Lecture 16 – Accident Investigation Techniques

Student Notes

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Heinrich's Domino Model of Accident Causation

Herbert W. Heinrich was a key figure in occupational safety research. In 1931, he published **Industrial Accident Prevention: A Scientific Approach**, based on extensive analysis of accident data from his employer, a large insurance company. Heinrich's work, which spanned over thirty years, identified crucial factors contributing to industrial accidents, notably "unsafe acts by people" and "unsafe mechanical or physical conditions" (Heinrich, 1931).

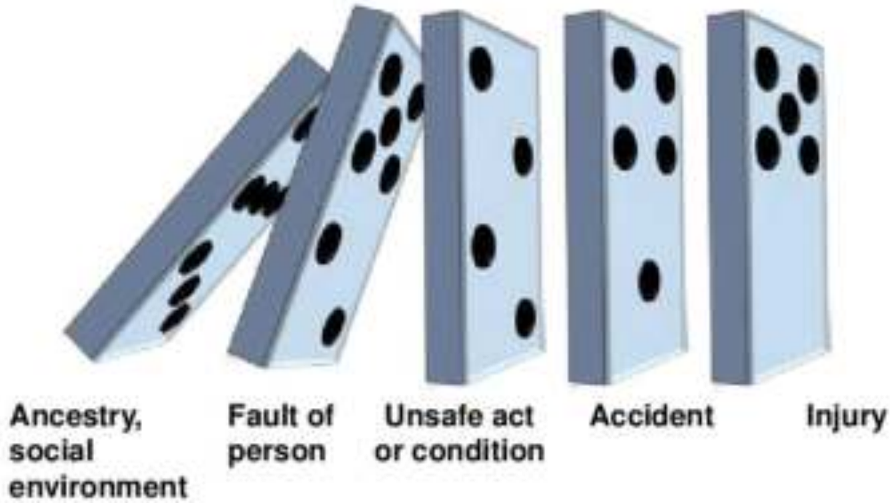
Heinrich is particularly renowned for introducing the **safety pyramid** and the **five domino model** of accident causation. This model illustrates how accidents can result from a sequence of events, similar to dominos falling in a chain reaction. The initial domino's fall triggers the subsequent ones, leading to an accident. If we can stop even one domino from falling, we can prevent the accident, as shown in the diagrams below.

The Domino Model

Heinrich conceptualised a "preventable injury" as the culmination of a series of events, akin to a line of dominos. The chain reaction can be interrupted, preventing the injury from occurring. The five factors identified in Heinrich's original model, published in 1931, are:

1. **Ancestry and Social Environment**: These factors influence a worker's skills, beliefs, and character traits. Heinrich suggested that traits like recklessness and stubbornness could be inherited, a view now considered outdated and problematic (Heinrich, 1931).
2. **Worker's Carelessness**: Personal faults may lead to a lack of attention to tasks, contributing to accidents. This idea is sometimes linked to the "accident-proneness" theory, which posits that certain individuals are more likely to have accidents, although this notion has faced significant scrutiny (Burnham, 2008).
3. **Unsafe Acts or Physical Hazards**: This includes actions like standing under suspended loads or equipment failures, which create unsafe conditions for workers.
4. **The Accident**: This is the actual occurrence of an event leading to injury or loss.

5. **Injuries or Loss**: The consequences of the accident, which can include physical injuries, lost production, or damage to equipment.



Accident-Proneness Theory

Between 1920 and 1960, some psychologists proposed that specific individuals are more "accident-prone" than others, often based on personality traits. However, research since the 1960s has largely discredited this theory, showing that while certain demographics may experience more accidents (e.g., young male drivers), organisational and environmental factors have a far greater influence on accident rates (Burnham, 2008). The focus on individual blame can lead to negative consequences for workplace safety, including decreased reporting of unsafe conditions.

Over time, the initial focus on ancestry and personal faults has shifted. Recent iterations of Heinrich's model replace these elements with aspects related to **management control**, **planning**, and **work organisation**.

Interpretation and Impact

Heinrich's linear model is straightforward and allows managers to identify underlying causes of accidents. It offers a methodology for interrupting the accident sequence by addressing root causes, a concept that has influenced safety management practices significantly. However, this model can also lead to a tendency to seek out individuals to blame rather than understanding the broader systemic factors that contribute to accidents (Heinrich, 1950).

Criticism of the Domino Model

The domino model is often viewed as overly simplistic in today’s complex work environments. Critics argue that it does not adequately account for the multifaceted nature of accidents, which are typically caused by various interacting factors (Safety Institute of Australia, 2020). The model can erroneously suggest that human error is the primary cause of accidents, diverting attention from necessary improvements in system design, workload management, and organisational culture.

In conclusion, while Heinrich’s domino model provided valuable insights into accident causation and prevention, it has limitations. Its focus on linear causality may overlook the complexities inherent in modern workplace safety, necessitating a more comprehensive approach to understanding and preventing accidents.

