

FAILURE MODE AND EFFECTS ANALYSIS OF CHOKE AND GATE VALVES IN A BACK PRESSURE MANIFOLD

Khusnun Widiyati^{1*}, Athalla Aqsha Suryoatmodjo¹, Dompok Sitorus²

¹Department of Electrical Engineering, Faculty of Industrial Engineering, Universitas Pertamina

²PT Pertamina Drilling Service Indonesia

Abstract

Choke and gate valves are critical components of a back pressure manifold (BPM), supporting pressure regulation, flow control, and isolation during drilling operations. Their failure may compromise well-control reliability and operational safety. This study identifies and prioritizes failure modes of choke and gate valves using a workshop-based Failure Mode and Effects Analysis (FMEA). Data were obtained from workshop observations, hydrostatic testing, maintenance documentation, and consensus assessments by three maintenance personnel. Four choke-valve and five gate-valve failure modes were evaluated based on severity, occurrence, and detection ratings, from which Risk Priority Numbers (RPNs) were calculated. The results showed that choke-valve seat erosion or wear had the highest RPN of 324, followed by leakage, erosion, or wear at the gate/seat-ring interface with an RPN of 225, and sticking or unresponsive operation of the choke-valve stem and actuator with an RPN of 210. The choke valve exhibited a higher average RPN than the gate valve because its throttling function exposes internal components to substantial pressure drops, accelerated flow, turbulence, and possible particle-induced erosion. The findings demonstrate that sealing-surface integrity and valve-operating reliability are the main maintenance priorities. Maintenance strategies should combine RPN ranking with severity assessment and incorporate internal visual inspection, hydrostatic and functional testing, dimensional examination, cleaning, lubrication verification, and targeted nondestructive testing. Although the identified degradation mechanisms require further verification, this study provides a structured basis for prioritizing BPM valve inspection and maintenance.

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Corresponding Author:

Khusnun Widiyati

Department of Mechanical
Engineering, Universitas Pertamina,
Indonesia

Email:

khusnun.widiyati@universitaspertamina.ac.id

1. Introduction

1. Introduction

Maintaining wellbore pressure within a safe operating window is one of the most critical requirements in drilling operations. When formation pressure exceeds the hydrostatic pressure exerted by the drilling fluid, formation fluids may enter the wellbore and initiate a kick. If not properly controlled, this condition can escalate into loss of well control and potentially lead to a blowout. A back pressure manifold (BPM), commonly associated with a choke manifold system, is therefore used to direct returning well fluids and apply controlled surface backpressure while the kick is circulated out of the well. The system generally consists of high-pressure piping, fittings, pressure-monitoring devices, choke valves, and isolation valves arranged to provide alternative flow paths.

The design and performance requirements of choke-and-kill equipment are addressed in API Specification 16C, reflecting the safety-critical role of this equipment in drilling operations [1].

Within a BPM, choke valves and gate valves perform different but complementary functions. A choke valve regulates flow by creating a controlled restriction, thereby producing the pressure drop required to maintain the desired wellbore pressure. In contrast, gate valves are primarily used to isolate, open, or redirect flow through selected manifold lines. Reliable operation of both valve types is essential because the choke valve controls the magnitude of backpressure, whereas the gate valves establish and isolate the intended flow path. Failure of either component may reduce the ability of the manifold to control pressure and safely handle well fluids.

These valves operate under demanding conditions involving high pressure, substantial pressure differentials, multiphase flow, rapid changes in flow velocity, corrosive media, and entrained solid particles. Such conditions expose the valve trim, seat, gate, stem, packing, seals, body, and internal passages to several degradation mechanisms. Common failure modes include internal and external leakage, erosion of the seat and flow-control components, corrosion, obstruction of internal passages, stem sticking, packing deterioration, and deformation or cracking of pressure-containing components. Previous research has shown that choke-valve erosion is strongly influenced by flow velocity, pressure drop, particle loading, particle-impact angle, valve opening, material properties, and manifold geometry [2–4]. Computational studies have also demonstrated that changes in inlet pressure and manifold configuration can alter the local flow field and erosion distribution, causing certain valves or internal regions to experience more severe material loss than others [3].

Failure of a choke valve may produce unstable pressure regulation, an unintended change in flow rate, loss of throttling accuracy, excessive vibration, and progressive erosion of downstream equipment. Severe deterioration of the seat or trim may also prevent the valve from maintaining the required pressure differential. Gate-valve failure can similarly compromise flow isolation. Damage to the gate or seat ring can cause internal leakage even when the valve is nominally closed, while degradation of the packing or bonnet seal can allow well fluids to escape to the surrounding environment. Sticking or deformation of the stem may delay valve operation during a critical well-control response. Failure of the valve body is less frequent but potentially more severe because it can affect pressure containment. These failures may result in unplanned shutdowns, increased maintenance expenditure, equipment damage, environmental release, personnel exposure, and reduced reliability of the overall well-control system.

