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Research Article

Analyzing Service Queue Performance at Fuel Stations Using Fishbone Diagram and Queuing Theory: Evidence from Surabaya–Gresik Toll Rest Area

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Abstract: This study aims to determine and analyze service waiting times, identify the root causes of long queues, and develop a strategy to improve service performance at the 5361137-gas station (SPBU) at the Surabaya-Gresik Toll Rest Area. The research method used is a mixed-methods approach with an exploratory sequential design. This study combines quantitative analysis using Queuing Theory to measure system performance (arrival rates and service times) and descriptive qualitative analysis using a Fishbone Diagram. Data were collected through direct observation, interviews, and *g-form* techniques. The results indicate that the current queuing system performance is in a critical or severe condition, indicated by a server utilization rate of 0.94 to 1.02 during peak hours. The average time spent by vehicles in the system is 14.3 minutes, of which 9.6 minutes (67%) is spent waiting in the queue. Fishbone diagram analysis revealed that the root cause of the main problem lies in the complex interaction of factors: Machine factors (EDC signal failure and pump repair downtime), Human and Method factors (implementation of static shifts and reactive maintenance), and Environmental factors (narrow layouts that hinder large vehicle maneuvers). As a solution, this study formulated a hybrid improvement strategy that includes short-term business process engineering (the use of Floating Staff and lane segregation) and long-term investment in additional pumps to change the queuing model from Single Channel to Dual Channel. This strategy is expected to reduce the utility level to a safe zone below 0.80 with a target waiting time of 3–5 minutes.

Keywords: Fishbone Diagram, Queuing System, Queuing Theory, Service Efficiency, Waiting Time.

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1. Introduction

In the contemporary era of hypercompetition, the efficiency and responsiveness of service operations have become a central determinant of business success and customer satisfaction. Service-oriented industries, including fuel distribution networks, face increasing operational challenges due to fluctuating demand, limited-service capacity, and customer expectations for immediate service delivery (Heizer & Render, 2016). As the transportation sector expands rapidly across developing economies such as Indonesia, fuel stations play an essential role in sustaining mobility and economic activities. Consequently, understanding and optimizing the queue management system in these service facilities are imperative for enhancing customer satisfaction and operational performance.

In Indonesia, the growing number of motorized vehicles has led to a corresponding increase in fuel consumption, particularly in densely populated regions like East Java. According to the Badan Pusat Statistik (2024), the province recorded over 26.5 million registered vehicles, signaling an unprecedented rise in energy demand and service utilization.

Table 1. Number of Registered Vehicles by Regency/Municipality in East Java Province.

Regency / City	Passenger Cars	Buses	Trucks	Motorcycles	Total
Pacitan	30,702	509	6,145	187,184	224,540
Ponorogo	100,202	1,854	26,627	472,695	601,378
Trenggalek	241,151	620	31,557	311,129	584,457
Tulungagung	163,417	2,455	40,450	689,732	896,054
Blitar	134,063	3,271	49,477	493,701	680,512
Kediri	203,007	1,631	46,948	771,741	1,023,327
Malang	223,635	3,281	74,568	1,108,636	1,410,120
Lumajang	135,692	632	63,411	325,250	524,985
Jember	236,640	767	38,349	725,747	1,001,503
Banyuwangi	336,854	534	49,775	756,029	1,143,192
Bondowoso	54,267	204	34,031	184,105	272,607
Situbondo	108,483	373	14,510	199,995	323,361
Probolinggo (Regency)	65,698	669	18,502	272,224	357,093
Pasuruan (Regency)	140,488	785	27,478	467,988	636,739
Sidoarjo	207,376	1,822	69,853	1,423,157	1,702,208
Mojokerto (Regency)	46,882	893	78,772	483,993	610,540
Jombang	50,691	936	45,075	608,569	705,271
Nganjuk	121,008	1,572	37,302	552,537	712,419
Madiun (Regency)	430,329	568	26,885	345,211	802,993
Magetan	201,597	1,091	23,557	375,980	602,225
Ngawi	226,960	1,191	24,440	413,826	666,417
Bojonegoro	38,136	1,319	24,753	512,334	576,542
Tuban	37,315	648	32,908	519,999	590,870
Lamongan	36,811	1,305	33,260	555,884	627,260
Gresik	78,863	841	43,657	727,397	850,758
Bangkalan	168,945	1,745	37,982	245,175	453,847
Sampang	118,937	1,117	17,471	140,363	277,888
Pamekasan	186,705	1,888	20,929	269,486	479,008
Sumenep	78,154	287	20,414	256,780	355,635
Kediri (City)	71,311	1,497	13,948	337,697	424,453
Blitar (City)	44,864	294	12,137	290,994	348,289
Malang (City)	275,852	936	22,000	535,090	833,878
Probolinggo (City)	104,955	539	9,140	175,288	289,922
Pasuruan (City)	93,187	549	7,416	249,840	350,992
Mojokerto (City)	21,647	295	8,158	208,970	239,070

Madiun (City)	51,821	1,102	6,855	217,555	277,333
Surabaya	588,333	4,033	179,118	3,034,754	3,806,238
Batu (City)	86,042	242	8,797	168,249	263,330
East Java (Total)	**5,541,020**	**44,295**	**1,326,655**	**19,615,284**	**26,527,254**

Source: Central Bureau of Statistics (Badan Pusat Statistik), East Java Province.

