

Root Cause Analysis and Repair Strategy for Cake Breaker Conveyor Damage in a Palm Oil Mill

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ABSTRACT

Unplanned breakdowns of the Cake Breaker Conveyor (CBC) can halt the kernel station of a palm oil mill. Previous CBC research addressed spare-part planning, whereas this study traces the root causes of CBC damage and converts them into measurable repair actions derived from minimum cut sets. A descriptive-qualitative case study was conducted at PT Socfindo Kebun Bangun Bandar using semi-structured interviews with workshop mechanics, technicians and CBC operators, direct observation, and breakdown records for November 2023–January 2024. Twelve damage events were recorded; broken conveyor pins (50.0%) and CBC pipe replacement (33.3%) accounted for 83.3% of them. Fault Tree Analysis (FTA) linked four damage types through one OR gate and two AND gates to six basic events and four minimum cut sets: bearing service life, shaft service life, a third-order combination of excessive raw-material load, repair-schedule clashes and unstable machine pressure, and pipe corrosion. Six 5W+1H strategies, each with a measurable indicator, were formulated: scheduled bearing and shaft replacement, capacity control, repair scheduling, pressure monitoring and pipe inspection. The results offer an evidence-based basis for shifting CBC maintenance from corrective to preventive practice.

INTRODUCTION

Indonesia's palm oil industry occupies a strategic position in the national economy. Palm oil mills are expected to convert fresh fruit bunches into crude palm oil (CPO) and palm kernel (PK) through a continuous, tightly sequenced mechanical process. Any interruption at one processing station propagates downstream, delays throughput, and can degrade the quality of raw material that has already undergone partial processing. Ensuring that production machinery performs reliably is therefore not merely a maintenance concern but a direct determinant of plant productivity and product quality.



Reliability, in this context, refers to the ability of equipment to perform its intended function satisfactorily under specified operating conditions for a defined period of time; when a machine's condition is unstable or defective, both production continuity and product quality are put at risk (Sembiring & Batubara, 2019). Routine, planned maintenance is one of the principal means of keeping equipment reliable, since it is intended to extend machine and system life and to keep the production line in an optimal, ready-to-operate condition.

PT Socfindo Kebun Bangun Bandar operates a palm oil mill that produces CPO and palm kernel (PK) from fresh fruit bunches supplied by its own plantation. The production process runs from the weighing station through sterilisation, threshing and pressing, oil purification, and finally the kernel station. At the kernel station, the Cake Breaker Conveyor (CBC) machine is responsible for conveying and breaking up the compacted press-cake so that it can be separated further at the depericarper. Because the CBC sits directly in the material-transfer path between the press station and the kernel-recovery process, any failure of this single machine is sufficient to stop the downstream process entirely.

Company breakdown records for the three-month period of November 2023 to January 2024 show that the CBC machine experienced repeated component failures, yet the company had never previously carried out a structured investigation into why these failures kept recurring, and maintenance had so far been limited to corrective repair after each breakdown rather than being informed by an explicit reliability programme, a pattern also reported for CBC maintenance at another palm oil mill (Sembiring & Batubara, 2019). This reactive pattern leaves the plant exposed to unplanned downtime and makes it difficult to plan spare-part provisioning or preventive maintenance intervals. These conditions motivate a systematic root-cause study of the CBC failures at PT Socfindo Kebun Bangun Bandar.

Fault Tree Analysis (FTA) is well suited to this problem because it is a deductive, top-down technique that begins from an assumed top-level failure event and works backward through intermediate events, connected by logic gates, to the basic root causes (Wicaksono & Yuamita, 2022). Because the resulting fault tree is a graphical representation of the relationship between failure modes and their causes, it is comparatively easy for maintenance personnel to interpret and to use as the basis for improvement action. A substantial body of FTA literature has developed around conveyor and belt systems in mining, tunnelling and general industrial settings. Examples include reliability, availability and maintainability analysis of tunnelling conveyors (Ahmadi et al., 2019), integrated predictive-maintenance decision frameworks for belt conveyors (Liu et al., 2019), statistical fault diagnosis of troughing rollers (Muralidharan et al., 2020), and failure analysis of idler roller bearings (Vasić et al., 2020). Research was also focused on the FTA method itself, including its combination with fuzzy logic and pipeline risk (Badida et al., 2019), stochastic fault-tree analysis (Chovanec et al., 2020), reliability block diagrams (Jakkula & Mandela, 2020), minimum-cut-set optimisation via binary decision diagrams (Li et al., 2019), FMECA integration (Mzougui & Elfelsoufi, 2019), and dynamic Bayesian network extensions that address the binary-state and component-interaction limitations of classical FTA (Tchangani & Pérès, 2020).