Failure analysis is consequently important not only for identifying a damaged component, but also for understanding how the component failed, why the failure occurred, and how it affects the performance of the larger system. A repair-oriented approach that only replaces a seal, relaps a seat, or restores pressure tightness may return a valve to service without addressing the operating or maintenance conditions that initiated the degradation. A systematic analysis can distinguish the observed failure mode, such as leakage or sticking, from its possible mechanisms and causes, such as abrasive erosion, corrosion, surface damage, contamination, misalignment, inadequate lubrication, or improper assembly. A comprehensive investigation of a failed gate valve has, for example, shown the value of integrating visual inspection, nondestructive testing, material characterization, mechanical testing, and microscopic examination when establishing a defensible failure mechanism [5]. Nevertheless, such laboratory-based investigations may not always be feasible during routine workshop maintenance, particularly when operational history and failed-component samples are limited.

Failure Mode and Effects Analysis (FMEA) offers a practical approach for evaluating valve failures under these constraints. FMEA systematically identifies the function of each component, its potential failure modes, possible causes, and consequences. The relative importance of each failure mode is commonly assessed using severity (S), occurrence (O), and detection (D) ratings. These ratings may be combined into a Risk Priority Number (RPN).

The RPN can support maintenance prioritization by identifying failure modes that combine serious consequences, relatively high likelihood, and limited detectability. FMEA has been applied to valves and other oil-and-gas equipment to organize failure knowledge and guide inspection or mitigation measures [6,7]. However, the RPN must be interpreted alongside its individual severity, occurrence, and detection scores because different risk combinations can produce identical RPN values. Failure modes with very high severity should therefore remain a priority even when their estimated occurrence is relatively low.

Previous valve studies have mainly focused on predicting erosion through computational fluid dynamics, investigating specific material failures through laboratory examination, or applying FMEA to pipeline ball valves, butterfly valves, and broader subsea control systems [2–7]. These studies provide important insights into valve

degradation, but limited published work has comparatively prioritized failure modes of choke valves and gate valves within the same back pressure manifold using evidence obtained during actual workshop inspection and maintenance. The functional interaction between the two valve types is also rarely emphasized: deterioration of the choke valve affects pressure regulation, whereas gate-valve deterioration affects isolation and flow-path availability. Evaluating them separately may therefore overlook their combined contribution to manifold reliability.

To address this gap, the present study analyzes the failure modes of choke valves and gate valves in a back pressure manifold maintained at the BOP Workshop of PT Pertamina Drilling Services Indonesia, Indramayu. Data were obtained through workshop observation, interviews with maintenance personnel, documentation of inspection and repair activities, and a review of relevant literature. FMEA was employed to identify potential failure modes, assess their effects and causes, and establish maintenance priorities using severity, occurrence, detection, and RPN values. This study contributes a workshop-based comparison of the risk profiles of choke and gate valves and provides recommendations for inspection, repair, and preventive maintenance. Because detailed operational histories and laboratory material analyses were unavailable, the identified mechanisms are interpreted as technically plausible causes supported by field observations and expert judgment rather than definitive root-cause conclusions.

2. Method

A. Reserach Design

This study employed a descriptive case-study design combined with Failure Mode and Effects Analysis (FMEA) to identify and prioritize potential failure modes of choke valves and gate valves installed in a back pressure manifold (BPM). The case-study approach was selected because the investigation focused on valve conditions encountered during actual workshop inspection, repair, and testing activities. FMEA was used as a structured risk-assessment technique because it enables the systematic examination of component functions, failure modes, failure effects, potential causes, existing controls, and recommended actions.

The application of FMEA was consistent with the general principles of risk assessment described in IEC 31010:2019, which recognizes FMEA as a technique for identifying how components or processes can fail and evaluating the consequences of those failures [8]. The technical functions and component boundaries of the choke-and-kill equipment were interpreted with reference to API Specification 16C. However, API Spec 16C primarily establishes requirements for the design and manufacture of choke-and-kill equipment and does not provide a complete procedure for field repair; therefore, the workshop's approved maintenance procedures and acceptance criteria remained the primary operational references [1].

The research was conducted at the BOP Workshop of PT Pertamina Drilling Services Indonesia, Indramayu, Indonesia, from 1 August to 30 September 2025. The units of analysis were a choke valve and a gate valve forming part of a BPM undergoing workshop maintenance. The study was limited to the condition of the valves observed during the maintenance period and did not include long-term monitoring of the valves during drilling operations.

B. Reserach Objects and System Boundaries

The BPM was treated as a well-control subsystem that directs fluid flow and generates controlled surface backpressure. Within the defined system boundary, the choke valve was considered a flow-regulating component, whereas the gate valve was considered an isolation and flow-routing component.

The choke-valve analysis covered the following functional elements:

1. seat or flow-control interface;
2. stem and actuator;
3. seal and packing system; and
4. internal flow passage.

The gate-valve analysis covered:

1. gate and seat ring;
2. stem and handwheel;

3. valve body and body bushing;
4. bonnet and retainer; and
5. packing and sealing system.

External piping, instrumentation, manifold support structures, control panels, and downstream drilling equipment were excluded unless their conditions directly affected the interpretation of a valve failure effect. This boundary was established to maintain consistency between the available workshop evidence and the scope of the FMEA.

C. Data Sources and Collection Procedures

The study used primary and secondary data. Primary data were obtained through direct observation of valve maintenance, interviews with workshop personnel, and documentation of inspection and repair activities. Secondary data were obtained from technical manuals, workshop records available during the study, relevant standards, and published literature concerning valve degradation and FMEA.