This surge has placed significant pressure on gas stations (*Stasiun Pengisian Bahan Bakar Umum*, SPBU) to maintain smooth and efficient service flows, particularly in high-traffic zones such as toll road rest areas. The SPBU 53.61137 located at the Surabaya–Gresik Toll Rest Area exemplifies such a high-demand service point, where long vehicle queues frequently occur during peak travel hours, adversely affecting customer experience and service productivity.

Queue formation in service systems reflects the imbalance between demand and service capacity (Tjutju, 1992). Prolonged waiting times not only reduce operational efficiency but also erode customer trust and satisfaction, key dimensions in service quality management (Tjiptono, 2019). Numerous studies have applied queuing theory to optimize service operations across sectors, including transportation hubs (Ricardianto et al., 2022) and manufacturing systems (Mas et al., 2022). However, there remains limited empirical research focusing on queuing system optimization in Indonesian fuel stations using an integrated quantitative–qualitative approach.

To address this research gap, the present study adopts a mixed-methods design combining queuing theory with Fishbone Diagram analysis to identify both measurable performance inefficiencies and their underlying root causes. Queuing theory provides a quantitative framework to analyse system parameters such as arrival rates, service times, and utilization levels (Charles, 1990), while the Fishbone Diagram facilitates qualitative identification of root causes across six dimensions—manpower, machines, methods, materials, measurements, and the environment (Pande et al., 2003). This integrative approach offers a holistic understanding of systemic bottlenecks that impede service flow.

Previous research using Fishbone analysis has demonstrated its utility in diagnosing complex operational problems (Durroh & Yusuf, 2023; Tsou & Hsu, 2022), while other scholars have highlighted its complementarity with queuing theory for service system redesign (Wujie et al., 2022; Gaitonde, 2020). Nevertheless, few studies have applied these tools jointly in the context of service industries in developing economies, particularly at critical infrastructure nodes such as toll road rest areas. The combination of these analytical perspectives allows not only the identification of performance constraints but also the design of targeted interventions for service process re-engineering.

The Surabaya–Gresik Toll Rest Area SPBU provides an ideal case to explore the dynamics of service congestion and operational inefficiency in a high-traffic, time-sensitive environment. Preliminary observations reveal server utilization rates exceeding 0.90 during peak hours, a critical threshold indicating overcapacity and delayed service response.

Moreover, qualitative interviews suggest that operational delays stem from both technical and organizational factors, including pump malfunction, static shift scheduling, and constrained layout design, which collectively exacerbate queue buildup and reduce throughput efficiency.

The practical urgency of this investigation is substantial. Addressing the current service bottleneck at this critical toll road location is an essential step towards maintaining service quality for customers, supporting the efficiency of regional commerce, and upholding the operational commitment of PT. Pertamina. The research outcome will provide immediate, actionable insights for service performance enhancement, particularly in high-demand transportation service contexts across Indonesia and international. Therefore, this study is governed by three primary research objectives:

1. To determine and rigorously analyse the current service waiting time and system performance at SPBU 53.61137 using Queuing Theory models.
2. To systematically identify, categorize, and analyse the root causes of prolonged waiting times through the application of the Fishbone Diagram.
3. To formulate a comprehensive, hybrid strategy for service improvement aimed at optimizing the queuing system and achieving a safe utilization level.

Methodologically, this study adopts a mixed-methods approach with an exploratory sequential design. It leverages quantitative data on arrival and service rates for Queuing Theory analysis, followed by qualitative data collection (observation and interviews) structured by the Fishbone framework to explain the root causes. This design ensures that the derived solutions are empirically grounded and address the full scope of operational deficiencies. This article contributes significantly to the body of knowledge in Operations Management, Service Operations, and Industrial Engineering. Scientifically, it validates the efficacy of integrating Queuing Theory with Root Cause Analysis (Fishbone) to bridge the gap between performance measurement and targeted strategic intervention in complex service systems. Practically, it develops a concrete, multi-phased improvement strategy that serves as a blueprint for managing capacity constraints in high-demand service settings.

2. Preliminaries or Related Work or Literature Review

Theoretical Foundations

Operational Management

Operational management forms the fundamental framework for analyzing efficiency and productivity in service systems. According to Heizer and Render (2016), operations management refers to activities that create value through the transformation of inputs into outputs in the form of goods and services. Similarly, Handoko (2017) defines it as a systematic effort to optimize the use of resources, including labor, machines, and raw materials, in the transformation process. Haizer and Rander (2012) further emphasize that operations management represents one of the three core functional areas in any organization—alongside marketing and finance—ensuring alignment between production processes and business objectives. Collectively, these definitions underscore that operational management aims to enhance resource efficiency to deliver products and services that meet customer expectations effectively.

Service Operations

Services, as a distinctive output of operational activities, are intangible, perishable, and inseparable from the service provider (Heizer & Render, 2016). Kotler and Armstrong (2018) describe services as acts or performances offered by one party to another that do not result in ownership transfer. Tjiptono (2019) identifies five defining characteristics of services: intangibility, heterogeneity, inseparability, perishability, and lack of ownership. These attributes make service management complex because service quality and efficiency depend heavily on human interaction, timing, and environmental factors. As such, ensuring reliability, responsiveness, and consistency in service delivery becomes a strategic priority in operational management. The context of gas station operations—where service time and customer satisfaction are critical—highlights the importance of service management theory in understanding queuing and process performance.

