The Cold War, the space race, an expanding process industry,

and the emergence of various safety tools, models, and techniques

LEGEND
- Safety scientist/activist
- Safety problem
- Safety legislation/milestone
- Safety concept

1950-1970

During this period in the United States

The emergence of the modern management approach, influenced by post-war Japan, brought forth a new emphasis on information processing and decision-making to ensure high production levels, quality, and safety within business organizations. This approach viewed organizations as open systems, engaging with internal and external stakeholders.

Quality control is the result of the pioneering work of Deming and Juran, which played a crucial role in revitalizing Japan's industry, aiming to prevent the spread of communism and uplift the poverty-stricken nation just after WWII. Both Deming and Juran made significant contributions to the reconstruction of Japanese industry. The introduction of statistical process control (SPC) enabled the prediction and correction of process variations before actual products were manufactured. Total Quality Management (TQM) principles gained recognition as a vital school of management in the Western world.

W. Edwards Deming (1900-1993), an American statistician renowned for his intellectual contributions across multiple disciplines. Deming was crucial in industrial management and quality control methodologies.

Joseph M. Juran (1904-2008), a Romanian-born American engineer and management consultant, was a leading figure in developing quality management processes.

Frank E. Bird Jr. (1921-2007), an American safety expert and industrial safety pioneer, is best known for developing the "accident triangle."

The damage iceberg was presented in "Damage Control" by Bird and Germain (1966), who applied the domino metaphor, expanding the scope of consequences beyond injuries to include near accidents and property damage. Their investigations at Lukens Steel Co. revealed that accidents without injuries could still result in significant damage, often surpassing the costs of worker injuries. This realization underscored the importance of accident prevention. The book also offered practical insights into effective damage control, including reporting mechanisms, work preparation, auditing procedures, and cost calculations.

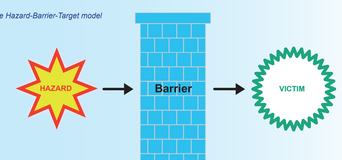
	Host (Human Factors)	Agent (Chemical Factors)	Physical Environment	Social Environment
Pre-Event	Training on spill response	Proper labelling and storage of chemicals	Facility designed with spill containment in mind	Safety regulations and workplace safety culture
	Regular health and safety drills	Regular inspection of containers	Availability of safety equipment and signage	Policies for reporting and preventing incidents
Event	Use of personal protective equipment	Immediate containment measures for spills	Activation of ventilation systems	Coordination with emergency services
	Quick response team activation	Emergency shutdown mechanisms	Accessibility to emergency exits and equipment	Clear communication channels within the facility
Post-Event	Medical attention for exposure	Neutralization and disposal of spilled chemicals	Area isolation and decontamination	Review and analysis of incident for learning
	Psychological support for employees	Assessment of chemical impact on environment	Inspection and repair of affected areas	Updating policies and training based on incidents

A schematic example of the Haddon Matrix for a chemical spill

The Haddon matrix was developed by translating the epidemiological triangle into a matrix format, enabling the identification of different stages in the accident process and the relevant factors associated with each stage. Unlike traditional accident investigations that focused solely on immediate causes, the Haddon matrix provided a comprehensive framework for considering other factors and controls throughout the accident process. Yet, it took some time before the causes of accidents were separated from their consequences.

The hazard-barrier-target model, originating from the epidemiological triangle, explored the interference of barriers with vectors connecting hazards or environmental conditions to the victim. The hypothesis was that unwanted energy exchange, surpassing the body's resistance, was a common factor leading to injuries. This concept, proposed by DeBlois 40 years earlier, categorized accidents and their mechanisms based on energy exchange. Gibson expanded on this idea, presenting a detailed classification of energy types, such as radiation, potential, kinetic, mechanical, thermal, chemical, and electrical energy, each associated with different types of injuries.

The Hazard-Barrier-Target model



Reliability engineering originated from the mass production of weapons. It gained further significance by introducing interchangeable parts in industries like automobile manufacturing. After World War II, organizations such as AGREE in the U.S. formalized reliability engineering as a discipline. Its primary focus was collecting and analyzing failure probabilities of components in technical systems, leading to the development of standards and methods for reliability predictions. Reliability engineering also played a critical role in risk assessment for safety studies. The Apollo I fire tragedy prompted a shift from the "fly-fix-fly" routine to a system safety approach that included hazard and fault tree analysis.

The complexity of flight instruments and controls of a Boeing B-52 Stratofortress built in the early 1960s.

Photo credit: U.S. Air Force, Photo by Ken Larock

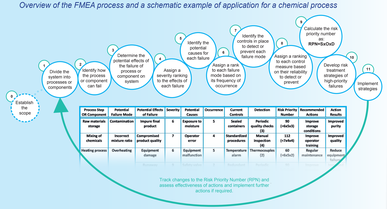
Ergonomics gained prominence due to the development of military equipment and machinery, which posed increased complexity and control challenges. "Human factors" and "ergonomics" refer to studying the relationship between humans, machines, and work. In the United States, human factor engineering emphasizes efficiency and quantifying human errors in man-machine systems. Despite the limitations posed by challenges in quantifying human error probabilities, human factor specialists emphasized enhancing human performance and efficiency to improve safety.

Loss prevention gained prominence during this period. Away from human failure, it focused on process safety measures to address the far-reaching effects of containment loss and alleviate public concerns regarding major accidents. The chemical process industries witnessed significant expansion, resulting in more complex processes that led to devastating fires, explosions, and releases of toxic substances, often causing extensive impacts beyond the boundaries of the plants and significant financial losses.