Within the palm oil sector specifically, FTA-related work has so far focused on spare-part planning for the CBC using a reliability-centred spares approach (Sembiring & Batubara, 2019), on root causes of oil losses at the pressing station (Panjaitan et al., 2025), and on conveyor congestion at the thresher station (Syahputri & Clement, 2022), while several quality-engineering studies outside the palm oil sector have paired FTA-type deductive trees with the 5W+1H method to translate identified causes directly into corrective actions (Kusnendar et al., 2022; Solihudin et al., 2023; Yusuf et al., 2020). The 5W+1H method, which answers what, why, where, when, who and how, is used precisely to formulate clear, actionable corrective proposals once root causes have been identified (Siregar et al., 2020). Three gaps nevertheless remain. First, CBC research has so far addressed spare-part planning (Sembiring & Batubara, 2019) rather than the root causes of CBC damage. Second, the FTA–5W+1H combination is itself established, but, to the authors' knowledge, the studies cited above do not tie each 5W+1H action to a specific minimum cut set or set a measurable target for it against the plant's own damage record. Third, no study appears to have followed a kernel-station machine of a palm oil mill from recorded damage frequency, through a field-based fault tree and its minimum cut sets, to repair actions that each carry a measurable indicator. The novelty of this study therefore lies in this explicit chain, from damage frequency to cut-set order to measurable repair actions, applied to the CBC.

This study addresses three research questions. (RQ1) Which damage types recur on the CBC machine at PT Socfindo Kebun Bangun Bandar over the November 2023–January 2024 period, and what share does each contribute? (RQ2) Which root causes and minimum cut sets underlie these damage events according to a fault tree built from field data? (RQ3) Which measurable 5W+1H repair strategies follow from the minimum cut sets? Accordingly, the study aims to identify the recurring damage events, trace their underlying causes through a fault tree, and translate the resulting root cause analysis into structured repair strategies with measurable indicators using the 5W+1H method.

METHODS

This study used a descriptive-qualitative case-study design to investigate the causes of Cake Breaker Conveyor (CBC) failure at the kernel station of PT Socfindo Kebun Bangun Bandar and to formulate corrective-action proposals. The object of the research was the CBC machine itself, with the analysis focused on identifying the performance and damage patterns of its main components.

1. Data Collection

Data were collected through three complementary techniques: a literature study, a field study (semi-structured interviews and direct observation), and a review of company breakdown records. The literature study built the conceptual and methodological foundation of the research, drawing on published work on Fault Tree Analysis, conveyor and machine-reliability studies, and the 5W+1H method.

Informants were selected purposively as the people directly involved in CBC repair and operation: workshop mechanics and technicians responsible for CBC repairs, and CBC operators. In



total, five informants were interviewed: three workshop mechanics/technicians (M1, a senior workshop mechanic; M2, a workshop mechanic; M3, a workshop technician) and two CBC operators (O1, a senior operator; O2, an operator). Their experience with the machine ranged from 5 to 12 years (M1, 12; M2, 8; M3, 6; O1, 10; O2, 5 years), with a mean of 8.2 years. Because the structure of the fault tree depends on the informants' knowledge, only people with direct experience of CBC damage and repair were included.

The interviews were semi-structured and conducted on site at the plant, each lasting 45–60 minutes (mean 51 minutes). They focused on the types of damage that recur on the CBC and on the factors the informants believed contributed to each type of damage. Direct observation was carried out on eight visits between 7 November 2023 and 30 January 2024, coinciding with the period of the breakdown log. The visits covered, in turn, the general condition of the CBC and its main components; the conveyor pins and drive system; the pipe and material accumulation; the bearing and shaft; machine pressure and operating conditions; the pin installation process and maintenance SOP; the repair schedule against processing hours; and, at the last visit, verification of the findings and cross-checking against the breakdown log.

