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A Performance Analysis of a Commercial Filling Station using ARENA Simulation: A South African Case Study

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Abstract

This study develops a discrete-event simulation model of a commercial fuelling station in Johannesburg, South Africa, to analyse operational performance and revenue generation under varying service conditions. Two scenarios were simulated: (i) vehicles refuelling only, and (ii) vehicles refuelling while also visiting a convenience shop. Key performance indicators including average waiting time, total service time, queue lengths, and resource utilization of pumps, attendants, and cashiers were measured. Results show that diesel refuelling accounted for over 70% of total revenue in the fuelling-only scenario, while average waiting times ranged between 2.5 and 3.7 minutes. Incorporating retail services slightly increased system complexity, with minor reductions in process efficiency for petrol customers and an increase in attendant and pump utilization. Overall system efficiency remained above 98% in both scenarios, demonstrating effective capacity management. The findings highlight the practical value of simulation modelling for identifying bottlenecks, optimizing resource allocation, and supporting operational decisions in urban fuelling stations, ultimately improving service efficiency and revenue outcomes.

Keywords
Simulation modelling, Fuelling station operations, Queue management, Resource utilization and Operational efficiency

1. Introduction

Simulation is a research method in which the object of study is replaced by a model. Experiments are conducted on the model with the aim of generating information that can later be used to understand and analyse the real system (Straka, et al., 2018). Simulation modelling, mathematical programming, and statistical analysis can be considered useful tools for managers, researchers, and practitioners to analyse dynamic systems without interrupting their operations (Tako, et al., 2015; Pinto , et al., 2015). Thus, a simulation model is an algorithm that propagates a system's state forward in time, typically implemented as a computer program. Unlike a purely mathematical model, this propagation relies on a set of explicit rules or equations that define future states directly, rather than employing calculus-based analytical techniques (Law, 2013). The benefits of using a simulation modelling approach include financial, time, material, and energy savings, as well as the streamlining of practical activities (Rosova, et al., 2020). Simulation models are widely used by researchers to address problems primarily related to transportation, material handling, production processes, and ecology (Straka, et al., 2016; Malandri, et al., 2018). This study focuses on a newly invested filling station in Vanderbijlpark, Gauteng, South Africa. It consists of petrol 93 and petrol 95 fueling pumps, as well as a convenience (quick) shop.

Petrol filling stations have transitioned from single-function fuel dispensing facilities into complex service systems, integrating fuel sales with ancillary operations such as vehicle maintenance, retail merchandising, and food services, thereby increasing operational complexity and the need for systematic performance evaluation and process optimisation (Qasem, 2025). After refuelling their vehicles, customers may enter the convenience shop to make purchases, if desired. Public Fuel Filling Stations are critical infrastructure that underpin mobility and ensure the reliable operation of transportation networks. Beyond supplying fuel to motorized vehicles, Public Fuel Filling Stations form an essential component of public service infrastructure that underpins economic and social activities. The growing number of vehicles, particularly in densely populated urban areas, has substantially increased demand for fuel services. This surge frequently leads to operational challenges, most notably long queues at fuel stations during peak hours, which disrupt service efficiency (Nasir & Andesta, 2024; Qamari & Trizula, 2022). Vehicle queues at fuel stations are not only linked to extended waiting times but also result in broader consequences, including traffic congestion around the stations, time losses, and customer dissatisfaction. This inefficiency is largely attributed to an imbalance between service capacity and fluctuating demand (Pellondou, et al., 2022).

