modelling Approaches in Reviewed Studies

| Modelling Approach | Number of Studies | Percentage (%) |
|---|---|---|
| **Queueing Theory** | 7 | 21.2 |
| **Discrete Event Simulation** | 7 | 21.2 |
| **Petri Nets** | 7 | 21.2 |
| **System Dynamics** | 2 | 6.1 |
| **Intelligent and Hybrid Approaches** | 10 | 30.3 |
| **Total** | 33 | 100 |

Table 2 shows that intelligent and hybrid approaches account for the largest proportion of the reviewed studies (30.3%), while queueing theory, DES and Petri nets each account for 21.2%. System Dynamics has the smallest representation, with 6.1% of the reviewed studies. The relatively high representation of intelligent and hybrid approaches suggests increasing research interest in adaptive, predictive and data-driven modelling. However, the equal representation of queueing theory, DES and Petri nets also indicates that conventional and formal modelling techniques remain important components of gas station research.

**Research Theme Analysis**

The reviewed studies indicate that current research on gas station modelling is primarily centred on operational efficiency, queue management, resource utilisation, service optimisation, customer waiting time reduction, and performance evaluation. Emerging themes include predictive analytics, intelligent decision support, energy-efficient station management, digital twin technologies, and the application of machine learning for operational optimisation. These developments demonstrate a gradual transition from conventional operational modelling towards intelligent and autonomous gas station management systems.

**Research Gap Analysis**

Despite considerable progress in modelling and simulation of gas station operations, several research gaps remain evident. First, most studies investigate isolated operational processes rather than integrated end-to-end service workflows. Second, relatively few studies combine formal modelling techniques with artificial intelligence, optimisation, and Internet of Things technologies to support intelligent operational management. Third, limited attention has been devoted to digital twin-enabled gas station systems capable of real-time monitoring and predictive decision-making. Finally, comparative evaluations across multiple modelling techniques remain scarce, limiting the availability of practical guidelines for selecting appropriate modelling approaches under different operational conditions. Addressing these gaps would contribute significantly to the development of intelligent, adaptive, and sustainable gas station systems.

The research-gap analysis identifies four major areas requiring further investigation: integrated end-to-end modelling of gas station operations, integration of formal modelling with artificial intelligence and optimisation, adoption of IoT and digital-twin technologies for real-time monitoring, and comparative evaluation using common performance criteria. These gaps provide a basis for defining future research directions in gas station modelling. The conceptual relationship between the identified gaps and proposed research directions is presented in Figure 4. The Figure summarises the proposed direction for future research by linking the identified limitations of existing studies with opportunities for integrated and intelligent modelling. The roadmap emphasises the integration of formal modelling, simulation, artificial intelligence, optimisation, IoT and digital-twin technologies. It also highlights the need to extend modelling beyond isolated operational activities towards comprehensive representations of gas station processes.

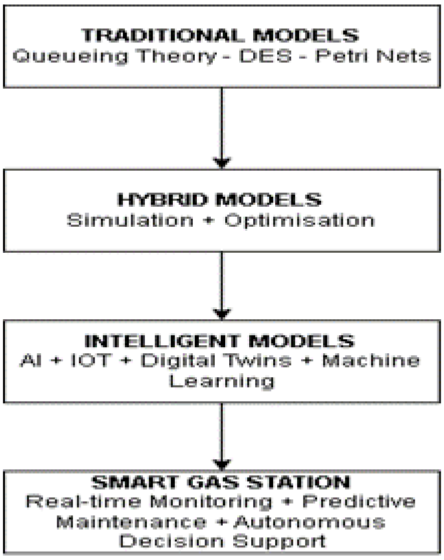


**Figure 4.** Conceptual Roadmap for Future Research

**Research Hotspots and Future Directions**

The bibliometric analysis revealed several emerging research hotspots in the modelling and simulation of gas station systems. These include intelligent systems, Internet of Things technologies, Artificial Intelligence, optimisation frameworks, and hybrid modelling approaches. Furthermore, increasing attention is being directed towards real-time monitoring, predictive analytics, and autonomous decision-making capabilities.