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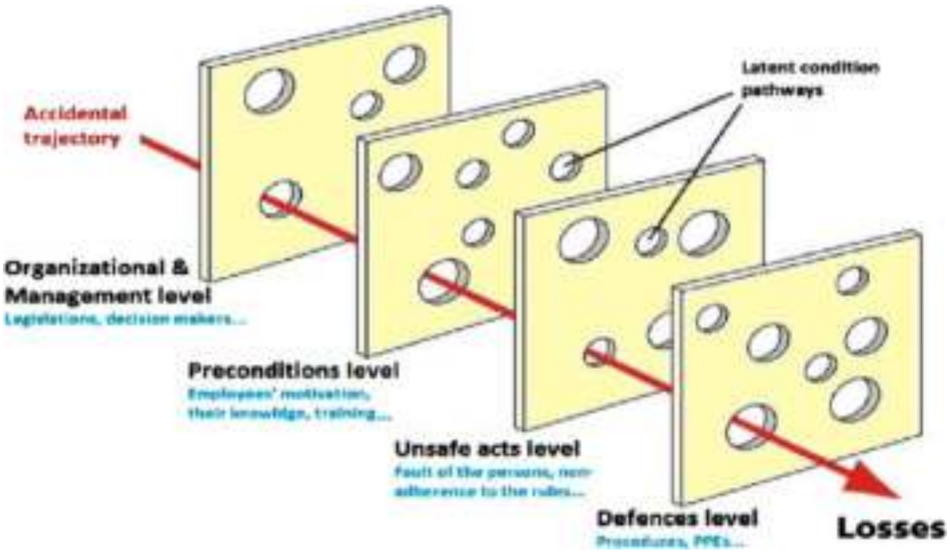
Reason’s Swiss Cheese Model

One of the most well-known systems theories on accident causation is James Reason’s Swiss Cheese Model, first introduced in 1990. This theory suggests that each stage in a process carries a risk of failure (Reason, 2003). It explains how accidents and failures occur in complex systems. It is widely used in industries such as healthcare, aviation, nuclear energy, and engineering to understand safety risks and prevent incidents.

The model highlights how failures happen at multiple levels within an organisation, from frontline workers to senior management. These failures are divided into two categories:

- Active Failures: Immediate errors made by individuals (e.g., a pilot misreading an instrument, a technician bypassing a safety procedure, or a doctor prescribing the wrong dosage).
- Latent Failures: Systemic weaknesses that may remain unnoticed until they contribute to an accident (e.g., understaffing in an air traffic control tower, outdated safety procedures in a power plant, or a lack of maintenance on heavy machinery).

The model is visualised as slices of Swiss cheese, where each slice represents a safety barrier. Holes in the slices symbolise weaknesses in the system. An accident occurs when these holes align across multiple layers, creating a pathway for failure.



The diagram above, is a way to understand how accidents happen in complex systems like workplaces, transport, and healthcare. It explains that accidents are rarely caused by a single mistake. Instead, they result from multiple failures at different levels of an organisation.

Imagine a stack of slices of Swiss cheese, where each slice represents a layer of defence designed to prevent accidents. These layers could include:

1. Organisational & Management Level – Policies, regulations, decision-making, and leadership.
2. Preconditions Level – Employee motivation, training, workload, and workplace conditions.
3. Unsafe Acts Level – Human errors or violations, such as ignoring safety rules or making mistakes under pressure.
4. Defences Level – Physical protections like PPE (Personal Protective Equipment), procedures, and safety barriers.

Each slice of cheese has holes, which represent weaknesses or gaps in the system. Normally, these holes do not align, meaning a failure in one layer is caught by another layer. However, when the holes across all slices line up, an accident happens because all defences have failed.

This alignment of failures is called the "accidental trajectory", leading to losses such as injuries, equipment damage, or environmental harm.

Applications Across Industries

The Swiss Cheese Model is widely used in root cause analysis (RCA) to investigate safety incidents and prevent future failures. Some key industries that rely on this model include:

1. Healthcare

Used to improve patient safety, reduce medical errors, and guide investigations into surgical mistakes, medication errors, and hospital-acquired infections.

2. Aviation

Aviation safety professionals use the model to analyse flight accidents, improve pilot training, and design safer air traffic control systems. The Human Factors Analysis and Classification System (HFACS) is based on this model.

3. Nuclear Energy and Engineering

The model helps identify and mitigate risks in nuclear power plants, construction projects, and industrial safety by addressing latent system failures before they result in catastrophic incidents.

4. Transport and Road Safety

Used to investigate train crashes, maritime accidents, and road collisions, helping authorities strengthen safety regulations and improve infrastructure design.

5. Workplace and Occupational Safety

Organisations apply the model to reduce workplace injuries, ensure machinery maintenance, and improve risk management in sectors like manufacturing, oil and gas, and construction.

Why the Swiss Cheese Model Matters

Critics argue that the Swiss Cheese Model oversimplifies accident causation. However, when understood correctly, it remains an effective tool for identifying risks and improving safety. The model highlights that:

- Not all system failures lead to harm—many are identified and corrected before they cause damage.
- Failures occur at different rates and are dynamic, meaning some risks emerge frequently while others remain hidden for years.
- Most accidents result from multiple active and latent failures, rather than a single mistake.

Beyond Fixing Individual Errors

A common mistake in safety management is focusing only on active failures (e.g., adding more pilot checklists or hospital protocols). While these fixes are important, they do not address the deeper latent failures—such as poor communication, excessive workload pressures, weak leadership, or outdated regulations—that allow errors to happen repeatedly.

Instead, a comprehensive approach is needed, targeting both active and latent failures to strengthen the entire safety system.