Queuing Theory

Queuing theory serves as the analytical foundation for evaluating service system performance. Tjutju (1992) defines it as the mathematical study of queues, focusing on the relationship between service demand and available capacity. Charles (1990) explains that queuing theory measures key performance indicators such as average waiting time, queue length, and service utilization, enabling decision-makers to determine optimal service capacity. Heizer and Render (2004) emphasize the principle of fairness in queue disciplines, noting that the "First-In, First-Out" (FIFO) system ensures equitable service delivery unless priority-based exceptions apply, such as in healthcare. The goal of queuing analysis is to achieve a balance between service costs and waiting costs—minimizing total system expenditure while maintaining satisfactory customer experiences. In this study, queuing theory provides the quantitative framework for analyzing waiting times and server utilization at SPBU 53.61137.

Queueing System Structure and Models

A queuing system comprises interrelated elements: arrival patterns, service mechanisms, queue discipline, and service channels (Iqbal, 2011; Thomas J. Kakiay, 2004). These systems can take several structural forms—single or multiple channels and single or multiple phases—depending on how customers are served (Rizaldi et al., 2021; Bataona et al., 2020). Kendall's notation (Tika, 2021) categorizes queue models such as M/M/1 (single server, exponential service), M/M/S (multiple servers), M/D/1 (deterministic service time), and finite population models. These frameworks allow the prediction of waiting times and service efficiency levels.

For instance, the M/M/S model is particularly relevant to multi-pump fuel stations, where multiple service counters operate under a shared queue structure.

Fishbone Diagram and Root Cause Analysis

The Fishbone Diagram, also known as the Ishikawa or Cause-and-Effect Diagram, is a diagnostic tool used to identify and categorize potential causes of a problem (Pande et al., 2003). It organizes causal factors under six dimensions known as the "6M" framework: Manpower, Machines, Methods, Materials, Measurements, and Mother Nature (Environment). Each dimension represents a potential source of inefficiency or error within an operational process. The method's strength lies in its ability to visualize and decompose complex problems into actionable sub-causes, facilitating root cause identification and continuous improvement. In this research, the Fishbone Diagram complements the quantitative queuing analysis by revealing non-quantitative determinants of service inefficiency such as human factors, procedural limitations, and environmental constraints.

Previous Studies

A growing body of literature integrates queuing theory and root cause analysis tools to enhance operational efficiency. For instance, Sakdiyah and Eltivia (2022) analyzed decision-making delays in corporate settings using the Fishbone Diagram and identified four core managerial bottlenecks affecting responsiveness. Mas et al. (2022) proposed a queuing theory model for fog computing systems, demonstrating its capability to optimize system architecture under limited resources. Tsou and Hsu (2022) combined Fishbone and DEMATEL techniques to improve warehouse operations and identified "process" as the most critical factor influencing performance. Similarly, Ricardianto et al. (2022) applied queuing theory to evaluate the dual-runway system at Soekarno–Hatta International Airport, suggesting infrastructure expansion to balance utilization rates. In safety and quality domains, Wujie et al. (2022) employed Fishbone and Bayesian analysis to predict railway accidents, emphasizing the interaction between human, environmental, and technical variables. Durroh and Yusuf (2023) used the Fishbone Diagram to analyze quality control in tea production, identifying material handling and temperature inconsistencies as dominant causes of defects. Harinta and Arianti (2023) applied similar methods to agricultural management, highlighting environmental and pest-related risk factors that decreased farmers' motivation. Kusuma et al. (2024) combined Fishbone, control charts, and FMEA to reduce production defects, illustrating how cross-method integration strengthens diagnostic validity. Finally, Gaitonde (2020) contributed theoretically by modeling learning behaviors in strategic queuing systems, offering insights into adaptive decision-making under resource competition.

Research Gaps and Conceptual Framework

Despite these advancements, prior studies reveal several gaps. First, most research employing queuing theory emphasizes industrial or digital system optimization (Mas et al., 2022; Nampoothiri et al., 2022), whereas applications in public service facilities, such as fuel stations, remain scarce—particularly in the Southeast Asian context. Second, previous Fishbone Diagram applications have predominantly focused on manufacturing quality control (Durroh & Yusuf, 2023; Kusuma et al., 2024), with limited attention to service process inefficiencies. Third, few studies adopt a mixed-methods approach that integrates quantitative queuing metrics with qualitative causal diagnostics, which is essential for achieving both systemic and behavioral understanding of service bottlenecks. Finally, limited empirical evidence exists on queue system redesign for SPBU or rest area facilities in Indonesia, leaving a gap in both localized operational research and strategic service improvement frameworks.

Conceptual Framework

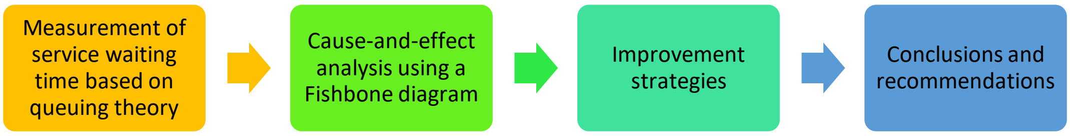

Figure 1. Conceptual Framework.