The engineering approach took center stage in addressing safety concerns, shifting the focus towards preventing or minimizing the consequences of "loss of containment" incidents. Various tools, such as failure mode and effects analysis (FMEA), fault tree analysis (FTA), hazard and operability studies (HAZOP), and energy analysis, were developed to improve equipment and process reliability.

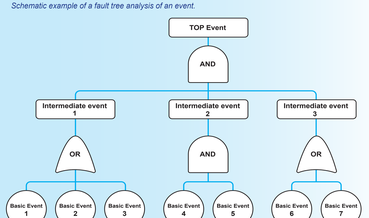
Failure Modes and Effect Analysis (FMEA) is a method for evaluating the impact of failures in system components or functional blocks on the operability or the quality of operations in the system. FMEA was initially described in a military document in the late 1940s and gained significant recognition during the development of the Apollo project in the 1960s.

Overview of the FMEA process and a schematic example of application for a chemical process



Fault Tree Analysis (FTA) is a tool that originated in the military sector and was developed in response to major accidents, such as the detonation of missiles in 1958 in New Jersey, US. The U.S. Air Force commissioned FTA to prevent accidental launches of intercontinental ballistic missiles. It uses a tree-like structure to organize sub-events that lead to an undesirable top event logically. It is primarily applied to high-risk areas like nuclear and military sectors. The use of FTA in preventing unauthorized missile launches faced objections due to concerns about potential delays during emergencies.

Schematic example of a fault tree analysis of an event.



During this period, the United Kingdom

Experiences one of the major accidents of the 1960s where 116 children and 28 adults lost their lives to a colliery spoil tip slide in the Welsh village of Aberfan on 21 October 1966. This was the first widely televised accident in the U.K.

Aerial view of the Aberfan disaster's aftermath

HAZOP, developed by Imperial Chemical Industries Ltd (ICI) in 1963, originated in the process industry and stands for hazard and operability analysis. It is a formal and systematic review method to identify design deviations and potential process aberrations in new or existing installations. HAZOP sessions involve experts from different disciplines discussing the design specifications of each process component, guided by a piping and instrumentation diagram (P&ID). The group examines process safety issues line by line and section by section, considering guide words and process parameters that help identify possible process deviations and are applied to materials, production functions, and layout issues.

Node	Deviation	Possible causes	Consequences	Existing Safeguards	Additional Safeguards	Recommendations
Input Valve	More Flow	Valve fails to close automatically	Overflow of tank	Automatic shutdown linked to level sensor; Visual overfill indicator for operator	Regular maintenance and testing of valve and sensor	Implement routine inspection and maintenance schedule for valves and sensors
Input Valve	Less Flow	Partial blockage or malfunction	Incomplete filling, delay in process	Implement pre-filling checks for blockages	Implement pre-filling checks for blockages	Establish protocol for regular inspection and cleaning of input valve
Liquid Level Sensor (Visual)	No Indication	Sensor malfunction or obstruction	Operator unaware of actual liquid level	Regular cleaning and inspection of visual sensor	Regular cleaning and inspection of visual sensor	Introduce redundancy with another visual indicator
Liquid Level Sensor (Automatic)	Incorrect Reading	Sensor failure, miscalibration	Automatic valve fails to close at correct level, risk of overflow or underfilling	Regular calibration checks	Regular calibration checks	Enhance sensor calibration frequency and accuracy checks
Output Valve	No Operation	Valve stuck or jammed	Inability to discharge contents	Regular functional checks	Regular functional checks	Ensure routine maintenance and checks for output valve functionality

A simple example of a HAZOP study table for filling a tank

During this period in the Netherlands

Willem Winsemius (1917–1990) contributed significantly to understanding occupational accidents in the Netherlands. He developed the theory of 'task dynamics' influenced by British ergonomists, emphasizing the active and dynamic nature of accident causes. Through an extensive study of 1,300 occupational accidents at Hoogovens, a Dutch steelworks, from 1946 to 1948, Winsemius identified the influence of specific work environment factors and the complexity of accidents.

Accidents can be understood by analyzing actions within the context of task dynamics, where three options for action are identified: a slightly riskier but faster path, a considerably longer safe path, or a very high-risk path. Process disturbances always lead to remarkably high task dynamics, resulting in the worker's intuitive choice of the fastest, riskiest path of action. Winsemius emphasized minimizing process disturbances, creating comfortable work environments, and their implications for machinery design.

In the 1960s, the Dutch journal 'De Veiligheid' was vital in promoting safety awareness, covering topics like accident proneness theory and Heinrich's metaphors. Safety education and the use of safety posters received significant attention in the Netherlands. The Dutch Health Council introduced Haddon's model and a classification system for causes of injuries. The journal served as a valuable resource for professionals. German, American, and British sources influenced articles in the Netherlands. Lateiner's visit introduced his method, influencing safety professionals' education and examination requirements. Safety committees and services were established, involving collaboration between "doctor-hygienists" and safety inspectors. Senior executives and managers gradually engaged in operational safety. The 1960s saw the beginnings of a "safety management system."

Criticism arose regarding Heinrich's concepts, with Winsemius highlighting the limitations of tests for identifying accident-prone workers. Debates centered on work adaptation and considering the dynamic relationship between work and workers for optimal safety outcomes.

"PROTECT YOURSELF in your work!" (1957)

"PROTECT THEM" (1966)

WORK SAFE" (1965)

"You have it in your hand" (1954)

"Enjoy your holidays — WORK SAFE" (1956)

"Three causes of accidents I don't SEE it, I didn't THINK it through, I didn't KNOW!" (1962)

"Lubricating machines is DANGEROUS" (1956)

"Reduce the number of ACCIDENTS" (1955)

"UNSAFE report immediately" (1953)

Based on the book *From Safety to Safety Science* (Swuste et al., 2022)