Data collection comprised four main activities:

- observation of the valve condition before, during, and after disassembly;
- examination of visible indications of leakage, wear, surface deterioration, obstruction, or impaired movement;
- interviews with personnel involved in BPM inspection and maintenance; and
- documentation of the repair sequence, including hydrostatic testing, dismantling, cleaning, inspection, lapping, component replacement where required, reassembly, and final hydrostatic testing.

The initial hydrostatic test was used to identify pressure-boundary or seat-leakage indications before dismantling. Disassembly and cleaning were then performed to provide access to the internal components. Visual examination focused on the seat, gate, stem, packing, sealing surfaces, body, and internal flow passages. Where recoverable surface irregularities were identified, lapping was performed to restore sealing-surface contact. The valve was subsequently reassembled and subjected to a final hydrostatic test according to the workshop procedure.

The final manuscript should report the test pressure, holding duration, test medium, allowable pressure loss, leakage criterion, and pass/fail result. These values should not be inferred from API Spec 16C because the specification addresses manufacturing requirements and does not, by itself, represent the company's field-repair procedure [1].

D. Expert Respondents

Risk assessment involved three workshop personnel who were directly familiar with BPM maintenance: a senior mechanic, a mechanic responsible for BPM-related work, and a workshop helper. Their involvement enabled the analysis to incorporate practical knowledge concerning component functions, observable failure symptoms, likely failure causes, operational consequences, and the ability of existing inspection practices to detect degradation.

Before publication, the manuscript should add each respondent's years of experience, technical role, relevant certification, and level of involvement in choke- and gate-valve maintenance. These characteristics are necessary because the present FMEA is expert-based and the reliability of the ratings depends partly on the respondents' competence and experience.

Structured or semi-structured expert interviews are recognized risk-identification techniques under IEC 31010 [8]. Nevertheless, expert judgment can introduce subjectivity and inconsistency into conventional FMEA ratings, especially when detailed failure-frequency data are unavailable [10,11]. The findings were therefore interpreted as relative maintenance priorities within the investigated workshop context rather than as statistically estimated failure probabilities.

E. Identification of Failure Modes

Failure modes were identified by integrating three sources of evidence:

1. observable valve conditions during inspection and repair;
2. maintenance personnel's experience; and
3. technically plausible failure modes reported in standards and valve-failure literature.

For each component, the analysis documented:

- component function;
- potential failure mode;
- local effect;
- effect on BPM operation;
- possible cause or degradation mechanism;
- existing detection or control method; and
- recommended mitigation.

A distinction was maintained among an observed failure mode, a potential failure mechanism, and a root cause. Leakage, sticking, obstruction, or loss of pressure regulation could be identified as failure modes based on functional evidence. Erosion, corrosion, contamination, misalignment, insufficient lubrication, and assembly defects were treated as possible mechanisms or causes unless supported by dimensional measurements, material characterization, microscopic examination, or operating-history data. This distinction prevented workshop observations from being presented as definitive root-cause conclusions.

Four failure modes were identified for the choke valve:

- erosion or wear of the seat;
- sticking or loss of response of the stem/actuator;
- leakage through the seal or packing; and
- obstruction of the internal flow passage.

Five failure modes were identified for the gate valve:

- leakage, erosion, or wear of the gate/seal-ring interface;
- sticking, bending, or wear of the stem/handwheel assembly;
- cracking, deformation, or erosion-corrosion of the body/body bushing;
- leakage at the bonnet, retainer, flange, or gasket; and
- leakage through the packing or seal.

F. Severity, Occurrence, and Detection Assessment

Each failure mode was evaluated using severity (S), occurrence (O), and detection (D) ratings on a 1–10 ordinal scale. Higher values represented more adverse conditions. Severity described the magnitude of the consequences if a failure occurred. A low severity score represented a minor effect with limited influence on valve operation, whereas a high score indicated possible loss of pressure regulation, loss of isolation, pressure-containment failure, safety consequences, or disruption of well-control capability.

Occurrence represented the estimated likelihood of the failure mode or its associated cause. Because complete data on operating hours, valve cycles, population size, and historical failure frequency were unavailable, occurrence scores were based primarily on the respondents' workshop experience and the relative frequency with which similar damage had been encountered. Accordingly, occurrence values should be interpreted as qualitative expert ratings rather than numerical probabilities.

Detection represented the likelihood that the existing controls would identify degradation before the valve was returned to service or before the failure produced a critical consequence. A low detection score indicated a high likelihood of detection through visual inspection, functional checking, or hydrostatic testing. A high score indicated that the failure was difficult to identify using the available inspection and testing practices.

The manuscript should include the complete rating criteria used for scores 1–10. Without explicit rating anchors, the assessment cannot be independently reproduced. Table 1 provides a compact framework that may be adapted to the company's actual scoring criteria.

Table 1 Rating Severity, Occurrence and Detection

Rating	Severity	Occurrence	Detection
1–3	Minor operational effect	Rarely encountered	Highly likely to be detected
4–6	Moderate functional degradation	Occasionally encountered	Moderately detectable
7–8	Major loss of function	Repeatedly encountered	Difficult to detect
9–10	Safety-critical or pressure-containment consequence	Very frequent or persistent	Very unlikely to be detected before failure

These ranges should not replace the original questionnaire. They should be expanded into ten defined levels and validated by the respondents before submission.