Conclusion

The Swiss Cheese Model is a powerful tool for understanding and preventing accidents across multiple industries. It provides a structured way to analyse safety failures and develop better preventive measures. When properly applied, it helps organisations shift from blaming individuals to improving systems, ultimately reducing risks and enhancing overall safety.

Whether in healthcare, aviation, nuclear energy, transport, or workplace safety, the Swiss Cheese Model remains a key framework for building safer systems and preventing disasters.

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Heinrich’s & Bird’s Triangles

The **Safety Triangle**, also known as Heinrich's Triangle or the Accident Pyramid, is a foundational concept in industrial accident prevention. It illustrates the relationship between varying severities of workplace incidents, suggesting that addressing minor accidents and near misses can reduce the occurrence of major accidents.

Origins of the Safety Triangle

In 1931, Herbert William Heinrich, a pioneer in workplace health and safety, introduced this model in his book *Industrial Accident Prevention: A Scientific Approach*. Analyzing over 75,000 accident reports, Heinrich identified a consistent ratio: for every major injury, there were 29 minor injuries and 300 near misses. This finding implied that by reducing minor incidents, organizations could proportionally decrease serious accidents.

Evolution of the Model

Building upon Heinrich's work, Frank E. Bird conducted a comprehensive study in 1966, examining 1.7 million accident reports from nearly 300 companies. Bird's research refined the original model, presenting a revised ratio: for every serious injury, there are 10 minor injuries, 30 incidents causing property damage, and 600 near misses. This expanded perspective emphasized the significance of near misses and property damage incidents in predicting and preventing severe injuries.

Components of the Safety Triangle

1. **Near Misses**: Events where an accident was narrowly avoided, posing no immediate injury but indicating potential hazards.
2. **Minor Injuries**: Injuries that do not require hospitalization, such as cuts or minor wounds treatable on-site.
3. **Property Damage Incidents**: Events resulting in damage to equipment or facilities without causing personal injury.
4. **Serious Injuries**: Severe incidents leading to significant harm or fatality.

Implications for Workplace Safety

The Safety Triangle underscores the importance of addressing all levels of incidents:

- **Proactive Measures**: Implementing safety protocols and training to prevent minor incidents can help avert more severe accidents.
- **Comprehensive Reporting**: Encouraging employees to report near misses and minor incidents fosters a culture of safety and awareness.

- **Continuous Improvement**: Regular analysis of incident data aids in identifying patterns and implementing effective preventive measures.

Criticisms and Modern Perspectives

While the Safety Triangle has been instrumental in shaping safety practices, it has faced criticism:

- Data Validity: The exact ratios proposed by Heinrich and Bird have been questioned, as they may not universally apply across all industries.
- Focus on Minor Incidents: Some argue that an emphasis on reducing minor incidents might divert attention from addressing the root causes of serious accidents.

Despite these critiques, the Safety Triangle remains a valuable tool, highlighting the interconnectedness of all incident levels and promoting a holistic approach to workplace safety.

Source: Safety Triangle Analysis

Ferrell's Human Factors Theory

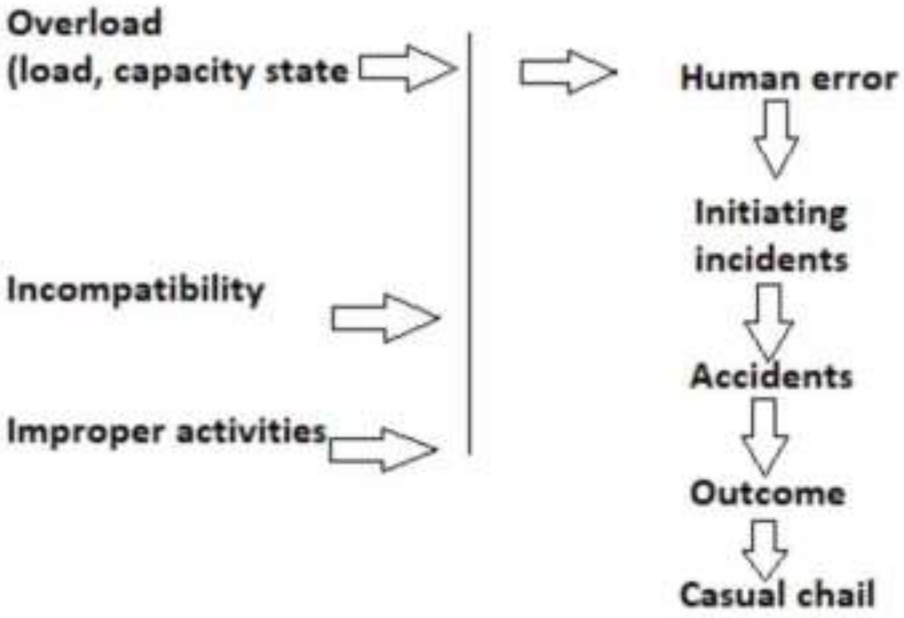
Introduction

Ferrell's Human Factors Theory, developed by Dr. Russell Ferrell, explains accident causation by focusing on human error as the primary contributing factor. Unlike Heinrich's single-chain reaction model, Ferrell's theory takes a multi-causal approach, emphasising that accidents result from multiple interacting factors rather than a single failure.