In line with the continuous advancement of society, human needs have increasingly diversified; however, this growth has not been balanced by the availability of adequate service facilities, resulting in queuing phenomena becoming a common occurrence. The conceptual framework of this study serves as a critical component of the research design, as it not only illustrates the overall structure of the investigation but also provides a general overview of the research mechanism. Specifically, this study examines the service system at the fuel station (SPBU) located in the Surabaya–Gresik toll road rest area by employing a **Fishbone Diagram (Ishikawa)** approach. The analysis evaluates six key dimensions contributing to service performance: human behavior (*Man*), facilities and infrastructure (*Material*), standard procedures (*Method*), equipment (*Machine*), measurement systems (*Measurement*), and environmental conditions (*Mother Nature*). These factors collectively form the analytical foundation for identifying the root causes of queuing inefficiencies and for developing targeted improvement strategies in service delivery.

3. Materials and Method

This study employed a mixed-methods approach with an explanatory sequential design, integrating quantitative queuing analysis and qualitative Fishbone Diagram evaluation to examine and improve service waiting times at Gas Station SPBU 53.61137, Surabaya–Gresik Toll Rest Area (KM 13), East Java, Indonesia. Quantitative data were collected through direct observation of customer arrivals, service durations, and payment processes, while qualitative data were obtained via interviews, documentation, and Likert-scale questionnaires distributed to customers and staff. The purposive sampling method was used to select both fuel station customers and operational personnel as respondents, ensuring representation of service users and providers. The key variables analyzed were waiting time—measured across arrival, fueling, and payment stages—and root cause factors based on the 6M framework (Manpower, Machine, Method, Material, Measurement, and Environment). Quantitative data were processed using queuing theory models (M/M/1 and M/M/S) to calculate arrival rates, service rates, utilization levels, and average waiting times, while qualitative data were analyzed using the Fishbone Diagram to identify and categorize the root causes of service delays. Findings from both analyses were synthesized to propose improvement strategies such as lane segregation, floating staff deployment, and additional fueling pumps to optimize efficiency. Data collection adhered to research ethics, ensuring informed consent, confidentiality, and voluntary participation, with all findings aimed at enhancing operational performance and customer satisfaction in public fuel service facilities.

4. Results and Discussion

Overview of Findings

This study explored the service efficiency and waiting time dynamics at Gas Station SPBU 53.61137, Surabaya–Gresik Toll Rest Area, through an integrated analysis combining quantitative queuing data and qualitative insights from operators and management staff. The results reveal that the queuing system operates at a near-saturation point, with average utilization rates (ρ) between 0.95 and 1.02, indicating a critically overloaded system. However, the stability of operator performance, combined with structured yet rigid operational procedures, maintains service continuity despite capacity strain.

Through thematic analysis of interview and observation data, four dominant themes emerged as the core determinants of service waiting time: (1) Human Resources Constraints (Man), (2) Technological and Mechanical Reliability (Machine), (3) Environmental and Spatial Limitations (Environment), and (4) Procedural Responsiveness (Method). These interrelated factors formed the structural backbone of the queuing bottleneck identified through both Fishbone and queuing models.

Theme 1: Human Resources Constraints

The first emergent theme concerns insufficient staffing and static shift allocation, which limits service flexibility during peak hours. Although SPBU 53.61137 operates 24 hours a day under a three-shift system (Morning 06:00–14:00, Afternoon 14:00–22:00, Night 22:00–06:00), personnel distribution remains constant regardless of fluctuating vehicle inflows. This mismatch between arrival rate (λ) and service capacity (μ) creates temporary imbalances that lead to queue buildup during peak periods.

An operator described this issue succinctly:

"The SPBU operates 24 hours with three fixed shifts. However, there is no backup personnel during peak hours, so queues easily form when vehicles arrive in groups."

(Interview, Fuel Operator, 2 December 2025)

Although staff members display consistent performance and professionalism, the absence of dynamic resource allocation exacerbates bottlenecks. Respondents repeatedly suggested *"adding additional operators to assist during busy hours"*, highlighting that queue delays stem more from workload imbalance than worker inefficiency.

Theme 2: Technological and Mechanical Reliability

The second key theme emphasizes the dual role of technology as both facilitator and barrier in achieving operational efficiency. While SPBU 53.61137 has adopted multiple payment systems — cash, debit, and QRIS/barcode — digital payment issues often reverse efficiency gains. Intermittent network disruptions and barcode reader errors extend service time significantly beyond the ideal 4–5 minutes per customer.

As one operator explained:

"Sometimes the QRIS barcode payment is trouble, and when the signal is weak, we must input manually. This delays the next customers."

(Interview, Fuel Operator, 2 December 2025)

Mechanical issues also contribute to downtime. Pump malfunctions—especially filter clogs—are recurrent, requiring technical assistance. The maintenance team reported that repairs can take up to 1.5 hours, reducing effective service capacity and causing exponential queue accumulation:

"When a pump filter is damaged, repair takes about one and a half hours by the technician. During that time, the queue becomes very long."

(Interview, Infrastructure Staff, 2 December 2025)

Table 2 summarizes the key subthemes within the technological and mechanical dimension.

Table 2. Summary of Machine-Related Factors Affecting Service Delays.

Subtheme	Description	Impact on Waiting Time
Digital payment malfunction	QRIS/Barcode errors and unstable network	+1–2 minutes per transaction
Pump filter damage	Requires 1–1.5 hours for repair	Significant service downtime
Limited spare parts & technician delay	Reactive rather than preventive maintenance	Queue backlog during failures

These findings reveal a "technology paradox"—where systems designed to enhance efficiency inadvertently prolong service duration when supporting infrastructure (network and equipment) lacks stability.