G. Aggregation of Expert Ratings

The scores reported in the study were obtained through discussion among the three respondents and recorded as a collective assessment for each failure mode. If individual respondent forms are available, a more transparent approach is to report the three individual ratings and use the median as the final S, O, and D score:

$$\begin{aligned}
 S_j &= \text{median}(S_{1j}, S_{2j}, S_{3j}) \\
 O_j &= \text{median}(O_{1j}, O_{2j}, O_{3j}) \\
 D_j &= \text{median}(D_{1j}, D_{2j}, D_{3j})
 \end{aligned}$$

where j denotes the evaluated failure mode. The median is preferable to the arithmetic mean for a small panel using ordinal rating scales because it is less affected by an unusually high or low assessment and preserves an integer rating. The recorded values were reached through consensus rather than calculated from individual ratings.

H. Risk Priority Number and Risk Ranking

The Risk Priority Number for each failure mode was calculated as:

$$RPN_j = S_j \times O_j \times D_j$$

where S_j , O_j , and D_j are the final ratings for failure mode j . With each parameter ranging from 1 to 10, the possible RPN range was 1–1000. Failure modes were ranked from the highest to the lowest RPN to establish relative maintenance priorities.

The resulting priorities were examined separately for choke and gate valves and then compared across both valve types. The comparison considered:

- the RPN ranking;
- the severity score;
- the affected component function;
- the consequences for pressure regulation or flow isolation;
- the available detection methods; and
- the feasibility of the proposed mitigation.

No universal low-, medium-, or high-risk RPN thresholds were imposed because the original workshop assessment did not establish validated acceptance limits. Instead, RPN was used as a relative ranking tool. This treatment is important because different combinations of S, O, and D can generate the same RPN despite having different risk implications [10–12]. A failure mode with very high severity was therefore retained as a maintenance priority even when its occurrence score and total RPN were lower than those of another mode.

I. Mitigation and Projected Residual Risk

Recommended mitigation measures were developed from the identified failure modes, existing workshop practices, expert input, and relevant literature. The recommendations included:

- more detailed inspection of seat and gate sealing surfaces;
- dimensional or surface-condition verification where applicable;
- cleaning and flushing of internal passages;

- inspection and lubrication of stem and actuator mechanisms;
- replacement of deteriorated packing, seals, or gaskets;
- controlled lapping of repairable sealing surfaces;
- hydrostatic and functional verification after reassembly; and
- documentation of recurrent failures to improve future occurrence estimates.

When residual RPN values are presented, they were identified as projected values rather than measured post-maintenance outcomes. The projected residual RPN can be calculated as:

$$RPN_{j,res} = S_{j,res} \times O_{j,res} \times D_{j,res}$$

The estimated percentage reduction is:

$$RPN\ reduction_j = \frac{RPN_{j,initial} - RPN_{j,res}}{RPN_{j,initial}} \times 100\%$$

Severity should normally remain unchanged unless the mitigation alters the physical consequence of failure. Preventive maintenance is more likely to reduce occurrence, whereas improved inspection or monitoring primarily reduces the detection rating. Residual-risk values should only be reported as validated results after the proposed controls have been implemented and reassessed using the same rating criteria.

J. Data Analysis

The analysis was descriptive. The S, O, D, and RPN values were tabulated and ranked to determine the dominant failure modes. Choke and gate valve results were compared according to their different functions within the BPM: pressure and flow regulation for the choke valve, and isolation and flow routing for the gate valve.

The interpretation was triangulated using workshop observations, maintenance-personnel assessments, repair documentation, and relevant literature. No inferential statistical analysis was performed because the study involved one workshop case, three expert respondents, and no complete population-based failure dataset.

3. Result and Discussion

A. Actual Valve Condition and Scope of the Findings

Initial workshop inspection and hydrostatic testing indicated leakage in the choke valve and gate valve of the investigated back pressure manifold (BPM). The valves were subsequently dismantled, cleaned, visually inspected, repaired, reassembled, and subjected to final hydrostatic testing. These observations established leakage as the principal functional problem encountered during maintenance.

The inspection process focused particularly on the sealing surfaces, seats, gate, stem, packing, seals, valve body, bonnet, and internal flow passages. Surface restoration by lapping and the replacement or adjustment of sealing components were conducted where required. However, because the available data did not include dimensional measurements, surface-roughness measurements, metallographic examination, corrosion-product analysis, or complete operating histories, the physical causes of the leakage could not be conclusively established.

Accordingly, this study distinguishes between:

1. the actual functional problem identified during workshop inspection, namely valve leakage;
2. degradation indications observed during dismantling and visual examination;
3. potential failure modes identified through expert-based FMEA; and
4. technically plausible mechanisms inferred from maintenance experience and the literature.

This distinction is important because leakage is a failure mode, whereas erosion, corrosion, contamination, misalignment, and material deterioration are possible failure mechanisms or causes. Establishing a definitive root cause would require additional evidence, such as surface morphology, wall-thickness measurements, material analysis, fluid composition, operating pressure, valve-opening history, and the concentration and characteristics of entrained solids.

B. FMEA Results

Nine failure modes were evaluated: four for the choke valve and five for the gate valve. Each mode was assessed using severity (S), occurrence (O), and detection (D) ratings. The Risk Priority Number (RPN) was calculated. Table 2 and Table 3 presents the FMEA result for choke valves and gate valves, respectively.