This theory identifies three primary causes of accidents:

1. Overload – When the demands on a worker exceed their capacity to respond effectively.
2. Incompatibility – A mismatch between human abilities and work conditions.
3. Improper Activities – Errors made due to lack of knowledge or deliberate risk-taking.

By understanding and addressing these factors, organisations can minimise injuries and losses, creating safer work environments.



Overload: The Most Complex Cause of Accidents

Overload occurs when a person is unable to handle the demands of their work environment. It is caused by a combination of load, capacity, and state:

- Load: The amount of physical, mental, and emotional effort required for a task.
    - Physical – Complexity of tasks requiring high mental processing.

  - Environmental – Factors such as noise, lighting, distractions, and hazards.
  - Internal – Emotional stress, worry, fatigue, or lack of motivation.
  - Situational – Ambiguity in tasks, unclear goals, or inherent dangers.
- Capacity: The individual's ability to handle a given task.
  - Physical condition – Fitness, genetics, or medical issues.
  - Mental capacity – Training, knowledge, and experience.
  - External influences – Exposure to stressors like drugs, pollutants, and fatigue.
- State: The person's psychological and emotional readiness to perform a task.
  - Motivational level – How engaged and prepared they are.
  - Arousal level – Their ability to remain alert and focused.

When load exceeds capacity and state, human error is more likely, increasing the risk of accidents.

Incompatibility: Mismatch Between Worker and Work Conditions

Incompatibility occurs when work conditions do not align with human capabilities, leading to incorrect responses or misjudgments.

This can take several forms:

- Stimulus-Response Incompatibility: Mismatched controls and displays, making it difficult for workers to interpret information.
- Stimulus-Stimulus Inconsistency: Different displays providing conflicting or unclear data.
- Response-Response Conflict: Controls or tools that are hard to operate efficiently.
- Workstation Design Issues: Poor ergonomic setup, including improper sizing, force requirements, or positioning of equipment.

Such mismatches cause confusion, slow reactions, and errors, increasing the likelihood of accidents.

Improper Activities: Human Behaviour Leading to Accidents

Improper activities refer to actions taken by workers that increase accident risk. This can happen in two main ways:

1. Lack of Knowledge: The worker does not know the correct way to perform a task safely.
2. Deliberate Risk-Taking: The worker knowingly takes shortcuts or ignores safety measures due to:
    - A low perceived probability of an accident occurring.
    - A low perceived cost if something does go wrong.

These actions often stem from complacency, overconfidence, or workplace culture, making it essential for organisations to enforce clear safety training and accountability.

The Casual Chain of Accidents

Ferrell's model follows a causal sequence of failures leading to accidents:

1. Overload, Incompatibility, or Improper Activity
2. Human Error
3. Initiating Incident (The point where an error begins to create danger)
4. Accident Occurrence
5. Outcome (Injury, damage, or loss)
6. Casual Chain Continues (Unless preventative measures are taken)

By addressing the root causes, workplaces can break this chain and prevent future accidents.

Comparison with Heinrich's Theory

- Heinrich's Theory:
    - Accidents result from a single chain reaction of failures.
    - Focuses on individual behaviour as the primary cause.
    - Less specific about the exact nature of failures.
- Ferrell's Human Factors Theory:
    - Accidents arise from multiple interacting factors.

    - Highlights workplace conditions, human limitations, and behavioural choices.
    - Provides a detailed breakdown of why errors occur.

Ferrell’s approach is more practical for modern safety management, as it considers environmental and psychological factors, rather than simply blaming individual workers.

Practical Applications of Ferrell’s Model

Ferrell’s Human Factors Theory is widely used in high-risk industries, including:

- Manufacturing & Construction – Preventing overload by ensuring workload balance and ergonomic design.
- Aviation & Transport – Addressing stimulus-response mismatches to improve control interfaces.
- Healthcare – Reducing cognitive overload in emergency rooms to prevent human error.
- Oil & Gas – Preventing fatigue-related errors by improving shift management.

Conclusion

Ferrell’s Human Factors Theory provides a detailed and multi-layered approach to understanding accident causation. By addressing overload, incompatibility, and improper activities, organisations can reduce human error, minimise injuries and losses, and improve workplace safety.

Rather than blaming workers for accidents, this model helps identify and fix systemic issues, creating a more effective and proactive safety culture.

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Petersen’s Accident–Incident Causation Theory

