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As a library, NLM provides access to scientific literature. Inclusion in an NLM database does not imply endorsement of, or agreement with, the contents by NLM or the National Institutes of Health. Learn more: PMC Disclaimer | PMC Copyright Notice An improved accident causation model which demonstrates the relationships among different causal factors was proposed in this study. It provides a pathway for accident analysis from the individual level to the organizational level. Unsafe acts and conditions determined by individuals' poor safety knowledge, low safety awareness, bad safety habits, etc. are the immediate causes of an accident. Deficiencies in safety management systems and safety culture remain the root causes, which can cause consequences at the individual level. Moreover, the weaknesses of an organization's safety culture can have a great impact on the formation of a good safety climate and can further lead to poor decision-making and implementation of procedures in the safety management system. In order to contribute to a better perception and understanding of the accident causation model, one typical case in the process industry, the oil leak and explosion of the Sinopec Donghuang pipelines, was selected for this study. The causality from immediate causes to root causes is demonstrated in sequence and can be shown in this model explicitly and logically. Several important lessons are summarized from the results and targeted measures can be taken to avoid similar mistakes in the future. This model provides a clear and resourceful method for the safety and risk practitioner's toolkit in accident investigation and analysis, and the organization can use it as a tool to conduct staff trainings and thus to keep accidents under control. Keywords: accident causation model, accident investigation, causes analysis, individual, organization Accident analysis/investigation is widely recognized as a crucial part of comprehensive and efficient safety management [1]. The investigation report provides details about the occurrence and process of the accident and provides first-hand information for accident analysis and prevention. The best approach to learning about safety is to draw lessons from accidents: it is a great challenge to remember key safety cases so as to avoid unsafe acts in practice since there are endless accident cases, and accompanying causes, throughout the world [2]. Finding out various causes embodied in past cases is of vital importance, and on this basis, feasible mitigation strategies can be made to avoid similar mistakes further. The accident causation model plays an important role in this work by demonstrating the logical relationships among different causal factors, which can help people better understand and remember key lessons easily. In the past 100 years, numerous accident causation models (theories) were proposed in the domain of safety research, and currently, several typical ones dominate the literature: Greenwood and Woods's accident-proneness model [3]; Heinrich's domino-accident causation model [4]; Bird's loss causation model [5,6]; Rasmussen's risk management framework (i.e., the AcciMap) [7]; Reason's omnipresent Swiss Cheese model (SCM) [8]; Wiegmann and Shappell's human factors analysis and classification system (HFACS) [9,10]; Leveson's systems theoretic accident modeling and processes model (STAMP) [11,12]. Each accident causation model (theory) engenders its own distinct approach when used for analyzing accidents. Through accurate comparison, their common disadvantage lies in that they fail to define the accident cause and each level so that people may not prevent accidents by directly, accurately, or conveniently applying the analytical processes and interpreting their results [2,13]. For example, Greenwood and Woods thought accidents frequently occurred to more accident-prone individuals, but they did not figure out who was accident-prone, so it is difficult to make targeted measures to control people's behaviors [3]. Heinrich proposed unsafe acts were directly caused by people's shortcomings which arise from the genetic and socio-environmental factors. However, this model did not give a well-defined connotation of unsafe acts, human shortcomings, genetic factors and their social context, so it is hard to use the hypothesis in practice [4]. Bird believed human shortcomings are formed due to deficiencies in organizational control, but he did not give a definition thereof when an updated domino model was first proposed [5,6]. The SCM observed that unsafe acts are eventually derived from organizational influence factors, but it did not define the organizational factors and the taxonomy requires further work, which makes the hypothesis difficult to apply in practice [8]. Leveson proposed systematic accident analysis methods based on the research of Rasmussen's high-level functional mechanism and advocated the systematic analysis of the causes of each accident from the top–down (i.e., from a national legislation level to the worker) [11,12]. However, the analytical results and process used are not simple enough to investigate the direct causes of an accident. Our research team has always been committed to determining how accidents unfold and based on the existing accident causation models (theories) mentioned above, extensive research has been conducted in recent years. We summarized the advantages and disadvantages of those models (theories) and determined the taxonomies and specific contents of various accident causes to further optimize their logical relationships and theoretical framework. As a result, an improved accident causation model and a detailed accident analysis method was proposed [14]. This approach has already been applied in different domains, such as coal mine accidents [15,16,17], hazardous chemical accidents [18,19], aviation accidents [20,21], ferry accidents [22], and construction accidents [23]. The research shows that