Damage frequency data were taken from the mill's official workshop breakdown log for November 2023–January 2024 and were used to cross-check the causes reported in the interviews against the documented frequency of each failure type. The following operational definitions were applied. A damage event is a single occasion on which a CBC component was found damaged and had to be repaired or replaced, recorded as one entry in the log; recurrences of damage to the same component on different occasions were counted as separate events. A repair or replacement is the corrective response to a damage event and was not counted separately. Damage categories were defined by the damaged component: broken conveyor pin (a fractured conveyor pin that was replaced), CBC pipe replacement (a pipe replaced because of damage), shaft repair or replacement (a damaged shaft that was repaired or replaced), and bearing replacement (a damaged bearing that was replaced).

2. Fault Tree Analysis Procedure

Fault Tree Analysis (FTA) is a technique used to identify the risks that contribute to the occurrence of a failure, applying a top-down approach that begins with the assumed failure of a top-level event and then details the causes of that top event down to a basic root cause (Wicaksono & Yuamita, 2022). The construction of a fault tree relies on two logic gates, the AND gate and the OR gate, which express the relationship between the basic events (the states of individual system components) and the top event. The symbols used in this study are summarised in Table 1.

Table 1. FTA Symbols Used in This Study

Symbol	Name	Description
Rectangle	Top / intermediate event	An undesired deviation from the normal state of a system component, positioned at the top of the tree or as an intermediate node.
Inverted trapezoid – OR	OR logic gate	The output event occurs if at least one of the input events occurs.
Inverted trapezoid – AND	AND logic gate	The output event occurs only if all of the input events occur simultaneously.
Triangle	Transferred event	Indicates that the description of the event continues on another page or branch of the tree.
Circle	Basic event	A root-cause event that is not developed further because no additional information is available to break it down.

Source: adapted from Wicaksono & Yuamita (2022).

The fault tree was built through three sequential steps. First, the top-level event was identified by studying the CBC machine's function, scope, and documented breakdown history so that the type of undesired failure to be analysed was clearly defined. Second, the fault-tree diagram itself was constructed by tracing each type of recorded breakdown back to the intermediate and basic events reported by the informants described in Section 1, connecting them with the appropriate AND or OR logic. Third, the completed tree was analysed to extract clear information about the system and the improvements required, including the derivation of minimum cut sets, which are the smallest combinations of basic events that are necessary and sufficient to produce the top event.

A factor was designated as a basic event when two conditions were met: the informants could not trace it to a deeper cause and direct observation did not reveal one, and the damage type it leads to was documented in the breakdown log. A cause that the informants could explain further was kept as an intermediate event and developed down to its own basic event. Informant statements were cross-checked against direct observation and the breakdown log before they were entered in the tree.

3. 5W+1H Repair Strategy Formulation

Once the root causes had been identified through the fault tree, the 5W+1H method (what, why, where, when, who, and how) was used to formulate clear and detailed repair strategies, one for each basic event (Siregar et al., 2020). The strategies were drafted by the first author from the minimum cut sets and the informants' explanations of each cause. For every strategy, “what” is the action that counters the basic event, “why” is the failure mechanism shown in the fault tree, “where” is the CBC machine at the kernel station, “when” is the operating phase in which the factor occurs, “who” is the staff position responsible, and “how” is the procedure and the measurable indicator by which its implementation can be checked. Targets for these indicators were set against the baseline

damage frequencies in Table 2. At this stage the strategies are proposals; they have not yet been validated with the maintenance head or mill management (see the limitations in the Discussion).

RESULTS

1. CBC Failure Event Profile

The three-month breakdown log (November 2023–January 2024) recorded four distinct types of CBC damage, totalling 12 damage events. Each entry is an independent damage event recorded on a separate occasion, not a repair activity; repeated damage to the same component, such as the six broken pins, is counted as recurrences. The recapitulation is presented in Table 2.

Table 2. CBC Machine Failure Data, November 2023–January 2024

No.	Cause of Failure	Frequency	Percentage	Cumulative %
1	Broken conveyor pin	6	50.0%	50.0%
2	CBC pipe replacement	4	33.3%	83.3%
3	Shaft (ass) repair / replacement	1	8.3%	91.7%
4	Bearing replacement	1	8.3%	100.0%
Total		12	100.0%	

Source: PT Socfindo Kebun Bangun Bandar workshop breakdown records (company records), field interview data.