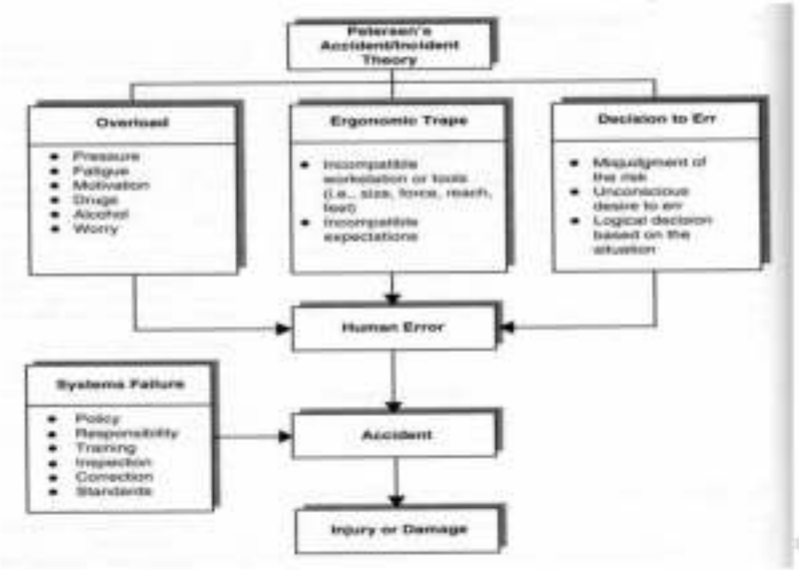
Introduction

Petersen’s Accident–Incident Causation Theory builds upon Ferrell’s Human Factors Model while incorporating aspects of Heinrich’s Domino Theory. This model explains accidents as the result of human error and system failure, with a particular emphasis on decision-making errors and organisational deficiencies.

However, unlike Ferrell’s model, which primarily attributes accidents to overload, incompatibility, and improper activities, Petersen introduces additional categories, including:

1. Ergonomic Traps – Design flaws in workstations, controls, and displays.
2. Decision to Err – Conscious or unconscious choices that increase risk.
3. System Failure – Organisational deficiencies that fail to correct human errors.

By addressing these factors, organisations can prevent incidents, minimise injuries, and improve workplace safety.



Overload: Similarities to Ferrell’s Model

Petersen retains Ferrell’s concept of overload, where accidents occur due to a mismatch between a worker’s capabilities and job demands. Overload is caused by three interrelated factors:

- Load: The physical, mental, and environmental demands placed on a worker.
- Capacity: The worker’s ability to handle these demands, influenced by factors such as training, experience, and fatigue.

- State: The worker’s psychological and emotional condition, including stress and motivation levels.

When these factors are unbalanced, the risk of human error and accidents increases.

Ergonomic Traps: The Role of Workplace Design

Petersen introduces ergonomic traps as a distinct contributor to accidents. These traps occur when workstations, controls, or displays are poorly designed, making it difficult for workers to perform their tasks safely. Examples include:

- Defective or awkward workstation layouts.
- Incompatible controls and displays, leading to confusion.
- Poor ergonomics, increasing strain and fatigue.

By identifying and correcting these design flaws, organisations can reduce workplace hazards and improve worker efficiency.

Decision to Err: Why Workers Take Risks

Unlike Ferrell, Petersen separates the decision to err as an independent cause of accidents. He categorises these decisions into three types:

1. Logical Decisions Based on the Situation:
    - Workers may intentionally take risks due to financial pressure or deadlines.
    - Cutting corners might seem efficient in the short term but increases long-term risk.
2. Unconscious Desire to Err:
    - Psychological factors such as overconfidence, stress, or distraction can lead to errors.
    - Workers may act impulsively or without fully assessing risks.
3. Perceived Low Probability of an Accident:
    - Workers may underestimate the likelihood of an accident occurring.
    - This perception can stem from both actual low-risk situations and human tendencies to ignore potential dangers.

This aspect of Petersen’s model aligns with the rational choice perspective in criminology, which suggests that individuals weigh risks and rewards before making decisions.

System Failure: Organisational Weaknesses that Enable Accidents

A major addition in Petersen’s model is system failure, which acknowledges that human error alone does not always cause accidents. Instead, organisational deficiencies can either prevent or enable incidents.

Examples of system failures include:

- Poor policies and procedures that fail to prevent or mitigate risks.
- Lack of accountability within management, allowing safety lapses to persist.
- Inadequate training or orientation, leaving workers unprepared for hazards.
- Failure to detect or correct errors, leading to repeated incidents.
- Weak hazard recognition processes, preventing proactive risk management.

By addressing system-wide issues, organisations can create a safer and more resilient work environment.

The Causal Chain of Accidents in Petersen’s Model

Petersen’s model follows a sequence of events that leads to accidents:

1. Overload, Ergonomic Traps, or Decision to Err
2. Human Error
3. Incident or Accident Occurs
4. Injury or Loss Results
5. System Failure Can Aggravate or Prevent Future Accidents

This highlights how both individual actions and organisational weaknesses contribute to workplace incidents.

Comparison with Ferrell's and Heinrich's Models

- **Heinrich's Domino Theory**
    - Views accidents as a linear chain of failures, starting from unsafe conditions and behaviours.
    - Focuses on removing unsafe acts to prevent incidents.
- **Ferrell's Human Factors Model**
    - Emphasises overload, incompatibility, and improper activities as primary accident causes.
    - Considers both individual capabilities and environmental factors.
- **Petersen's Accident–Incident Causation Theory**
    - Expands on Ferrell's model by introducing ergonomic traps and decision-making errors.
    - Highlights the role of system failures in allowing accidents to occur.

Petersen's model provides a more holistic view by acknowledging that workplace design, human behaviour, and organisational policies all interact to create risk.

Practical Applications of Petersen's Model

Petersen's theory is widely applied in safety management, risk assessment, and accident prevention across various industries:

- **Construction & Manufacturing:** Preventing overload and ergonomic hazards in physically demanding jobs.
- **Aviation & Transport:** Reducing human error through improved control layouts and decision-making protocols.
- **Healthcare:** Addressing system failures that contribute to medical errors.
- **Corporate & Industrial Safety:** Implementing stronger policies, training, and accountability measures.