Thus, service industries have acknowledged that improving and optimising service quality is critically important for increasing efficiency within competitive markets (Hurst, 2014). Petrol companies can enhance their profitability by improving customer satisfaction. Competitive advantage in this industry is typically assessed through fuel quality, service speed, and pricing. Quality and price are commonly comparable in most markets, service speed and queue lengths can be considered the most influential factor affecting customer satisfaction and, correspondingly, revenue (Conway & Briner, 2016). Nowadays, a variety of software tools are employed for computer simulation, including Witness, Tecnomatix Plant Simulation, Extend, FlexSim, Arena and SimMin (Saderova, et al., 2021). Arena Software by Rockwell Automation is used to perform simulations in a logical and highly dynamic manner, enabling the identification of improvements in operating conditions such as bottlenecks, queue behavior and visualization, waiting times, resource utilization, and overall system performance (Bizerra, et al., 2024).
This study uses Arena software to analyse the performance of a newly invested commercial filling station in Gauteng, South Africa. The objectives of the research are to:

- To create a fuel filling station simulation model.
- To perform scenario analysis on the model on cases where a customer arrives to refill fuel only and where a customer arrives to refill fuel and shop refreshment items in the quick shop.
- To quantify how many numbers of cars can be served in an operational shift for both customer arrives to refill fuel only and where a customer arrives to refill fuel and shop refreshment items in the quick shop.
- To evaluate resource utilisation, efficiencies, revenue generation and revenue contribution as a function of fuel types sold.

2. Literature Review

Dewandaru et al. (2021) used Arena simulation software with discrete event simulations at two servers to analyse waiting time and worker utilisation on a gas station in Indonesia. The main goal was to optimise the petrol station queuing system and sales rate. Real data collection was achieved through observation for a period of 30 minutes for five working days during rush hours with a focus on motorist and Pertalite gas refuelling. The research examined two improvement scenarios: the addition of an extra server and the allocation of an additional operator to the existing server. The findings showed that introduction of an additional server reduced the average waiting time to 7.58 minutes for the first server and 19.86 minutes for the second server. Moreover, this scenario resulted with an increase of 1.04% in overall system productivity. In a case study by Samad et al. (2025) on witing line of a CNG Filling Station through Arena simulation modelling approach, it was noted that reduction in queuing length and average waiting time of a filling station, customer satisfaction will be increased and can be decreased waste of time.

The case study by Purba, et al.(2025) on analysis of a gas station queuing system revealed through Arena simulation a more realistic representation of actual operating conditions, revealing no significant waiting lines but highlighting uneven workload distribution among fuel pumps, with some exceeding 70% utilization while others remained underutilised. Furthermore, the study indicates that although the system is generally efficient, improvements in vehicle routing and pump allocation are required. The recommended measures include optimizing the station layout, enhancing operator training, and adopting automated distribution systems to improve operational efficiency and customer satisfaction.

Furthermore, in a study by Galankashi et al. (2015), a petrol station queuing system was evaluated using a simulation-based design of experiments (DOE) approach implemented in WITNESS 2014 to optimise queue performance and sales rate. A two-level full factorial DOE with centre points examined the effects of pumps, cashiers, and interarrival times on queue length and sales rate, revealing that queue length was significantly influenced by cashiers and interarrival time, while sales rate was affected by all factors and their interactions.

In Sri Lanka, Dilanthi et al. (2019) investigated operational efficiency at a town-based petrol filling station experiencing congestion due to high demand and limited capacity. Observational data collected between 14:00 and 16:00 were modelled as a single-server, infinite-capacity queue operating under a First-Come-First-Served discipline using Rockwell ARENA 14.5, with inter-arrival and service times fitted to Beta and Gamma distributions. The simulation results indicated a service utilisation rate of 92.6%, average waiting times of 4.29 minutes in the queue and 5.16 minutes in the system, and an average queue length of six vehicles. The study recommended capacity expansion through the addition of a service counter or pump, as well as a separate payment counter, to reduce customer waiting times, subject to economic feasibility.

Queue management to mitigate congestion caused by demand exceeding supply was examined by Adeke & Joel (2019) through a priority queuing simulation study at the TOTAL petrol station in Makurdi. Discrete-event simulation with the SimEvents toolkit in MATLAB was applied using field data on vehicle arrivals and pump service times. The model evaluated Normal and Priority Queues under varying demand splits (3-30%). Results showed significant reductions in queue length and waiting time, with optimal performance achieved at 80-85% demand in the Normal Queue and 15-20% in the Priority Queue.