Table 2. FMEA for the choke valves

No.	Component	Function	Failure Mode	Cause of Failure	Effect of Failure	S	O	D	RPN
1	Seat	Provides the seating surface against which the stem closes tightly to stop fluid flow.	Erosion/wear	Solid particles (<i>debris</i> or sand) in the fluid cause abrasive damage.	Loss of pressure-control capability and an increased risk of a kick or blowout.	9	6	6	324
2	Seal/packing	Provides sealing to prevent fluid leakage.	Leakage	Seal-material degradation due to high temperature, excessive pressure, or exposure to aggressive chemicals.	Loss of back pressure manifold (BPM) integrity and potential safety hazards.	8	5	5	200
3	Stem/actuator	Moves upward and downward to regulate fluid flow.	Sticking/Unresponsive operation	Corrosion or contaminants (<i>debris</i>) on the stem or within the actuator assembly.	The valve cannot open or close properly, resulting in impaired flow control.	7	5	6	210
4	Internal passage/body	Serves as the main valve structure that houses the internal components and provides the fluid-flow passage.	Blockage caused by sediment accumulation	Accumulation of solid particles or chemical deposits within the passage, compounded by inadequate upstream filtration.	Restricted flow, increased upstream pressure, and disruption of system operation.	6	4	7	168

Table 3. FMEA for the gate valves

No	Component	Function	Failure Mode	Cause of Failure	Effect of Failure	S	O	D	RPN
1	Gate/seat ring	Serves as the main barrier to fluid flow and prevents leakage through the gate.	Seat leakage/wear/erosion	Abrasive particles in the fluid cause wear on the gate and seat surfaces.	Leakage through the isolation system, difficulty achieving isolation, and increased operational risk.	9	5	5	225
2	Body and body bushing	Houses the internal components and prevents leakage	Cracking, deformation, or erosion–corrosion	Exposure to excessive pressure or water hammer, corrosion	Loss of structural integrity, potential major	10	3	6	180

No	Component	Function	Failure Mode	Cause of Failure	Effect of Failure	S	O	D	RPN
		through the valve body.		caused by aggressive fluids, or condensation.	leakage, and safety hazards.				
3	<i>Stem</i>	Acts as the actuating rod used to open and close the gate.	Sticking, bending, or wear	Inadequate lubrication causes excessive friction. The stem may also corrode due to exposure to fluids or moisture.	The valve becomes difficult to operate and may fail to open or close properly.	8	4	6	192
4	<i>Packing/seals</i>	Provide sealing to prevent fluid leakage.	Leakage caused by seal degradation	Degradation due to high temperatures or exposure to aggressive chemicals. Incorrect installation may also result in packing that is either too tight or too loose.	Loss of sealing performance, minor leakage, and the need for frequent replacement.	6	5	4	120
5	<i>Bonnet/retainer</i>	Closes the upper section of the valve body and provides access for maintenance.	Leakage at the flange or gasket	Gasket damage caused by excessive pressure or high temperature. Leakage may also result from uneven flange surfaces or flange corrosion.	External leakage, potential blow-by, and impaired maintenance access.	7	4	5	140

The choke-valve failure modes produced an average RPN of 225.5, compared with 171.4 for the gate-valve failure modes. Although these averages are not statistical estimates of absolute risk, they indicate that the assessed choke-valve failures generally presented higher relative maintenance priorities. This result is consistent with the choke valve's throttling function: it is intentionally exposed to a large pressure drop and locally accelerated flow, making its internal components more susceptible to wear and difficult-to-detect degradation.

The three highest-ranked failure modes were associated with the flow-regulation and sealing functions:

- choke-valve seat erosion or wear, with an RPN of 324;
- gate/seat-ring leakage, erosion, or wear, with an RPN of 225; and
- choke-valve stem or actuator sticking, with an RPN of 210.

The results therefore show that sealing-surface integrity and reliable valve movement represent the main maintenance priorities in the investigated BPM.

C. Choke-Valve Seat Erosion and Wear

Seat erosion or wear was the highest-ranked failure mode, with $S = 9$, $O = 6$, $D = 6$, and an RPN of 324. Its high severity reflects the importance of the seat and trim in generating and maintaining a controlled pressure drop. Deterioration of this interface can alter the effective flow area, reduce throttling accuracy, and prevent the valve from maintaining the required backpressure.

Unlike a gate valve, a choke valve is designed to operate under partially open conditions. The restriction at the choke creates a high-velocity region accompanied by steep pressure and velocity gradients, turbulence, and changes in flow direction. When solid particles or liquid droplets are present, repeated impact on the trim and seat may progressively remove material. Classical research on oil-and-gas choke valves demonstrated that solid-particle and droplet impingement can produce substantial erosive damage in pressure-reduction geometries [12].

More recent numerical research has similarly shown that choke erosion is influenced by pressure, flow velocity, valve opening, particle concentration, particle size, and impingement location. Guo et al. [2] found that the predicted erosion rate increased with operating pressure and that erosion was concentrated in particular regions of the choke geometry rather than being uniformly distributed. Experimental and numerical investigations have also confirmed that entrained sand can cause localized erosion in choke geometries and that geometry modification may reduce damage [13].