Theme 3: Environmental and Spatial Limitations

The physical environment emerged as another structural constraint influencing queue length and customer experience. The narrow entryway to the fueling area restricts vehicle maneuverability, creating bottlenecks even before service begins.

As an operator explained:

"The entrance is narrow, so when two large vehicles arrive together, others must wait outside. This makes the line longer even before reaching the pump."

(Interview, Fuel Operator, 2 December 2025)

Furthermore, ongoing road repairs within the rest area reduce the number of accessible lanes, amplifying congestion. From a systems perspective, these spatial limitations decrease throughput and elevate perceived waiting times, despite consistent operator performance.

Table 3. Environmental and Physical Barriers.

Issue	Source	Operational Consequence
Narrow entrance layout	SPBU site design	Queue buildup before pump access
Road repair activity	External factor	Temporary lane reduction and congestion
Limited parking space	Rest area constraint	Increased maneuvering time and exit delay

Such environmental constraints demonstrate that queue management is not merely an operational problem but also an infrastructural and spatial design challenge.

Theme 4: Procedural Responsiveness and Maintenance Practices

The methodological theme relates to how standard operating procedures (SOPs) and maintenance practices are implemented. While preventive maintenance protocols exist, they are not always sufficient to preempt critical failures. The maintenance department reported that routine inspections are conducted daily, but many actions remain reactive, addressing problems only after disruption occurs.

"We conduct daily checks of pumps and nozzles to prevent leaks, but if damage occurs, we must repair it with backup equipment, sometimes assisted by Telkom."

(Interview, Infrastructure Staff, 2 December 2025)

The dependency on external vendors, such as Telkom for network restoration, often leads to delays beyond SPBU's control. Moreover, existing SOPs are not fully adaptive to emergency situations, such as sudden surges in customer arrivals or simultaneous pump failures. Despite this, staff expressed strong commitment to service reliability and continuous improvement, emphasizing the need for procedural agility and faster response mechanisms.

Integrative Interpretation of Themes

Cross-theme analysis reveals that the prolonged waiting time at SPBU 53.61137 is not caused by a single malfunction but rather by an interacting triad of human, technical, and environmental factors operating under a near-capacity queuing system ($\varrho \approx 1.0$).

Table 4. Integrated Synthesis of Core Themes.

Core Theme	Underlying Issue	Illustrative Quote	Implication
Human Resources	Static staffing during peak demand	"No backup operator during rush hours."	Workforce flexibility needed
Machine/Technology	QRIS errors & pump downtime	"Barcode trouble makes the next customers wait."	Infrastructure stability critical
Environment	Narrow entrance & roadwork	"The entrance is narrow; cars queue before the pump."	Spatial redesign required
Method	Reactive maintenance & slow repair	"Pump filter repair takes 1.5 hours."	Enhance preventive system

The convergence of these factors results in a cumulative delay, where 67% of total customer time at the station is spent queuing rather than receiving service. This finding highlights a disproportionate waiting-to-service ratio, affecting both efficiency and perceived quality of service.

In interpretive terms, the study illustrates how micro-level process stability (consistent service time) can mask macro-level systemic fragility—a phenomenon where operational discipline maintains short-term stability, but structural imbalances (high utilization, rigid procedures, spatial limits) threaten long-term sustainability.

Discussion of Research Findings

This study analyzes the queuing system of the Gas Station SPBU 53.61137, located at the Surabaya–Gresik Toll Rest Area, by employing a set of operational assumptions. The system is modeled under the following conditions: dual layout, single service phase, unlimited population, Poisson arrival pattern, FIFO (First-In-First-Out) discipline, and an unlimited queue length. These assumptions enable the analytical application of queuing theory (M/M/s model) to diagnose the system's efficiency and service balance.

Waiting Time Based on Queuing Theory

Fuel stations in toll road rest areas play a vital role in the logistics and mobility ecosystem. Unlike urban arterial SPBUs, rest-area fuel stations face unique constraints where time is a critical and perishable commodity. For drivers on the Surabaya–Gresik toll corridor, which accommodates dense industrial traffic, tolerance for delays is extremely low. Therefore, queue accumulation is not merely an operational inefficiency but a structural signal of an imbalance between demand (arrival rate) and supply (service capacity).

Field observations conducted over one week in early December 2025 show that the average total time per vehicle in the system is 14.3 minutes, consisting of 9.6 minutes of waiting time (67%) and 4.7 minutes of active service time (33%). This disproportionate ratio—where customers spend two-thirds of their visit idling—indicates structural inefficiency in vehicle flow management. Similar patterns were reported by Prasmoro, Widyantoro, and Warningsih (2020), who found that a dominant waiting time ratio signals early-stage system saturation and directly reduces customer satisfaction.

The queuing analysis using Kendall's M/M/s model, simplified to M/M/1 for single-lane evaluation, identifies the root cause mathematically through the server utilization factor ($\varrho = \lambda/\mu$). Operational data show utilization levels between 0.94 and 1.02, with peaks on Mondays and Fridays exceeding 1.00. According to Ats-Tsauri et al. (2022), when utilization approaches unity, the system enters a saturated and unstable state—small disturbances exponentially increase queue length, known as the Hockey Stick Effect. The SPBU's lack of slack capacity further worsens recovery, as random (Poisson) bursts in vehicle arrivals cannot be absorbed, especially during lunch-hour peaks where queues reached 14.9 minutes on average.