Despite these developments, relatively limited research has been devoted to integrated modelling of pre-service, service, and post-service activities. Similarly, the combination of formal modelling techniques with intelligent and data-driven approaches remains largely unexplored. Consequently, future research efforts should focus on the development of scalable and intelligent hybrid frameworks capable of providing comprehensive representations of gas station operations while supporting real-time decision-making and system optimisation.

The bibliometric findings demonstrate that research on gas station modelling has evolved from conventional analytical techniques towards increasingly intelligent and integrated modelling frameworks. Although discrete event simulation remains the dominant approach for operational performance analysis, growing interest in Petri net-based models and intelligent hybrid techniques reflects the need for more comprehensive, adaptive, and data-driven solutions capable of supporting next-generation gas station systems. These observations provide the foundation for the comparative analysis and future research directions discussed in the subsequent sections.

**RESEARCH GAPS AND FUTURE RESEARCH DIRECTIONS**

The analysis of the reviewed literature revealed several limitations and unresolved challenges associated with existing modelling approaches for gas station systems. Although significant progress has been achieved in the development of analytical, simulation-based, and intelligent modelling techniques, a number of important issues remain insufficiently addressed. This section highlights the major research gaps identified from the literature and discusses potential directions for future investigations aimed at improving the modelling and optimisation of gas station operations.

**Research Gaps**

The systematic review and bibliometric analysis identified several important gaps in the existing literature on gas station modelling and simulation. First, most studies focus on isolated operational components, such as queue management, fuel dispensing or payment systems, with limited attention to integrated end-to-end modelling of gas station operations. Second, although queueing theory and discrete event simulation are widely applied, relatively few studies exploit the formal verification capabilities of Petri nets for analysing concurrency, synchronisation and resource-sharing problems. Third, the integration of simulation and formal modelling techniques with artificial intelligence, optimisation algorithms, Internet of Things (IoT) and digital-twin technologies remains limited. Finally, comparative evaluations of multiple modelling techniques using common performance criteria are scarce, making it difficult to determine the suitability of particular approaches for specific operational conditions. These gaps indicate the need for more comprehensive and integrated modelling frameworks capable of representing the complexity of modern gas station operations.

**Future Research Directions**

Future research should prioritise the development of integrated modelling frameworks that combine formal modelling, simulation, optimisation and artificial intelligence. In particular, the integration of Hierarchical Timed Coloured Petri Nets with discrete event simulation, machine learning, digital twins and IoT technologies could support comprehensive representation of gas station processes, real-time monitoring, predictive maintenance and intelligent resource allocation. Future studies should also extend modelling beyond conventional single-fuel operations to multi-fuel stations, renewable-energy integration, electric vehicle charging infrastructure and sustainable fuel distribution systems. In addition, the development of benchmark datasets and standardised performance evaluation criteria would improve the comparability, validation and reproducibility of future modelling studies.

## CONCLUSION

This study presented a systematic literature review and bibliometric analysis of modelling and simulation approaches applied to gas station systems. The review identified five major modelling categories: queueing theory, discrete event simulation, Petri net-based modelling, System Dynamics, and intelligent and hybrid approaches. The findings indicate an evolution from conventional analytical and simulation-based techniques towards more integrated, intelligent and data-driven modelling frameworks. Intelligent and hybrid approaches constituted the largest category among the reviewed studies, while queueing theory, discrete event simulation and Petri net-based approaches maintained substantial representation.

The comparative analysis further showed that the suitability of a modelling approach depends on the characteristics and objectives of the gas station operation being investigated. Queueing theory is particularly useful for analytical evaluation of waiting and service performance, DES provides flexibility for representing stochastic operational processes, while Petri nets offer capabilities for modelling concurrency, synchronisation and resource interactions. System Dynamics is suited to system-level and long-term analysis, whereas intelligent and hybrid approaches provide opportunities for prediction, optimisation and adaptive decision-making.

The review also identified important gaps, including limited end-to-end modelling of gas station operations, insufficient integration of formal modelling with intelligent and data-driven technologies, and limited comparative evaluation of modelling approaches using common performance criteria. Future research should therefore focus on integrated frameworks that combine formal modelling, simulation, optimisation, artificial intelligence, IoT and digital-twin technologies, while also addressing emerging multi-fuel and sustainable energy station configurations. Overall, the findings provide a structured foundation for researchers and practitioners seeking to develop more comprehensive, adaptive and intelligent gas station modelling frameworks.

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