it can also improve safety in the process industry. The aim of this article is to verify the availability of this model in process safety in an attempt to promote this useful method to analyze and investigate accidents for researchers, practitioners, and investigators. In doing so, an analysis of a recent high-profile incident in the petrochemical domain, the oil leak and explosion of the Sinopec Donghuang pipelines, is presented as a case study. The improved accident causation model clearly demonstrates the relationship between cause and effect, as shown in Figure 1. It indicates that all accidents belong to the organization and are mainly attributed to internal organizational causes (at both individual and organizational levels) [2]. It is now generally accepted that an accident results from interactions among causal factors residing at all levels of the sociotechnical system, from the government to individuals in the involved organization [7,11]. For the sake of simplicity, causal factors can be classified as "internal causes" and "external causes" based on the manageable boundary of the organization [7,14]. The internal causes are much more changeable and controllable for the managers of the organization to improve safety performance; therefore, they usually serve as the key points for accident analysis. The external causes mainly involve factors from natural events, defective design, poor government supervision, etc., which generally contribute to accidents by influencing the internal causes. The improved accident causation model and the pathway for accident analysis [2,14,16,18,20].According to Heinrich's domino theory, unsafe acts and unsafe conditions are the immediate causes of an accident [4]; moreover, mutual impacts between the two also exist. The immediate causes are determined by various factors, mainly including individuals' safety knowledge (e.g., the theoretical knowledge, operating skill, field experience, etc., stipulated by the organization), safety awareness, and safety habits [24], as well as their psychological and physiological status [25]. It is recognized that errors from the individual level are caused by root causes (i.e., weaknesses in organizational safety management and safety culture) [8,26]. Safety management in an organization is carried out via a safety management system; therefore, deficiencies in the safety management system can be used as indicators to demonstrate the flaws in safety management. The elements of the management system have been introduced in previous literature [20,25,27], and mainly include safety objectives, organizational structure and safety accountabilities, management commitment and responsibilities, hazard identification, risk assessment and mitigation, training and education, resource management, safety communication, continuous monitoring of safety performance, emergency response planning, and continuous improvement. Safety culture, which reflects the beliefs, values, and attitudes shared by the staff related to safety, guides the creation and implementation of the safety management system [25]; thus, poor safety culture or climate in an organization will definitely lead to a deficient safety management system. Safety culture consists of many key elements affecting safety performance [28,29]. This study adopted 32 elements summarized by Fu [20,25,30] and extended from Stewart [31,32], some of which include the importance of safety, importance of a safety management system, economic benefits of safety, role of safety awareness, safety investment, demand for safety training, primary responsibility for safety, safety responsibility of managers, role of safety regulations, and emergency capability. In Figure 1, the red dotted line is the manageable boundary of an organization related to the accident, which divides all the causes in sociotechnical systems into "internal ones" and "external ones". The "internal causes" shown in the blue boxes are classified into five categories from individual flaws to organizational deficiencies. The blue arrows indicate the sequence of internal causes leading to an accident, including weaknesses in an organization's safety culture, deficiencies in the safety management system, flaws in an individual's safety knowledge, safety awareness, safety habits, etc.; then unsafe acts and unsafe conditions (there is a correlation between the two) eventually lead to an accident. The red arrows indicate the steps for accident analysis, which begins from bad outcomes to immediate causes, to flaws in an employee's safety knowledge, safety awareness, safety habits, etc., and deficiencies in the organization's safety management system, and finally to the weaknesses in safety culture. For the sake of application, the consensus process for the analysis of an accident is summarized as follows: Performing the events based on the process or timeline and identifying the critical events of the accident further. Identifying all organizations (e.g., the design institute, the maintenance unit, the regulators, etc.) related to the accident and figuring out in which one the accident occurred. Identifying unsafe acts and unsafe conditions leading to critical events, and then deducing the flaws in individuals' safety knowledge, safety awareness, safety habits, etc. Summarizing the deficiencies in organizational safety management system elements and safety culture elements based on the analysis results at the individual level. Performing an analysis of external factors influencing the internal factors or resulting in the accident directly. To contribute to the understanding of the accident causation model, a typical accident, Qingdao "11·22" oil leak and explosion of the Sinopec Donghuang pipelines, was selected as our case study. Additionally, the availability of the accident analysis method will be demonstrated in this section. Through analysis and discussion, readers will not only understand how and why this disaster occurred, but also remember key points in order to