To visualise the relative contribution of each failure cause, the data in Table 2 were plotted as a Pareto chart (Figure 1). Broken conveyor pins and CBC pipe replacement together account for 83.3% of all recorded failures, indicating that these two causes should receive priority attention in any improvement effort.

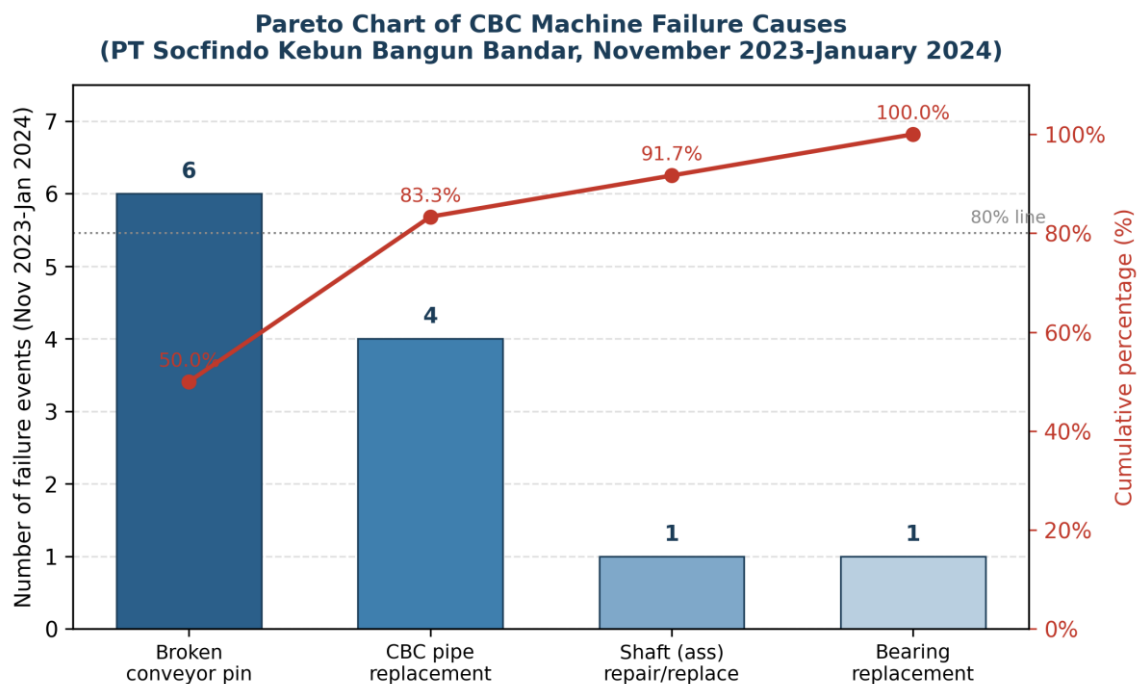


Figure 1. Pareto Chart of CBC Failure Causes

2. Fault Tree Construction

Following the interview and observation data, the top event of the fault tree was defined as “Cake Breaker Conveyor (CBC) failure.” This top event is connected through a single OR gate to four intermediate events, corresponding to the four failure causes identified in Table 2: bearing replacement, shaft (ass) replacement, conveyor-pin fracture, and pipe replacement. Because the top event is linked to its four branches by an OR gate, the occurrence of any one of the four intermediate events is sufficient, on its own, to produce a CBC failure. The complete fault tree is shown in Figure 2.