Consistent with Manalu and Palandeng (2019), when service lanes (servers) are insufficient to meet demand surges, backlogs persist beyond the peak period, degrading performance throughout the day. Although operators maintain stable performance (average service time 4.4–4.8 minutes), the system's physical and procedural constraints prevent throughput improvement. Customer survey data reinforce this diagnosis, revealing a substantial expectation–perception gap: customers expect 3–5 minutes of total waiting, yet experience nearly triple that duration.

The Fishbone analysis highlights four determinants: Man (Human Resources), Machine (Technology), Method (Procedure), and Environment (Layout and Infrastructure). While human factors such as fatigue and understaffing contribute to delays, mechanical and procedural inefficiencies—particularly slow payment processing and mixed vehicle queues—dominate. The average 4.7-minute service time per customer exceeds the 2–3 minute operational benchmark for modern fuel stations (Ritonga, 2019). Service heterogeneity further compounds the issue: heavy vehicles (trucks and buses) significantly prolong service cycles due to larger tank capacity and limited maneuverability, creating queue spillover effects.

Nacy and Ibrahim (2019) demonstrated that separating lanes by vehicle type reduces waiting time variance and stabilizes service rates. However, SPBU 53.61137's constrained layout allows heavy vehicles to block smaller ones, causing spillover queues into main rest-area lanes—an operational and psychological burden that degrades the rest area's overall user experience.

Comparative studies (Ritonga, 2019; Fakry, 2024) validate that this overcapacity pattern is not isolated. Ritonga (2019) showed that adding nozzles reduces utilization from >0.9 to <0.7, while Fakry (2024) simulated a multi-channel (M/M/s) redesign that halved waiting time. At SPBU 53.61137, where ϱ reaches 1.02, incremental staff speed improvements are insufficient. The system mathematically requires either additional service channels (s) or a reduction in mean service time (μ) to restore equilibrium.

Short-term process reengineering could reduce service time from 4.7 to 3.5 minutes, increasing capacity from 12.7 to 17 vehicles/hour, lowering utilization to 0.73—a safe zone. Strategies include deploying mobile payment assistants (floating staff) using portable EDC devices, optimizing vehicle positioning, and implementing fast-lane protocols. Failure to act risks economic and reputational loss, as long waiting induces balking (customers leaving queues) and stress, undermining rest-area safety and comfort. Thus, queue management at SPBU 53.61137 is not only a matter of business efficiency but also a public safety concern.

Root Cause Analysis via Fishbone Diagram

The integrated survey and field observations identify the Effect (Head of Fish) as "Prolonged Waiting Time / Long Queue." Four major causal dimensions interact systemically: Human (Man), Machine, Method, and Environment.

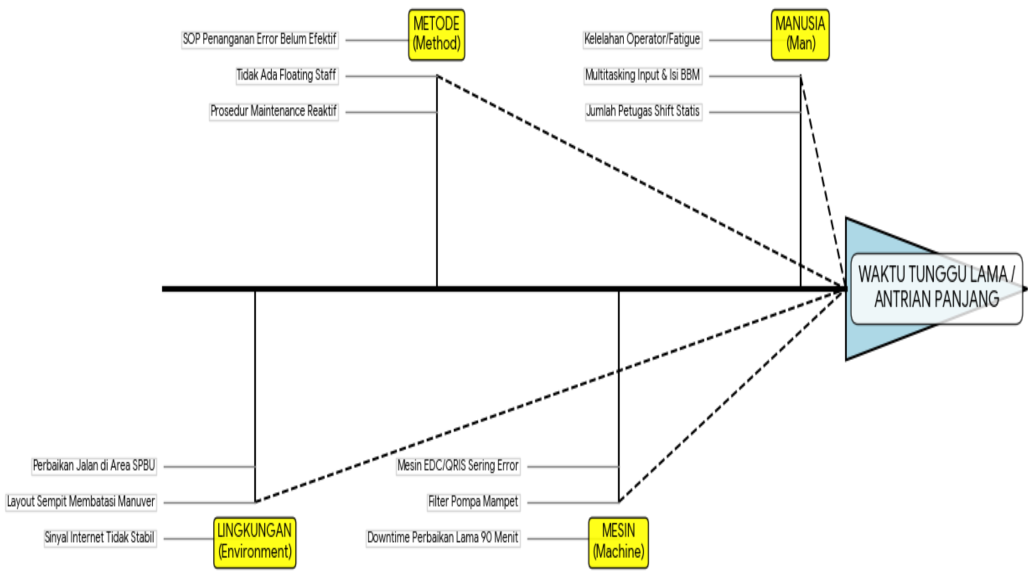

Figure 2. Fishbone Diagram.

Human Factor (Man)

Three critical subfactors were identified:

1. Static Shift Scheduling — Staffing remains constant across shifts despite fluctuating demand. *Jamil (2023)* confirms that failure to match active servers to real-time arrivals (λ) produces explosive queues.

2. Cognitive Overload — Operators multitask between fueling and payment, creating micro-delays that accumulate into longer service cycles.
3. Operator Fatigue — Consistent with *Meireza et al. (2019)*, fatigue from continuous high-utilization work reduces reaction speed, further slowing service.