These findings provide a technically reasonable explanation for the high RPN assigned to the choke seat. Nevertheless, the present study did not measure particle loading, impact velocity, seat-material loss, or surface morphology. Erosion should therefore be reported as a plausible degradation mechanism rather than a confirmed root cause.

The detection score of 6 indicates that early-stage seat deterioration may not be readily identified through external inspection. Leakage can become evident during hydrostatic testing, but the test primarily identifies a loss of sealing performance after degradation has progressed. It does not directly quantify the remaining seat thickness or predict future material loss. This limitation supports the use of more detailed internal inspection, dimensional examination, and systematic recording of leakage-test results.

D. Choke-Valve Stem and Actuator Failure

Sticking or loss of response of the choke-valve stem or actuator was ranked third overall, with an RPN of 210. The failure may prevent the valve from reaching the commanded position or cause its response to become slow, irregular, or inaccurate. Because surface backpressure is controlled by adjusting the choke opening, unreliable movement can compromise pressure regulation even when the seat remains capable of sealing.

Possible contributors include:

- contamination by solids or corrosion products;
- inadequate lubrication;
- stem wear or misalignment;
- thread deterioration;
- excessive operating force;
- internal deposit formation; and
- deterioration of the actuator or its mechanical connection.

The relatively high detection rating of 6 suggests that the problem may not be fully identified through visual inspection alone. A valve can appear externally acceptable while still exhibiting increased operating torque, intermittent sticking, or delayed response. Functional stroke testing should therefore supplement visual inspection and hydrostatic testing. Where technically possible, maintenance records should include opening and closing time, operating torque, actuator response, and evidence of abnormal resistance.

E. Choke-Valve Seal and Packing Leakage

Seal or packing leakage generated an RPN of 200. Its severity score of 8 reflects the potential release of pressurized fluid through the stem-sealing area. Depending on the fluid and operating pressure, such leakage may expose personnel, contaminate the workshop or operating environment, and reduce confidence in the valve's pressure integrity.

Packing deterioration may result from compression loss, abrasion, thermal exposure, chemical incompatibility, stem-surface damage, improper installation, or repeated operating cycles. Leakage may initially be minor but can worsen if stem movement further damages the packing or if the packing is excessively tightened. Over-tightening should not be treated as a universal corrective action because it can increase stem friction and contribute to the sticking failure identified in the preceding subsection.

Maintenance should therefore balance sealing performance and stem mobility. The packing should be inspected together with the stem surface, gland condition, alignment, and installation procedure. Replacement decisions should be based on the component condition and approved maintenance criteria rather than leakage alone.

F. Obstruction of the Choke-Valve Flow Passage

Internal obstruction was assigned the lowest choke-valve RPN, although its value of 168 still indicates a relevant maintenance concern. Deposits, corrosion products, foreign material, or solid accumulation may reduce the effective flow area and produce an unintended pressure drop. Partial obstruction can also modify the internal velocity distribution and redirect particle impacts toward previously unaffected surfaces.

This failure mode had the highest detection rating among the choke-valve modes ($D = 7$). A partial blockage may not be obvious during external inspection, particularly when the valve retains some flow capacity. Cleaning, flushing, borescope inspection where feasible, and comparison of pressure-flow behavior can improve detection. However, because no deposit samples or flow-performance measurements were available, the presence and composition of any obstruction could not be independently verified in this study.

G. Gate and Seat-Ring Leakage

Leakage, erosion, or wear of the gate/seat-ring interface was the highest-ranked gate-valve failure mode and the second-highest mode overall, with an RPN of 225. The severity score of 9 was appropriate because a gate valve is required to provide effective isolation. If the gate and seat ring cannot establish adequate sealing contact, fluid may pass through a nominally closed valve and compromise the isolation boundary.

Damage to this interface may be associated with:

- abrasive particles trapped between the gate and seat;
- scratching or galling during operation;
- erosion when the valve remains partly open;
- corrosion or erosion–corrosion;
- misalignment of the gate and seat;
- foreign-material deposition; and
- repeated opening and closing under differential pressure.

Gate valves are generally intended for fully open or fully closed service. Prolonged operation in a partially open position creates a restricted flow area and may substantially increase local velocity. A recent comprehensive analysis of a gas-tree gate valve reported that reduced gate opening accelerated the flow and promoted erosion–corrosion at the lower valve-body region. The study also showed that corrosive media and high-velocity flow could act together by forming and subsequently removing corrosion products [5].

The reported mechanism is relevant to the present interpretation, but it should not be treated as direct evidence that the investigated gate valve experienced the same material process. The study did not include chemical analysis of the service fluid, corrosion products, or damaged surfaces. It can only be concluded that loss of sealing at the gate/seat interface was a high-priority functional failure and that erosion, wear, contamination, and corrosion were possible contributors.

H. Gate-Valve Stem and Handwheel Failure

Sticking, bending, or wear of the gate-valve stem and handwheel assembly produced an RPN of 192. This failure affects the ability to open or close the selected BPM flow path. During a well-control operation, delayed isolation or inability to change the flow path may reduce operational flexibility and increase the time required to respond to an abnormal condition.