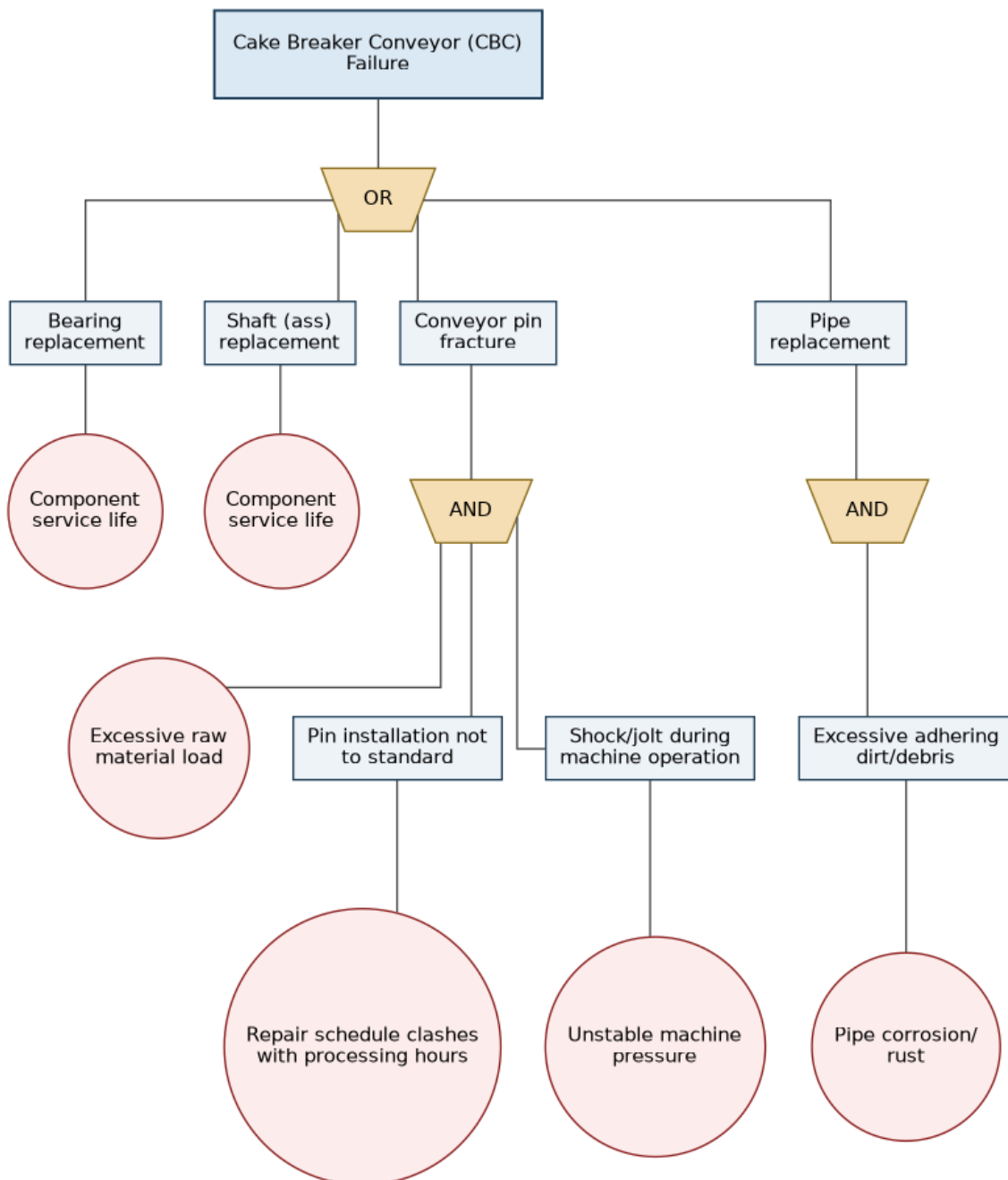


Figure 2. Fault Tree Analysis of Cake Breaker Conveyor (CBC) Failure



Two of the four branches trace directly to a single basic event. The bearing-replacement branch and the shaft-replacement branch are each attributed by the interviewed technicians to component service life, that is, normal wear that eventually requires the part to be replaced, with no further contributing factor identified for either branch.

The conveyor-pin-fracture branch is more complex. Field interviews indicated that a pin fracture requires the simultaneous presence of three conditions, which are therefore connected by an AND gate: (i) an excessive raw-material load on the machine, (ii) pin installation that does not conform to standard, itself attributed to a clash between the maintenance-repair schedule and the ongoing processing schedule, and (iii) a shock or jolt experienced by the pin while the machine is operating, itself attributed to unstable machine pressure during production.

The pipe-replacement branch was reported to result from an accumulation of dirt and debris adhering to the CBC pipe, connected to the top of this branch by an AND gate; this accumulation was in turn attributed by the technicians to corrosion and rust on the pipe surface, which roughens the interior surface and encourages material build-up.