Performance management of filling station is of great importance to ensure business continuity that serves a nation. This attested by Qasem (2025) where it was noted that, many petrol stations operate under fragmented management practices and lack standardised evaluation frameworks, which hampers operational efficiency, safety compliance, and continuous improvement.

3. Methods

3.1. Simulation procedure

The study adopted a structured discrete-event simulation modelling methodology consistent with established frameworks proposed by Law (2013) and similarly followed in a recent application for filling station performance analysis by Samad et al. (2025). Figure 1 illustrates the steps involved by the following steps:

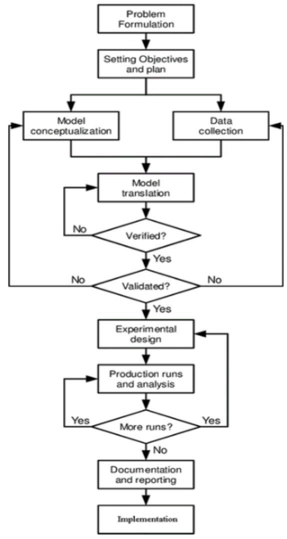

Figure 1. Steps in a simulation study (Law, 2013)

Real operational data were collected through direct observation of vehicle arrivals, service times, and customer behaviour at the fuelling station overall period of two weeks to arrive at averaged data. The two weeks period catered for periods of low demand such as in the second week of the month and peak periods such as the week after month end. Thus, data collection was conducted over a period of five consecutive operational days**,** with focused observations during peak and off-peak hours to capture variability in system behaviour. Each observation session lasted three hours**,** resulting in a representative dataset of vehicle arrivals, service times, and customer routing patterns. The collected data were then summarised and used to estimate input probability distributions for the simulation model.

The inter-arrival times were modelled using an exponential distribution, which is common in queuing theory and service system modelling due to its ability to represent random arrival patterns of entities such as observed in the fuel station. Service times for petrol refuelling were modelled using a uniform approximation (6-10 minutes), which indicates an observed minimum and maximum service durations influenced by tank capacity and transaction processes. Diesel service times were modelled using a triangular distribution TRIA(8, 10, 15), as this distribution applies when empirical data are limited but minimum, most likely, and maximum values can be reliably estimated from the field observations. The shopping service times were modelled using triangular distributions based on observed service ranges at the filling station. The selection of these distributions is consistent with simulation modelling best practices where triangular distributions are preferred for representing real-world processes with limited but structured data.

3.2. Verification and validation

Verification and validation were conducted to ensure that the simulation model accurately represents the real-world fuelling station operations and produces reliable results. Verification focused on confirming that the simulation model was correctly implemented according to the conceptual design, ensuring that the logic of vehicle arrivals, refuelling processes, queue formation, and resource allocation (pumps, attendants, and cashier) operated as intended within the simulation environment. This involved checking model assumptions, input parameters, and process flows to eliminate programming or logical errors. Thus, to ensure robustness of the results, the model was executed for 10 multiple independent replications for all scenarios in the modelling phase. Validation, on the other hand, involved comparing the model outputs with expected operational behaviour of a typical fuelling station in Johannesburg to ensure that the results were realistic and consistent with practical observations. Key performance indicators such as waiting times, service times, and resource utilisation were evaluated to confirm that the model reasonably reflects actual service dynamics. Together, verification and validation increased confidence that the simulation model is suitable for analysing system performance and supporting operational decision-making in the fuelling station.

4. Data Collection

4.1. Model formulation

4.1.1. First system description: Fuelling Station Only without customers walking to the quick shop for item purchase

At the fuel filling station, cars arrive at an exponential distribution interval of 10 min. As soon as the cars arrive 38.38% intends to refill petrol 95, 28.58% refills petrol 93 while the remaining refills Diesel. The petrol cars proceed for refilling with an aid of a petrol attendant using the petrol pump. Depending on the size of the fuel tank and the fuel quantity being filled together with the payment process, the process takes between 6-10 min. The diesel cars fuel filling process including payment takes a TRIA(8, 10, 15) min assisted by a diesel attendant using a diesel pump. A model was developed in Arena as depicted on Figure 2.