Conclusion

Petersen's Accident–Incident Causation Theory expands upon previous models by recognising the complex interplay between human error and organisational deficiencies. By addressing overload, ergonomic traps, decision-making errors, and system failures, organisations can reduce risks and build a proactive safety culture.

This approach moves beyond simply blaming individuals for mistakes and instead focuses on creating safer systems that prevent accidents before they happen.

Sources

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5-M Model Approach to Accident Investigation

Introduction

The 5-M Model is a structured approach to accident investigation, primarily used in aviation but also applicable to other high-risk industries such as maritime, road and rail transport, industrial safety, and healthcare.

The model categorises accident causes into five key areas:

1. **Man** – Human factors such as training, qualifications, and physiological/psychological state.
2. **Machine** – Equipment design, maintenance, and reliability.
3. **Medium** – Environmental conditions, including weather and infrastructure.
4. **Mission** – The complexity and nature of the operation.
5. **Management** – Organisational policies, safety culture, and decision-making.

By systematically identifying failures, the 5-M Model helps prevent future accidents and improve operational safety.

Breakdown of the 5-M Model

Man

Human factors often contribute to accidents. Investigators assess mental and physical fitness, effects of fatigue or stress, adequacy of training, and possible distractions or external pressures. Understanding human error allows for improvements in training, procedures, and operational decision-making.

Machine

Technology enhances efficiency but introduces complexity. Investigators examine equipment design, maintenance history, compliance with regulations, and the reliability of critical systems. For example, in aviation and maritime accidents, equipment failure can be catastrophic if not properly managed.

Medium

Environmental factors influence accident risk, including natural conditions like weather and turbulence, as well as artificial conditions such as runway markings, lighting, and infrastructure. Poor airport lighting, fog, or road hazards can contribute to accidents.

Mission

The type of operation affects accident likelihood. Investigators consider whether the mission was too complex or rushed, if external pressures affected decisions, and whether the operation involved inherent risks such as emergency response, military missions, or high-risk medical procedures. Some missions require stricter planning and risk assessment.

Management

Management decisions impact safety by ensuring adequate training and operational procedures, allocating resources effectively, and enforcing regulatory compliance. Weak management oversight can lead to systemic failures, increasing accident risk.

Application Beyond Aviation

Although developed for aviation, the 5-M Model is widely used in:

- Maritime & Shipping – Investigating ship collisions, grounding, and equipment failures.
- Road & Rail Transport – Analysing train derailments, traffic accidents, and infrastructure breakdowns.
- Industrial Safety – Examining workplace accidents, mechanical failures, and hazardous material incidents.
- Healthcare – Understanding medical errors, surgical mistakes, and operational inefficiencies.

By identifying human, equipment, environmental, operational, and management-related failures, the model improves accident prevention strategies across multiple industries.

Case Study: Singapore Airlines Flight 006

Incident Overview

On 31 October 2000, Singapore Airlines Flight SQ006 mistakenly attempted takeoff from a closed runway (05R) instead of the intended 05L at Taipei's Taoyuan International Airport. Due to poor visibility, the aircraft collided with construction equipment, resulting in 83 fatalities out of 179 passengers and crew.

Investigators applied the 5-M Model to identify key contributing factors.

Findings Based on the 5-M Model

Man

The pilot and co-pilot were qualified and current in training but failed to properly verify the taxi route using available charts. The pilot also did not use the Para-Visual Display, which would have indicated incorrect runway alignment.

Machine

The aircraft was airworthy, with no prior defects. Maintenance logs showed no mechanical issues contributing to the accident.

Medium

Typhoon Xangsane created severe weather and poor visibility. Deficient airfield lighting and signage contributed to misalignment, and there were no clear indicators, such as barriers or illuminated signs, marking the closed runway.

Mission

Due to deteriorating weather, pilots rushed departure to avoid delays, which may have impacted situational awareness.

Management

Ground radar for tracking aircraft in low visibility was not installed due to budget constraints. Taipei Airport's lighting and signage failed to meet ICAO safety standards, and no independent audits were conducted to ensure compliance.

Accident Analysis

While the machine (aircraft) was not a contributing factor, human error (man), environmental conditions (medium), mission urgency, and management failures all played a role in the accident.

Key contributing factors included:

1. Pilot error – Failure to verify the taxi route and use navigational aids.
2. Poor visibility – Heavy rain and darkness diminished situational awareness.
3. Deficient airfield lighting and signage – Contributed to runway misalignment.
4. Management lapses – Lack of oversight in airfield safety standards and radar installation.

Conclusion

The 5-M Model is a structured and effective approach for accident investigation, applicable beyond aviation into maritime, transport, industrial safety, and healthcare sectors.

In the case of Singapore Airlines Flight SQ006, analysis showed that human error and management failures were key contributors. By addressing systemic issues, organisations can prevent future accidents and enhance safety protocols across multiple industries.

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Fault Tree Analysis (FTA) in Accident Investigation

Introduction

Fault Tree Analysis (FTA) is a deductive, logic-based investigation method used to determine the root causes of accidents by tracing failure pathways. Unlike systemic models such as the 5-M Model or Swiss Cheese Model, FTA uses Boolean logic gates to map out the relationships between multiple contributing factors.

FTA is widely applied in transportation, nuclear safety, industrial operations, healthcare, and chemical processing to reconstruct accident sequences and enhance safety measures.