3. Minimum Cut Set Analysis

Reading the logic of the fault tree in Figure 2 from the basic events upward yields four minimum cut sets, which are the smallest combinations of basic events that are individually necessary and jointly sufficient to produce the top event. Because the top event uses an OR gate, each branch below it that is not itself further split by an AND gate contributes a first-order (single-event) cut set, while the pin-fracture branch, which passes through an AND gate with three inputs, contributes a single third-order cut set. These are summarised in Table 3.

Table 3. Minimum Cut Sets of the CBC Fault Tree

Cut Set	Basic Event(s)	Order
MCS ₁	Bearing service life	1st order
MCS ₂	Shaft (ass) service life	1st order
MCS ₃	Excessive raw-material load AND repair-schedule clash AND unstable machine pressure	3rd order
MCS ₄	Pipe corrosion / rust	1st order

Three of the four cut sets are first-order, meaning that a single unresolved factor, namely bearing wear, shaft wear, or pipe corrosion, is, on its own, enough to trigger a CBC failure. Only the pin-fracture pathway requires the co-occurrence of three separate operational conditions, which suggests that this failure mode is comparatively more preventable through operational control, since removing any one of the three contributing conditions is sufficient to break the chain.

4. 5W+1H Repair Strategy Formulation

Based on the six basic events identified through the fault tree, one repair strategy was formulated for each using the 5W+1H method. Each strategy carries a measurable indicator, and the targets are proposals set against the baseline frequencies in Table 2. The resulting matrix is presented in Table 4.

Table 4. Proposed 5W+1H Repair Strategies for CBC Damage

No	Factor	What	Why	When	Who	How
1	Bearing service life	Schedule inspection and planned replacement of the bearing	Prevents wear-out failure (MCS ₁ , first order)	At each inspection interval, in planned stoppages	Workshop mechanics	Inspect and lubricate at a fixed interval (initial reference: 40 days, Sembiring & Batubara, 2019, to be adjusted to the mill's duty cycle); record condition; replace before failure. Target: 0 unplanned bearing failures per quarter (baseline: 1).
2	Shaft (ass) service life	Schedule inspection and planned replacement of the shaft	Prevents wear-out failure (MCS ₂ , first order)	At each inspection interval, in planned stoppages	Workshop mechanics	Check shaft wear together with the bearing inspection; log findings; replace when wear exceeds the allowed tolerance. Target: 0 unplanned shaft failures per quarter (baseline: 1).
3	Excessive raw-material load	Regulate production processing capacity	Prevents overload beyond rated capacity, which can damage components (MCS ₃)	Every shift during processing	Technicians, workshop mechanics, processing manager	Brief staff on the work process; process within the set capacity; record throughput per shift. Target: 100% of shifts at or below the set capacity.
4	Repair schedule clashes with processing hours	Synchronize the machine-repair schedule with processing hours	Keeps pin installation aligned with the established SOP (MCS ₃)	Planned in advance, in scheduled stoppages windows	Workshop mechanics	Keep repair-history records and a maintenance schedule agreed with processing. Target: 100% of pin installations per SOP; broken pins from 6 to ≤3 per quarter.



5	Unstable machine pressure	Regulate machine pressure during operation	Prevents sudden jolts on the pins while operating (MCS ₃)	Before and during processing	CBC operator	Brief operators on pressure regulation; check pressure at the start of each shift and periodically; keep it within the set operating range. Target: 100% of shift checks recorded; no out-of-range reading left uncorrected.
		Perform periodic cleaning and corrosion inspection of the pipe	Prevents dirt and debris from adhering to the roughened pipe surface (MCS ₄)	Before each processing start	Workshop mechanics	Clean and inspect pipe sections; record corrosion locations; treat or replace affected sections. Target: pipe replacements from 4 to ≤2 per quarter.

Note: for all six factors, “Where” is the CBC (Cake Breaker Conveyor) machine at the kernel station. Baselines refer to the three-month period in Table 2; targets are proposed per quarter. Pin-fracture targets are shared by strategies 3–5.