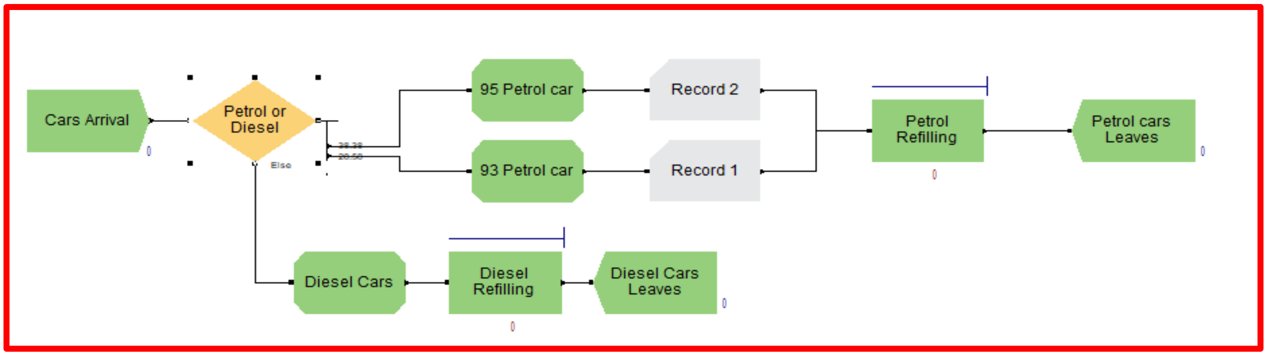

Figure 2. Arena simulation model for fuelling only without customers walking to the quick shop for item purchase.

4.1.2. Second system description

Fuelling station with customers walking to the shop for item purchase
At the fuel filling station or "garage", cars arrive at an exponential distribution interval of 10 min. As soon as the cars arrive 38.38% intends to refill petrol 95, 28.58% refills petrol 93 while the remaining refills Diesel . The petrol cars proceed for refilling with an aid of a petrol attendant using the petrol pump. Depending on the size of the fuel tank and the fuel quantity being filled together with the payment process, the process takes between 6-10 min. The diesel cars fuel filling process including payment takes a TRIA(8, 10, 15) min assisted by a diesel attendant using a diesel pump.

After refilling 60% of the petrol cars leaves the station while the remaining balance finds packing and goes to the quick shop. 45% of the petrol car driver going for shopping are 93 petrol while 55% are 95 petrol. The shopping process by petrol car drivers process assisted by a cashier takes a TRIA(8,10,14) min. Meanwhile 70% of Diesel cars refilled leaves the station and the 30% travels 7km for packing and leaving from the parking to the quick shop. The shopping process by diesel car drivers takes 5-7 min attended by a cashier.
A model was developed in Arena as depicted on Figure 3.