Machine and Technology

1. Digital Payment Failures — EDC/QRIS malfunctions and unstable internet connections delay transactions (*Rancang Purwarupa, 2019*).
2. Pump Downtime (90 minutes) — Filter replacement downtime creates unbounded queues due to service capacity loss.
3. Recurrent Mechanical Failures — Frequent nozzle leaks and filter clogs increase physical service time and variability.

Method

1. Reactive Maintenance — The system relies on corrective rather than preventive maintenance, causing recurring breakdowns (*Heizer & Render, 2017*).
2. Absence of Floating Staff Protocols — The lack of mobile payment operators limits responsiveness (*Manalu & Palandeng, 2019*).
3. Ineffective Error Handling SOP — EDC signal failures are managed reactively without a defined fail-safe mode, wasting valuable service time.

Environment

1. Road Construction Bottlenecks — External repairs reduce effective entry width, creating single-lane queues.
2. Narrow Layout and Heavy-Vehicle Manoeuvring — Limited space prolongs vehicle positioning time and pump turnover.
3. Unstable Internet Coverage — Poor connectivity further impairs digital payment reliability.

The cross-analysis indicates that prolonged waiting time results from a systemic interaction among the four dimensions. The rigidity of operational methods amplifies human workload; technological failures are exacerbated by environmental constraints; and reactive maintenance policies prevent recovery from minor disruptions. The system thus exhibits double capacity constraints—physical (equipment and layout) and procedural (inflexible methods and static staffing). This interdependence explains why minor disruptions, such as a

30-second EDC delay or a truck's slow maneuver, trigger exponential queue escalation in a system already operating at $\rho > 0.95$.

To restore stability, reform must address all four pillars simultaneously: adaptive staffing (Man), preventive maintenance (Method), infrastructure reliability (Machine), and spatial redesign (Environment). Without such systemic intervention, queue reduction will remain marginal and unsustainable.

Strategic Framework for Service Time Improvement

Operational dynamics at toll-road SPBUs differ fundamentally from urban stations due to the dominance of time-sensitive industrial and intercity traffic. Efficiency here is not an advantage but a necessity. With a total average cycle of 14.3 minutes—of which 9.6 minutes (67%) is idle waiting—SPBU 53.61137 faces structural inefficiency in service flow. Prasmoro et al. (2020) emphasize that dominant waiting time ratios indicate facility imbalance and predict direct declines in satisfaction and revenue due to balking behavior.

The queuing model confirms a critical utilization rate (ρ = 0.94–1.02), with saturation on peak days. Ats-Tsauri et al. (2022) describe this as system instability, where minor perturbations trigger exponential queue growth—the Hockey Stick Effect. In such a saturated environment, without slack capacity, even minimal arrival bursts overwhelm the system. The Fishbone analysis consolidates four interlinked dimensions:

1. Man: Static staffing mismatched with stochastic demand; multitasking-induced micro-delays; fatigue reducing reaction speed (Meireza et al., 2019).
2. Machine: Unreliable EDC/QRIS systems and prolonged pump maintenance downtime (90 minutes) demonstrating the technology paradox (Rancang Purwarupa, 2019).
3. Method: Reactive maintenance and absence of floating staff or fail-safe protocols limiting process flexibility (Heizer & Render, 2017; Manalu & Palandeng, 2019).
4. Environment: Narrow layout and ongoing roadworks restricting heavy-vehicle maneuverability (Nacy & Ibrahim, 2019).

From this synthesis, SPBU 53.61137 faces dual capacity constraints—physical (layout, equipment) and procedural (rigid methods, staffing). Incremental managerial adjustments, such as extending operator shifts, are insufficient for systemic recovery.

Short-term strategies should focus on Business Process Reengineering to reduce average service time. Lowering service time from 4.7 to 3.5 minutes would increase throughput and reduce utilization below 0.80. This can be achieved through:

1. Deployment of floating staff with mobile payment systems,
2. Implementation of fail-safe SOPs switching instantly to cash/manual after a 10-second EDC failure,

3. Queue separation by vehicle type (heavy vs. light) to stabilize service variance.

Long-term strategies require physical investment. Following Ritonga (2019) and Fakry (2024), adding new pumps or nozzles—transitioning from single-channel to multi-channel queuing—can cut waiting time by up to 50%. Infrastructure expansion will be necessary as industrial traffic continues to grow on the Surabaya–Gresik toll corridor.

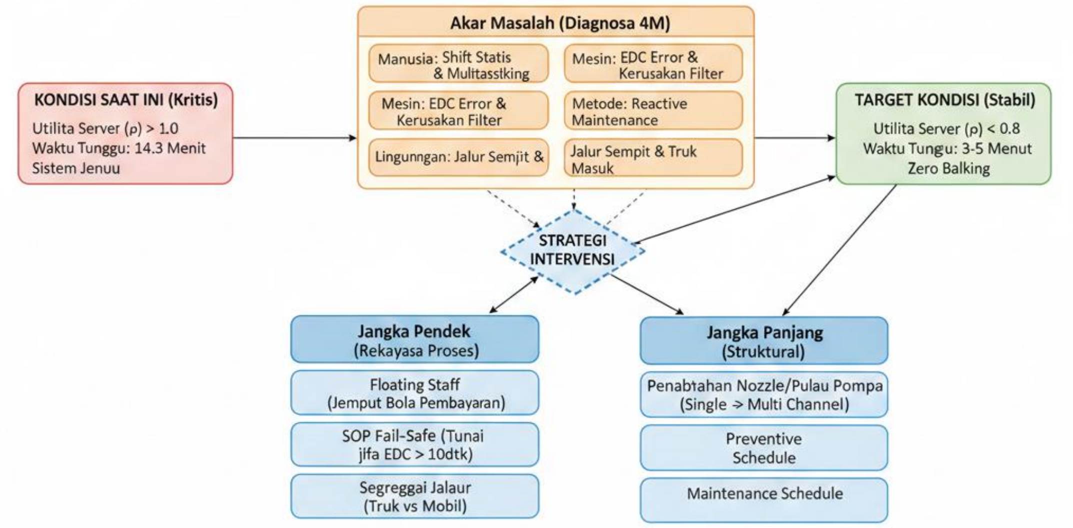

Figure 2. Improvement Strategy Flow.