This repair-strategy matrix covers all four minimum cut sets and is intended to help PT Socfindo Kebun Bangun Bandar address the root causes of CBC damage identified through the fault tree, enabling fast, targeted repair action that reduces the machine's breakdown frequency.

DISCUSSION

The Pareto distribution in Figure 1 shows that broken conveyor pins and CBC pipe replacement jointly account for 83.3% of all recorded failures, closely matching the classic 80/20 Pareto pattern in which a small number of causes is responsible for the large majority of observed effects. This pattern is consistent with reliability studies of other conveyor components, where a small number of dominant degradation mechanisms, such as deformation and oxidation corrosion in idler roller bearings, explain the majority of belt-conveyor failures (Vasić et al., 2020), and where statistical, decision-tree-based diagnosis has likewise been used to separate a few dominant fault modes from many minor ones in troughing rollers (Muralidharan et al., 2020). The practical implication for PT Socfindo Kebun Bangun Bandar is that concentrating improvement resources on the pin-installation process and on pipe-corrosion control is likely to yield a disproportionately large reduction in total CBC downtime relative to addressing the two lower-frequency causes.

The structure of the fault tree itself is also informative. The single OR gate at the top of the tree confirms that the four failure pathways are functionally independent routes to the same

undesired outcome, which is a structural feature that is common in reliability-block-diagram and FTA case studies of mechanical systems, where multiple, non-exclusive failure pathways converge on one top event (Jakkula & Mandela, 2020). At the same time, the two AND gates lower in the tree show that not every failure pathway is equally straightforward to prevent: the pin-fracture branch requires three operational conditions, namely excessive load, schedule clash, and pressure instability, to occur together, which is exactly the kind of component-interaction pattern that purely binary, classical FTA is sometimes criticised for oversimplifying (Tchangani & Pérès, 2020). Because these three conditions are managerial and operational in nature rather than purely mechanical, they are, in principle, more controllable through scheduling and monitoring than a wear-driven failure such as bearing or shaft degradation.

It is worth noting a limitation in how the pipe-replacement branch was constructed: the AND gate beneath “pipe replacement” in this study connects to only a single documented basic event (pipe corrosion), which is logically equivalent to a direct causal link rather than a true joint condition. This mirrors a broader, frequently raised limitation of field-constructed fault trees, namely that the granularity of the tree is bounded by what interviewees are able to articulate (Chovanec et al., 2020). A more complete tree might, for example, separate corrosion itself from a second contributing factor such as insufficient cleaning frequency or ambient moisture, which future work at this plant could investigate directly.

The minimum-cut-set analysis in Table 3 reinforces the Pareto finding from a different angle. Three of the four cut sets are first order, meaning that bearing wear, shaft wear, and pipe corrosion are each, individually, sufficient causes of a CBC failure; this is consistent with minimum-cut-set methods elsewhere in the FTA literature that similarly find single dominant events driving overall system unreliability (Li et al., 2019). Only the pin fracture pathway is a third order cut set, requiring three conditions to occur simultaneously. This structural feature helps explain why, despite being logically the most conjunctive branch, it is nonetheless the single most frequent failure cause in Table 2. Because raw-material load, maintenance scheduling, and machine pressure are all managerially adjustable and tend to co-occur under normal shift operations at a busy mill, all three conditions can be satisfied simultaneously more often than the tree's AND-gate logic alone would suggest if the conditions were assumed independent and rare.

The results are broadly consistent with, and further elaborate, prior work in the palm oil sector. Sembiring and Batubara (2019) analysed CBC spare-part needs at a different palm oil mill using a reliability-centred spares (RCS) approach and likewise reported that the company's prior corrective-maintenance practice did not consider component reliability. Their study identified the screw conveyor, hangers and bearings, and jig-drilled couplings as the CBC's three most critical components and derived scheduled discard intervals of 91, 40 and 21 days, respectively.