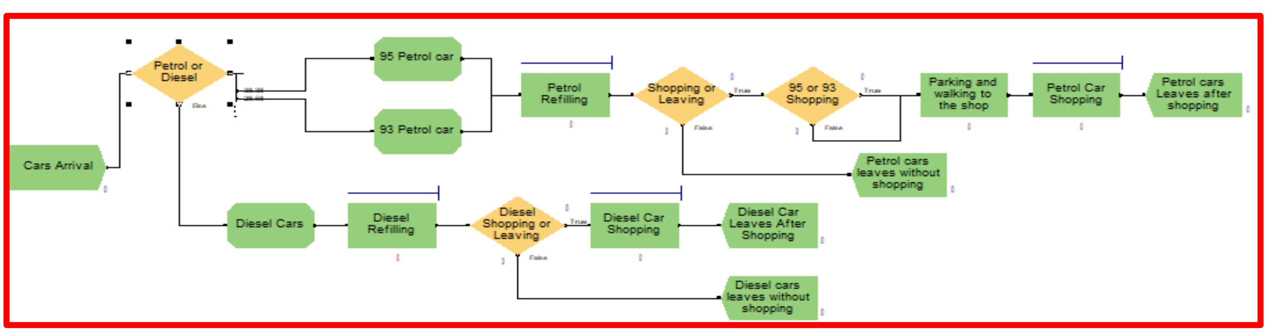

Figure 3. Arena simulation model for fueling and customers walking to the quick shop for item purchase.

5. Results and Discussion

5.1. Fuelling Station without Customers Visiting the Quick Shop

Table 1 presents the simulation results for the fuelling station when customers only refuel their vehicles and do not visit the quick shop. The results indicate that the total system input and output were equal, with 132 vehicles entering and leaving the system, which suggests that the fuelling station operated without any system losses or unserved customers during the simulation period. The distribution of fuel demand shows that 95 petrol had the highest demand (56 vehicles) followed by diesel (42 vehicles) and 93 petrol (34 vehicles). This reflects typical fuel consumption patterns in urban areas such as Johannesburg, where premium petrol grades are commonly used by modern passenger vehicles. The average value-added time for the refuelling process ranged between 7.84 minutes and 10.82 minutes, indicating that the fuelling operation itself is relatively efficient. However, the system also experienced average waiting times of 3.67 minutes for 93 petrol and 2.51 minutes for 95 petrol, suggesting moderate queue formation during peak demand periods.

The average total time spent in the system was 11.51 minutes for 93 petrol customers and 13.32 minutes for 95 petrol customers, which indicates that waiting time contributes significantly to the overall service duration. Even though the waiting times were relatively short, they still accounted for approximately 20–30% of the total service time.

The process efficiency of 100% across all fuel types suggests that all vehicles entering the process were successfully served without interruption or abandonment. Similarly, the overall system efficiency was 100%, meaning the system was able to process all arriving vehicles during the simulation period.

Resource utilisation results indicate that fuel attendants and pumps were utilized at 53% and 34% respectively. This suggests that the fuelling station still had spare service capacity and could potentially handle additional customer demand without significantly increasing waiting times.

Table 1. Simulation results

Parameter	Unit of Measure	93 Petrol	95 Petrol	Diesel
Process Input	Car	34	56	42
Process Output	Car	34	56	42
System Input	Car	132		
System Output	Car	132		
Average Value-Added Time	Min	7.84		10.82
Average Waiting Time	Min	3.67		2.51
Average Total Time	Min	11.51		13.32
Refilling Waiting Time	Min	3.67		2.51
Process Efficiency	%	100	100	100
System Overall Efficiency	%	100		
Attendant Resource	%	53		34
Pump Resource	%	53		34

Table 2 presents the commercial performance of the fuelling station based on the simulation results. The analysis shows that diesel sales generated the largest portion of revenue, contributing 71.55% of the total revenue, despite representing only 42 vehicles in the system output. This is mainly due to the significantly higher average quantity purchased per vehicle (90 litres) compared to 26 litres for 93 petrol and 8 litres for 95 petrol.

The total simulated revenue generated by the fuelling station during the operational period was ZAR 99,849.56. Diesel contributed ZAR 71 442, while 93 petrol generated ZAR 18 820.36 and 95 petrol generated ZAR 9 587.20.

These findings highlight the economic importance of diesel customers for fuelling stations, particularly those serving commercial vehicles such as delivery trucks, taxis, and logistics fleets. The results therefore suggest that station managers should ensure that diesel pumps are always operational and easily accessible to avoid losing high-value customers (Table 3).