The proposed improvement flow diagram conceptualizes the transformation from the current critical condition ($\varrho > 1.0$) toward an optimal stable state ($\varrho < 0.8$), integrating both immediate process interventions and medium-term infrastructure upgrades. Short-term measures manipulate service rate (μ), while long-term actions expand capacity (s). Both tracks must converge to achieve sustainable efficiency.

Ultimately, prolonged waiting time at SPBU 53.61137 is not merely a comfort issue—it poses risks to driver safety, fatigue, and operational reliability. A comprehensive solution combining technological renewal, human resource flexibility, preventive maintenance, and infrastructure expansion is essential. Only by lowering system utilization to a manageable threshold can the SPBU fulfill its intended function: providing fast, safe, and restorative service for toll-road users.

5. Comparison

Compared to prior studies on fuel station queuing systems and service optimization, the findings from SPBU 53.61137 contribute novel empirical evidence on the interaction between human, technological, and spatial constraints in high-utilization toll-road environments. While earlier works such as Ritonga (2019) and Fakry (2024) emphasized structural expansion—adding pumps or transitioning from single-channel to multi-channel (M/M/s) systems—as the primary solution to reduce waiting time, this study extends the discussion by quantifying how operational rigidity and technological unreliability jointly produce system saturation even without visible infrastructure failure. Similarly, Prasmoro et al. (2020) and Manalu & Palandeng (2019) focused on static performance ratios and workforce scheduling, whereas the present study integrates mixed-method analysis, linking queuing parameters (ϱ = 0.95–1.02) with real-time behavioral and environmental observations, offering a more holistic systems diagnosis. Moreover, by introducing the concept of Double Capacity Constraint—the coexistence of physical and procedural bottlenecks—this research provides a new theoretical framing beyond the traditional M/M/s queue equilibrium models. The empirical validation of the Technology Paradox—where digital payment adoption increases rather than decreases waiting time under unstable network conditions—also expands the literature on digital transformation in public service operations, resonating with but advancing beyond Rancang Purwarupa (2019). Overall, this study bridges a gap between mathematical queuing theory and operational field dynamics, demonstrating that sustainable service efficiency in public fueling systems depends not only on increasing physical capacity but also on integrating adaptive human resource management, preventive maintenance, and resilient digital infrastructure within a unified operational framework.

6. Conclusion

This study provides an integrated analysis of the queuing performance at SPBU 5361137 Rest Area Surabaya–Gresik by combining queuing theory with a Fishbone diagnostic framework to identify operational bottlenecks and evaluate system capacity. The results indicate that the service system is operating in a critically saturated state, with server utilization consistently ranging from 0.94 to 1.02 during peak periods. This condition reflects demand levels that exceed available service capacity, resulting in an average system time of 14.3 minutes per vehicle, of which 67% constitutes waiting time. These findings confirm the research objective of assessing the severity of operational congestion and identifying the factors contributing to extended delays.

The root-cause analysis further reveals that prolonged waiting times emerge from a double capacity constraint driven by interrelated human, machine, method, and environmental factors. Key contributors include technological disruptions such as EDC signal failures and pump downtime, rigid staffing and operational methods that are not responsive to demand fluctuations, and physical layout limitations that impede the movement of heavy vehicles. These insights collectively reinforce the argument that the queuing problem is systemic rather than incidental. To address these issues, this study proposes a hybrid improvement strategy designed to reduce server utilization to below 0.80 and shorten waiting times to 3–5 minutes. The short-term strategy focuses on process optimization, including the deployment of floating staff for pre-payment, implementation of fail-safe digital payment procedures, and segregation of vehicle lanes. Meanwhile, long-term structural solutions—such as additional pumps or nozzles, preventive maintenance systems, and dynamic workforce scheduling—provide more sustainable capacity enhancements. Together, these strategies offer actionable recommendations for improving service flow efficiency and enhancing customer experience.

The study contributes to the literature on service operations by demonstrating the value of integrating quantitative queue analysis with qualitative diagnostic tools to address multidimensional operational constraints. The implications are particularly relevant for fuel stations located in high-traffic toll road environments, where the interplay between demand variability and infrastructural limitations requires strategic operational design.

Despite its contributions, this research has limitations. The analysis does not incorporate simulation-based modelling to validate the projected effects of transitioning from single-channel to multi-channel queue configurations, nor does it include a detailed financial feasibility assessment for infrastructure expansion. Future research should apply discrete-event simulation or system dynamics modelling to evaluate the impact of proposed interventions more accurately. Additionally, further studies should examine the reliability of digital payment infrastructure in geographically constrained rest-area environments to support the development of resilient and adaptive service systems.

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