Origins of Fault Tree Analysis

FTA was developed in 1962 by Bell Telephone Laboratories for the U.S. Air Force to assess the reliability of the Minuteman ICBM system. Due to its effectiveness in identifying failure sequences, FTA was soon adopted by NASA, the nuclear industry, and manufacturing sectors for accident investigations and safety analysis.

Today, FTA is a crucial tool for accident investigators, risk analysts, and safety engineers across multiple industries.

How Fault Tree Analysis Works in Accident Investigation

FTA follows a structured, hierarchical method to examine an accident by starting from a top event (accident or failure) and breaking it down into possible contributing failures using logic gates.

- **Top Event:** The accident or failure under investigation.
- **Intermediate Events:** Factors contributing to the top event, requiring further breakdown.
- **Basic Events:** The fundamental causes, such as equipment failures, human errors, or environmental hazards.
- **AND Gate:** Indicates that multiple failures must occur simultaneously to cause the accident.
- **OR Gate:** Indicates that any one of several failures could independently cause the accident.

This structured breakdown allows investigators to determine how accidents unfold, ensuring that all possible causes are identified and mitigated.

Applications of Fault Tree Analysis in Accident Investigation

Nuclear and Industrial Accidents

FTA is used in the investigation of nuclear reactor failures, such as Fukushima and Chernobyl. It helps determine whether human error, mechanical failure, or procedural flaws contributed to the incident and ensures compliance with safety regulations and risk mitigation standards.

Chemical and Process Industry Accidents

FTA is applied in toxic gas leaks, plant explosions, and equipment malfunctions. It identifies failures in safety barriers, emergency response systems, and process controls, helping industries comply with OSHA, EPA, and international chemical safety standards.

Rail and Road Transport Accidents

FTA is used to analyze train derailments, tunnel fires, and highway collisions. It identifies contributing factors such as braking system failures, track defects, and human error while providing insights for improving infrastructure safety and operational procedures.

Healthcare and Medical Device Failures

FTA is applied in the investigation of surgical errors, medication administration failures, and medical device malfunctions. It helps determine whether system design, operator error, or procedural weaknesses caused the incident while supporting compliance with FDA, EMA, and hospital safety regulations.

Common Causes of Failure Identified in FTA

Human Error

Operator misjudgment, fatigue, miscommunication, or procedural non-compliance due to training deficiencies.

Equipment and System Failures

Mechanical wear and tear, software malfunctions, design flaws, and inadequate maintenance leading to unexpected breakdowns.

Environmental Factors

External hazards such as fires, floods, earthquakes, or chemical spills, as well as sudden weather changes affecting transportation and industrial operations.

Management and Organisational Weaknesses

Poor risk management, safety culture, regulatory non-compliance, and insufficient response to previous safety warnings.

Comparison with Other Accident Investigation Models

Feature	**Fault Tree Analysis (FTA)**	**5-M Model**	**Swiss Cheese Model**	**Petersen's Model**	**Ferrell's Model**
Purpose	Identifies logical failure pathways	Categorises accident causes into five areas	Identifies system weaknesses through barriers	Examines human decision errors & system failures	Focuses on human workload and error patterns
Methodology	Deductive logic-based analysis	Structured framework for accident causes	Visual model of multiple failure layers	Examines decision-making errors and management flaws	Studies how stress and workload contribute to accidents
Structure	Top Event → Logical gates → Root Causes	Man, Machine, Medium, Mission, Management	Layers of defences with holes (active/latent failures)	Decision to err, ergonomic traps, system failures	Overload, incompatibility, improper activities
Common Uses	Accident reconstruction, nuclear, transport, industrial safety	Aviation, maritime, transport, healthcare, industry	Healthcare, nuclear safety, industrial risk management	Corporate safety, aviation, workplace safety	Human factors analysis in aviation, transport, healthcare

Case Study: Industrial Explosion Investigation Using FTA

Incident Overview

On December 2, 1984, a chemical gas leak at the Union Carbide pesticide plant in Bhopal, India, led to one of the worst industrial disasters in history. The release of methyl isocyanate (MIC) gas exposed over 500,000 people, resulting in thousands of deaths and long-term health effects.

FTA was used to reconstruct the failure sequence and determine the root causes.

Findings Using FTA:

- **Top Event:** Uncontrolled release of toxic MIC gas.
- **Intermediate Events:**
  - Water entered MIC storage tank, triggering an exothermic reaction.
  - Pressure relief system failed.
  - Safety valves were non-functional.
- **Basic Events:**
  - Inadequate maintenance led to corroded pipeline valves.
  - Cooling system was turned off to cut costs.

    - Safety training was insufficient.

FTA helped investigators establish that a combination of mechanical failure, poor management decisions, and cost-cutting measures contributed to the disaster.

Conclusion

Fault Tree Analysis is an essential tool in accident investigations, providing a structured method to determine root causes, map failure sequences, and improve safety protocols.

While other models focus on broader systemic weaknesses, FTA excels in identifying specific failure interactions, making it indispensable in nuclear safety, transportation, industrial operations, and healthcare investigations.

Sources

- Vesely, W.E. et al. (1981). Fault Tree Handbook. U.S. Nuclear Regulatory Commission.
- NASA Safety Center. (2010). Fault Tree Analysis Application in Industrial Safety.