The bearing and shaft related first order cut sets identified in the present study point to the same underlying issue documented by Sembiring and Batubara (2019), namely that CBC wear components are being run to failure rather than replaced at planned intervals in a different plant. For this reason, strategies 1 and 2 in Table 4 propose scheduled inspection and planned replacement



of the bearing and shaft, with an initial interval referenced to the 40-day interval reported for hangers and bearings and to be tailored to the mill's own duty cycle. Similarly, Syahputri and Clement (2022) used Fishbone and FTA to trace conveyor congestion at a thresher station to raw material load and equipment sizing factors, echoing the excessive load condition found in the pin fracture branch of the present tree. Panjaitan et al. (2025) combined FTA with 5 Why analysis to trace oil losses at a pressing station to a mix of human, machine, material, and method factors. This illustrates that the multi category root cause pattern found here for the CBC, spanning wear, operational load, scheduling, and corrosion, is a recurring feature of palm mill machinery more broadly.

The 5W+1H matrix in Table 4 translates each identified root cause into an operational repair strategy, following the same logic used in other studies that pair a deductive fault tree with 5W+1H to move from diagnosis to action (Kusnendar et al., 2022; Solihudin et al., 2023; Yusuf et al., 2020). Three of the six proposed repair strategies, namely regulating processing capacity, synchronising the repair schedule and regulating machine pressure (strategies 3–5), each target one of the three conditions in the third order pin fracture cut set. Following the logic of Table 3, consistently implementing any one of them should already reduce the frequency of the plant's single most common damage mode, without requiring simultaneous success on all three fronts. Because each strategy carries a measurable indicator, the mill can verify its effect against the baseline in Table 2.

This study has several limitations that should be acknowledged. First, the analysis is based on a single machine at a single plant over a three-month observation window, so the generalisability of the specific failure proportions in Table 2 to other CBC units or other palm oil mills is limited. Second, the fault tree presented here is qualitative; it does not incorporate component failure-rate data or basic-event probabilities, which would be required to move from a qualitative minimum-cut-set analysis to a quantitative estimate of top-event probability, as has been done in probabilistic FTA studies elsewhere (Chovanec et al., 2020; Mzougui & Elfelsoufi, 2019). Third, the root causes reported here rely on interviews with five informants and on observation rather than instrumented condition monitoring, so subtler contributing factors may not have been captured. Fourth, the 5W+1H strategies and their targets were formulated by the researcher and have not yet been validated with the maintenance head or mill management, nor tested after implementation. Future research at this plant could therefore validate the strategies with maintenance management, measure damage frequency after implementation, and combine the qualitative fault tree developed here with quantitative reliability data, in the spirit of the reliability-centred spares approach previously applied to the CBC (Sembiring & Batubara, 2019), or integrate it with FMEA to prioritise corrective actions by risk rather than by frequency alone.

CONCLUSIONS

This study conducted a root cause analysis of Cake Breaker Conveyor (CBC) damage at the kernel station of PT Socfindo Kebun Bangun Bandar and formulated repair strategies for that damage using Fault Tree Analysis combined with the 5W+1H method. Over the three-month

observation period (November 2023–January 2024), the CBC machine recorded 12 damage events, dominated by broken conveyor pins (50.0%) and CBC pipe replacement (33.3%), which together accounted for 83.3% of all recorded damage. The constructed fault tree traced these four damage types through one OR gate and two AND gates to six basic events, yielding four minimum cut sets: bearing service life, shaft service life, a third-order combination of excessive raw-material load, repair-schedule clashes and unstable machine pressure, and pipe corrosion.

Building on this root cause analysis, six measurable repair strategies were formulated using 5W+1H, one for each basic event: scheduled inspection and planned replacement of the bearing and the shaft, regulating production processing capacity, synchronising the machine-repair schedule with processing hours, monitoring and regulating machine pressure, and periodic cleaning and corrosion inspection of the CBC pipe. Because three of the four minimum cut sets are first order, scheduled replacement and inspection of the bearing and shaft and periodic pipe inspection are likely to have an immediate effect on damage frequency, while the pin-fracture pathway can be interrupted by consistently implementing any one of its three contributing repair strategies.

Practically, these findings give PT Socfindo Kebun Bangun Bandar a structured, evidence-based basis for shifting CBC maintenance from a purely corrective, breakdown-driven practice toward a more preventive one, and the 5W+1H matrix in Table 4 can be adopted as a repair-strategy checklist once validated by plant management. Future research is recommended to extend this qualitative fault tree with quantitative failure-rate data to estimate top-event probability, and to integrate the root cause analysis with reliability-centred spares planning or FMEA so that repair strategies can be prioritised by risk as well as by frequency.

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