A detection score of 6 indicates that visual examination may not reveal the full extent of mechanical impairment. Potential causes such as stem misalignment, thread wear, corrosion, lack of lubrication, or excessive operating load may only become evident during functional testing or detailed dismantling.

Recommended controls include:

- full-stroke operational testing;
- examination of stem straightness and surface condition;
- inspection of threads and mechanical connections;
- verification of lubrication condition;
- monitoring of abnormal operating force; and
- replacement of bent, cracked, or excessively worn components.

Gate valves should also not be forced beyond their operating limit because excessive torque may damage the stem, handwheel, gate, or seat interface.

I. Valve-Body and Body-Bushing Failure

Cracking, deformation, or erosion–corrosion of the gate-valve body or body bushing had an RPN of 180. Although this value was lower than those of the gate/seat and stem failures, the mode received the maximum severity score of 10. This result demonstrates an important limitation of RPN-based prioritization: a potentially catastrophic pressure-containment failure can receive a moderate RPN when its estimated occurrence is relatively low.

Body failure may directly compromise the pressure boundary and can potentially cause uncontrolled fluid release. It should therefore remain a critical inspection priority regardless of its position in the RPN ranking. The assessment should combine RPN with a severity override in which all failure modes with $S = 9$ or $S = 10$ receive mandatory inspection or engineering review.

Appropriate examination may include:

- detailed visual inspection;
- dimensional and wall-thickness measurements;
- dye-penetrant or magnetic-particle testing for surface discontinuities;
- ultrasonic testing for internal discontinuities or wall loss; and
- engineering assessment of any crack, deformation, or localized thinning.

A visual examination alone is insufficient to exclude subsurface cracking or quantify remaining wall thickness. The selected nondestructive testing method should depend on component material, geometry, accessibility, and the suspected damage mechanism.

J. Bonnet, Retainer, Packing, and Seal Leakage

Leakage at the bonnet, retainer, flange, or gasket received an RPN of 140, while packing or seal leakage received the lowest gate-valve RPN of 120. These lower rankings should not be interpreted as indicating that the failures are unimportant. Both may cause external leakage and loss of pressure integrity, although they are generally more detectable and more readily addressed than concealed body damage or internal seat leakage.

The relatively low detection score for packing leakage ($D = 4$) suggests that it can usually be identified through visual observation or pressure testing. Nevertheless, the effectiveness of these methods depends on test pressure, holding time, cleanliness, inspection access, and clearly defined acceptance criteria.

Potential causes include gasket deterioration, insufficient or uneven bolt loading, damaged flange faces, packing wear, incorrect installation, stem scoring, and seal-material incompatibility. Corrective action should include examination of the sealing surface and connection condition rather than automatic replacement of the gasket or packing alone.

K. Comparison Between the Choke and Gate Valves

The different risk profiles of the two valves reflect their distinct functions within the BPM is shown in Table 5. The choke valve showed the greater relative risk because its internal components continuously interact with accelerated flow during throttling. The gate valve is less dependent on continuous flow regulation but must reliably establish isolation. Consequently, the choke valve requires degradation-oriented monitoring, whereas the gate valve requires strong verification of sealing integrity, operability, and pressure containment.

The two valve types should not be assessed independently from a system perspective. Seat degradation in the choke valve can reduce pressure-control accuracy, while gate-valve leakage can prevent effective isolation of the intended manifold line. If both conditions occur simultaneously, redundancy and operational flexibility within the

BPM may be reduced. The maintenance strategy should therefore consider both component-level RPN and the combined effect of multiple valve failures on manifold availability.

Table 5 Comparison of Choke and Gate valve

Aspect	Choke valve	Gate valve
Primary function	Regulates flow and surface backpressure	Isolates or redirects flow
Dominant failure	Seat erosion or wear	Gate/seat-ring leakage or wear
Highest RPN	324	225
Main operational effect	Loss of pressure-control accuracy	Loss of isolation integrity
Main exposure	Continuous throttling and large pressure differential	Opening/closing and sealing under pressure
Principal inspection priority	Trim, seat, flow passage, and actuator response	Gate-seat contact, stem movement, and pressure boundary

4. Conclusion

This study applied a workshop-based Failure Mode and Effects Analysis (FMEA) to identify and prioritize the failure modes of choke and gate valves in a back pressure manifold. Based on workshop observations, hydrostatic testing, maintenance documentation, and expert assessment, nine potential failure modes were evaluated: four in the choke valve and five in the gate valve.

The results indicate that choke-valve seat erosion or wear was the highest-priority failure mode, with an RPN of 324. This was followed by leakage, erosion, or wear at the gate/seat-ring interface (RPN 225) and sticking or unresponsive operation of the choke-valve stem and actuator (RPN 210). These findings demonstrate that the integrity of sealing surfaces and the reliability of valve-operating mechanisms are the primary maintenance concerns. Overall, the choke valve exhibited a higher average RPN than the gate valve because its throttling function exposes its internal components to large pressure drops, accelerated flow, turbulence, and possible particle-induced erosion.

The two valve types presented different but complementary risk profiles. Choke-valve degradation primarily affects the accuracy and stability of flow and backpressure regulation, whereas gate-valve degradation compromises flow isolation and routing. Simultaneous deterioration of both valves may therefore reduce manifold availability, operational flexibility, and well-control reliability. Furthermore, failure modes involving the valve body and pressure-containing components must remain critical inspection priorities because of their high severity, even when their overall RPN values are lower.