Table 2. Commercial calculations based on simulation results

Parameter	Unit of Measure	93 Petrol	95 Petrol	Diesel
System Output	Car	34	56	42
Average Quantity	Liter	26	8	90
Price Per Liter	ZAR	21.29	21.40	18.90
Revenue	ZAR	18 820.36	9 587.20	71 442
Total revenue	ZAR	99 849.56		
Revenue contribution	%	18.85	9.60	71.55

5.2. Second system description: fuelling station with customers visiting the quick shop

Table 3. Simulation results

<table>
<tr><th></th><th></th><th colspan="3">Fuel Refilling Only</th><th colspan="3">Refilled &Shopping</th></tr>
<tr><th>Parameter</th><th>Unit of Measure</th><th>93 Petrol</th><th>95 Petrol</th><th>Diesel</th><th>93 Petrol</th><th>95 Petrol</th><th>Diesel</th></tr>
<tr><td>Process input</td><td>Car</td><td colspan="2">102</td><td>38</td><td>15</td><td>24</td><td>8</td></tr>
<tr><td>Process output</td><td>Car</td><td colspan="2">61</td><td>30</td><td>15</td><td>24</td><td>8</td></tr>
<tr><td>System input</td><td>Car</td><td colspan="6">140</td></tr>
<tr><td>System output</td><td>Car</td><td colspan="6">138</td></tr>
<tr><td>Average value added time</td><td>Min</td><td>7.90</td><td>11.21</td><td colspan="3">10.80</td><td>6.31</td></tr>
<tr><td>Average waiting time</td><td>Min</td><td>4.76</td><td>2.08</td><td>0</td><td colspan="2">0</td><td>0</td></tr>
<tr><td>Average total time</td><td>Min</td><td colspan="2">12.66</td><td>13.30</td><td colspan="2">10.80</td><td>6.31</td></tr>
<tr><td>Queue time (Refilling and Buying)</td><td>Min</td><td colspan="2">4.79</td><td>2.08</td><td colspan="3">0</td></tr>
<tr><td>Process efficiency</td><td>%</td><td colspan="2">5.88</td><td>78.95</td><td colspan="3">100</td></tr>
<tr><td>System efficiency</td><td>%</td><td colspan="6">98.57</td></tr>
<tr><td>Resource Utilisation – Attendant</td><td>%</td><td colspan="2">59.85</td><td>32.28</td><td colspan="3">-</td></tr>
<tr><td>Resource Utilisation – Pump</td><td>%</td><td colspan="2">59.85</td><td>11.87</td><td colspan="3">-</td></tr>
<tr><td>Resource Utilisation – Cashier</td><td>%</td><td colspan="3">-</td><td colspan="3">18.86</td></tr>
</table>

Table 4 presents the commercial revenue generated when both fuelling and retail sales are considered. The total revenue generated under this scenario was ZAR 98 975.54, which is slightly lower than the first scenario but includes additional retail revenue streams.

The revenue contributions were distributed across both fuel sales and retail purchases. Diesel fuel continued to dominate revenue generation in the refuelling-only category, contributing 51.56% of the total revenue, while petrol grades contributed smaller percentages.

Customers who combined refuelling with shopping generated additional revenue through retail purchases, with an average spending of ZAR 32.80 per customer. Although retail purchases contributed less overall revenue compared to fuel sales, they represent an important supplementary income stream for fuelling stations.

Table 4. Commercial calculations based on simulation results

		Fuel Refilling Only			**Refilled &Shopping**		
Parameter	**Unit of Measure**	**93 Petrol**	**95 Petrol**	**Diesel**	**93 Petrol**	**95 Petrol**	**Diesel**
System Output	Car	26	35	30	15	24	8
Average Quantity Sold	Liter	26	8	90	26	8	90
Price Per Liter	ZAR	21.29	21.40	18.90	21.29	21.40	18.90
Average Spending	ZAR				32.80	32.80	32.80
Revenue	ZAR	14 392.04	5992	51 030	8 795.10	4 896	13 870.40
Total Revenue	ZAR	98 975.54					
Revenue contribution	%	14.54	6.05	51.56	8.87	4.95	14.01