Fishbone (Ishikawa) Analysis

1. Introduction to Fishbone Analysis

Fishbone Analysis, also known as the Ishikawa Diagram or Cause and Effect Diagram, is a structured approach to identifying potential causes of an issue. Originally developed by Dr. Kaoru Ishikawa, this tool is widely used in Health and Safety (H&S) risk management to systematically investigate workplace hazards, accidents, and inefficiencies.

2. Purpose and Benefits

Fishbone Analysis helps organisations:

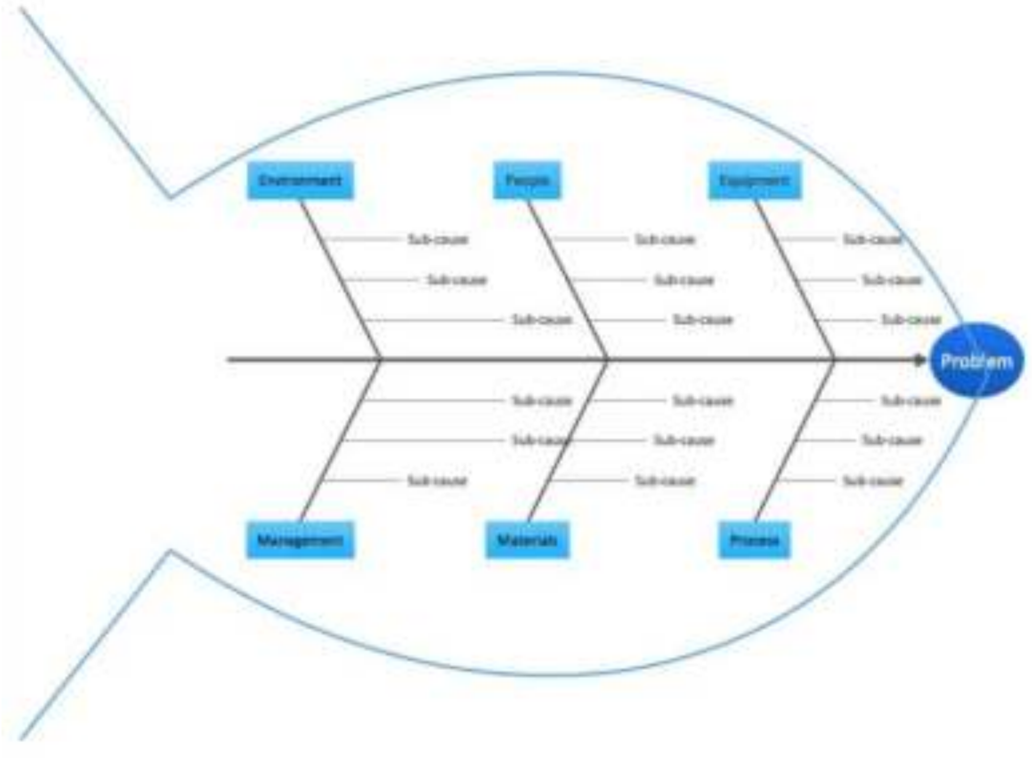
- Identify root causes of incidents or hazards rather than focusing solely on symptoms.
- Enhance problem-solving by categorising potential causes.
- Improve workplace safety by addressing underlying risk factors.
- Foster team collaboration through structured brainstorming.

3. Structure of the Fishbone Diagram

The diagram resembles a fish skeleton, with the "head" representing the problem and the "bones" representing categories of potential causes.

Common cause categories in Health & Safety Accident Investigations include:

1. **People** – Worker behaviour, training, competence, supervision.
2. **Processes** – Work procedures, SOPs, risk assessments.
3. **Equipment** – Machinery, tools, PPE, maintenance.
4. **Materials** – Chemicals, substances, handling procedures.
5. **Environment** – Workplace conditions, ergonomics, weather.
6. **Management** – Policies, enforcement, leadership commitment.



4. Steps to Conduct a Fishbone Analysis

Step 1: Define the Problem

Clearly state the issue, e.g., "Frequent Slips and Trips in Warehouse."

Step 2: Identify Cause Categories

Select the relevant cause categories from the list above.

Step 3: Brainstorm Potential Causes

Encourage participation from employees and management to identify possible contributing factors under each category.

Step 4: Analyse and Prioritise Causes

Assess which causes are most likely contributing to the issue and require immediate action.

Step 5: Implement Corrective Actions

Develop solutions to address root causes and monitor effectiveness.

5. Example

Problem: High incidence of back injuries among warehouse workers.

Cause Category	**Identified Issues**
People	Lack of manual handling training
Processes	No standardised lifting procedures
Equipment	Inadequate lifting aids available
Materials	Heavy loads without proper packaging
Environment	Slippery or cluttered floors
Management	Weak enforcement of safety policies

Corrective Actions: Implement manual handling training, introduce lifting aids, improve housekeeping practices.

6. Conclusion

The Fishbone Diagram is an invaluable tool in **Health & Safety management**, enabling organisations to uncover underlying risks and develop proactive solutions. Regular application of this method can significantly enhance workplace safety and reduce incident rates.

Sources:

- Fishbone Analysis - HSE Study Guide
- Root Cause Analysis and a Fishbone - Safety Made Simple
- Safety Conversations: Root Cause Analysis - EULA