The results support prioritizing the inspection of choke seats and trims, gate and seat-ring interfaces, stems, actuators, seals, packing systems, and pressure-containing components. Hydrostatic testing should be complemented by internal visual inspection, functional stroke testing, dimensional examination, cleaning, lubrication verification, and targeted nondestructive testing. Maintenance decisions should consider both the RPN ranking and the individual severity score because RPN alone may underestimate low-occurrence failures with potentially catastrophic consequences.

However, the findings represent relative maintenance priorities rather than statistically determined failure probabilities. The study was limited to one workshop case, three expert respondents, and incomplete operational and material-characterization data. Consequently, erosion, corrosion, contamination, misalignment, and inadequate lubrication should be regarded as technically plausible failure mechanisms rather than definitively verified root causes. Further research should incorporate larger valve populations, detailed operating histories, quantitative wear measurements, material and surface analyses, service-fluid characterization, and post-maintenance reassessment to validate the proposed controls and determine their long-term effectiveness.

References

- [1] American Petroleum Institute, *API Specification 16C: Choke and Kill Equipment*, 3rd ed. Washington, DC, USA: API, Mar. 2021.

- [2] L. Guo, Y. Wang, X. Xu, H. Gao, H. Yang, and G. Han, "Study on the erosion of choke valves in high-pressure, high-temperature gas wells," *Processes*, vol. 10, no. 10, Art. no. 2139, 2022, doi: 10.3390/pr10102139.
- [3] Q. Zhang, H. Yang, L. Ding, Z. Lian, and T. Lin, "Failure mechanism and flow field of choke manifold in a natural gas well: Computational fluid dynamic simulation," *Arabian Journal for Science and Engineering*, vol. 47, pp. 12103–12115, 2022, doi: 10.1007/s13369-022-06897-0.
- [4] B. H. Nystad, G. Gola, J. E. Hulsund, and D. Roverso, "Technical condition assessment and remaining useful life estimation of choke valves subject to erosion," in *Proceedings of the Annual Conference of the Prognostics and Health Management Society*, vol. 2, no. 1, 2010, doi: 10.36001/phmconf.2010.v2i1.1726.
- [5] D. C. Feng, W. Hou, L. L. Lu, Z. Y. Xu, Z. Z. Yang, A. Q. Fu, X. Q. Xu, and C. M. Wang, "Comprehensive failure analysis of Christmas tree gate valves in erosion-corrosion coupling condition," *Journal of Failure Analysis and Prevention*, vol. 25, pp. 1290–1302, 2025, doi: 10.1007/s11668-025-02200-z.
- [6] K. Sotoodeh, "Failure mode and effect analysis (FMEA) of pipeline ball valves in the offshore industry," *Journal of Failure Analysis and Prevention*, vol. 20, no. 4, pp. 1175–1183, 2020, doi: 10.1007/s11668-020-00924-8.
- [7] C. Liu, G. Li, W. Xiao, J. Liu, L. Tan, C. Li, T. Wang, F. Yang, and C. Xue, "Reliability analysis of subsea control system using FMEA and FFTA," *Scientific Reports*, vol. 14, Art. no. 21353, 2024, doi: 10.1038/s41598-023-42030-3.
- [8] International Electrotechnical Commission, *IEC 31010:2019 Risk Management—Risk Assessment Techniques*. Geneva, Switzerland: IEC, 2019.
- [9] M. Yucesan, M. Gul, and E. Celik, "A holistic FMEA approach by fuzzy-based Bayesian network and best–worst method," *Complex & Intelligent Systems*, vol. 7, pp. 1547–1564, 2021, doi: 10.1007/s40747-021-00279-z.
- [10] Y. Tang, Z. Sun, D. Zhou, and Y. Huang, "Failure mode and effects analysis using an improved pignistic probability transformation function and grey relational projection method," *Complex & Intelligent Systems*, vol. 10, no. 2, pp. 2233–2247, 2024, doi: 10.1007/s40747-023-01268-0.
- [11] H.-W. Lo, J. J. H. Liou, C.-N. Huang, and Y.-C. Chuang, "A novel failure mode and effect analysis model for machine tool risk analysis," *Reliability Engineering & System Safety*, vol. 183, pp. 173–183, 2019, doi: 10.1016/j.ress.2018.11.018.
- [12] L. Nøkleberg and T. Sønvedt, "Erosion in choke valves—Oil and gas industry applications," *Wear*, vols. 186–187, pt. 2, pp. 401–412, 1995, doi: 10.1016/0043-1648(95)07138-5.
- [13] F. Darihaki, E. Hajidavalloo, A. Ghasemzadeh, and G. A. Safian, "Erosion prediction for slurry flow in choke geometry," *Wear*, vols. 372–373, pp. 42–53, 2017, doi: 10.1016/j.wear.2016.12.008

Biographies of Authors



Khusnun Widiyati is a lecturer in Mechanical Engineering Department, Universitas Pertamina. Her research interests cover maintenance and reliability engineering.



Athalla Aqsha Suryoatmodjo is a final student of Mechanical Engineering Department, Universitas Pertamina, Indonesia. His research interest cover maintenance and life cycle analysis for biomass based-power generation plant