5.3 Proposed Improvements

Based on the simulation results obtained for both system scenarios, several operational improvements can be proposed to enhance the performance and profitability of the fuelling station. The simulation analysis indicates that waiting times and resource utilization increase when customers combine fuel refilling with quick shop purchases. Although the system maintains high efficiency levels, the presence of queues, particularly for 93 petrol customers, suggests that service bottlenecks may occur during peak periods. One potential improvement is the optimisation of pump allocation for the different fuel types. The simulation results show higher demand for certain fuels, particularly petrol, allocating additional pumps to the most frequently used fuel grades could reduce queue lengths and waiting times. Another improvement involves increasing the number of attendants during peak operating hours, which would reduce service delays and improve customer throughput.

The study also suggests that the integration of self-service payment technologies, such as card-based payment at the pump, could reduce dependency on attendants and shorten the total service time. In addition, the convenience store component presents an opportunity for revenue growth; therefore, optimizing the store layout and cashier efficiency could improve customer flow between fuelling and shopping activities. Implementing a separate queue for customers who wish to purchase items in the quick shop may further reduce congestion in the fuelling area.

These improvements could significantly enhance operational efficiency while maintaining customer satisfaction and maximizing revenue generation for the fuelling station.

6. Conclusion

This study developed a simulation model to analyse the operational performance of a commercial fuelling station under two different scenarios: a system with fuel refilling only and a system where customers also visit a convenience shop for item purchases. The results show that while fuel-only operations maintain high efficiency and relatively short waiting times, the introduction of retail activities increases system complexity and resource utilization. Despite this added complexity, the system maintains a high level of overall efficiency, demonstrating the capacity of the fuelling station to accommodate both fuelling and retail services. From a financial perspective, fuel sales remain the primary source of revenue, with diesel contributing the largest share due to higher fuel volumes per transaction. However, convenience store purchases provide additional revenue opportunities and contribute to the overall profitability of the station.

The study highlights the importance of simulation modelling as a powerful decision-support tool for analysing service systems and identifying operational improvements. By using simulation techniques, managers can evaluate different operational scenarios and make informed decisions aimed at reducing waiting times, improving resource utilization, and increasing revenue generation.

Future research could extend this study by incorporating more operational data, analysing peak-hour demand variations, and exploring additional service configurations to further optimise fuelling station performance.

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Asser Letsatsi Tau holds a Doctor of Philosophy (Ph.D) Degree in Operations Management and Master's Degree in Operations Management (with distinction) from the University of Johannesburg, a Master of Engineering (MEng) in Chemical Engineering from Tshwane University of Technology and a Postgraduate Diploma in Business Administration from the University of the Witwatersrand Business School. He is a researcher and engineer whose academic work focuses on operations management, industrial engineering, simulation modelling, manufacturing systems optimisation, and maintenance engineering. His research contributions are primarily centred on enhancing operational efficiency, improving equipment performance, and optimising processes across industrial and service systems.

Emmanuel Innocents Edoun is an academic, he holds a PhD from the University of Witwatersrand in Johannesburg South Africa. He has travelled widely between different countries in Africa while interacting with academic institutions, policy makers, policy implementers and community members. He is industrious and has good conceptual and organizational skills. He has consulted and spearheaded projects at the African Union, NEPAD , the Pan African Parliament ; AFRODAD. He has been involved as an academic at various University is South Africa and abroad. He has supervised more than 20 PhD Students, 30 full master's and 100 MBAs students. He has attended many conferences, locally and abroad, and has published many articles in the International accredited Journals.

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Delia Malejane holds a Diploma, Advanced Diploma, and Postgraduate Diploma in Industrial Engineering at the Vaal University of Technology, where she developed a strong interest in simulation modelling and systems analysis. She is currently employed in the automotive industry. Her research interests include simulation modelling, system optimisation, and the practical application of industrial engineering tools to enhance productivity and operational performance across diverse industries.