avoid similar mistakes within various industries. On 22 November 2013, a devastating oil leak and explosion occurred in Sinopec Donghuang (from Dongying to Huangdao District, Qingdao) pipelines located in Qingdao section, Shandong, China. The catastrophe resulted in many casualties (62 people killed and 136 injured), property loss, and marine pollution, as well as huge negative social impacts and widespread concerns in the process safety field. The appalling fire and explosion scene can be seen in Figure 2. About 40 days after this incident, the former State Administration of Work Safety (SAWS) completed an investigation on it. The report details the occurrence and process of the oil leak and explosion, and the various causes from individuals and organizations, which in combination led to the failure of the system [33]. The fire and explosion of the Donghuang oil pipeline. An accident is usually caused by sequential occurrences of multiple adverse events. This disaster began with an oil leak that further evolved into fires and explosions. Several sequential events were identified from the investigation report and are shown in Figure 3 based on the timeline. The Donghuang oil pipeline is in total about 248.5 km in length, and the accident section was administrated by the Weifang oil transportation agency affiliated with Sinopec. On 22 November 2013, around 2:12 a.m. (local time), an operator on duty in the Weifang oil transportation agency discovered the pipeline leak through the reduction of the oil pressure. In this urgent situation, the manager stopped the oil pump (at 2:25 a.m.) immediately, and meanwhile, reported and arranged a rush repair. Technicians got to the scene at 3:40 a.m. and began to organize people to excavate after judging the approximate area of the underground broken pipeline. In order to improve the efficiency, excavators and hydraulic hammers were further used for digging and drilling. The precise location of the oil leak was eventually determined at about 8:20 a.m. Due to the serious corrosion of pipelines and large amount of oil leaks, the repair work continued for another two h and the explosion occurred during the process of mechanical excavation (at 10:25 a.m.). The occurrence and process of the oil leaks and explosion.According to the timeline, the entire process of this accident can be divided into two critical events: (1) the oil leaks; (2) the explosion. For the sake of better illustration, an event sequence diagram (ESD) was developed (Figure 4). The oil leaked out where the underground pipeline and closed conduit crossed. Seawater intrusion often occurs in the closed conduit due to the tide; this formed an alternate dry–wet and salt-spray environment and caused the salinization of soil and high chloride content in the groundwater. It is no wonder that the pipelines' corrosion and rupture occurred in these conditions. A large amount of spilled oil flowed to the closed conduit and volatilized gradually, thus forming the inflammable and explosive gas mixture. When the rush repair was underway, the oil and gas mixture, affected by the seawater intrusion, spread and accumulated quickly in this space. Event sequence diagram (ESD) of the oil leaks and explosion.It should be noted more than eight h passed after the leaks were discovered, but repair of the broken pipelines was not completed because of poor emergency disposal. According to estimation, the total amount of oil leakage from the ground, closed conduit, and sea was up to 2000 tons during this period. However, people on site were not aware of the risk and still used non-explosion-proof tools to open the cover plate of the closed conduit without taking protective measures. The oil and gas mixture ignited and detonated from the exposed sparks of the mechanical drilling. The explosion seriously destroyed the block and caused extensive marine pollution. The damaged pipelines located in the dangerous section were discontinued and the closed conduit was transformed into an open one for the sightseeing and warning. The compared accident scenes of the present and past can be seen in Figure 5. Compared accident scenes of the present (left) and past (right). Through the process analysis above, two critical events (i.e., the oil leaks and the explosion) have been identified from this disaster and the cause analysis will be centered on them. There are large differences between the causes of the two events, especially in respect to individual causes; therefore, the analysis results are shown in separate models for the sake of clear and logical illustration. The accident section of the Donghuang oil pipeline is administrated by Weifang oil transportation agency, and the on-site personnel such as the management, repairmen, excavator operators, etc. are all employed by this unit. Therefore, Weifang oil transportation agency should take full responsibility for the accident. Causes in relation to this organization, usually considered as the internal ones, are of crucial importance. Additionally, this accident involved several local government agencies (e.g., the supervision department of work safety, the planning and design department, the office of emergency management, etc.) whose faults could also have contributed to the oil leaks and explosion. The internal causes illustrated in the improved accident causation model are shown in Figure 6 and Figure 7, respectively. Causes analysis of oil leaks based on the accident causation model. SOP: standard operating procedure. Causes analysis of explosions based on the accident causation model. The corrosion and rupture of the pipeline, which was considered to be the unsafe condition cause, directly led to the oil leaks. The pipelines corroded easily due to the effect of bad local hydrogeological conditions such as the salt-spray environment, salinization of soil, and high content of chloride in the groundwater. The Oil and Gas Pipelines Protection Law of the People's Republic of China (PRC) (article 23) stipulates that pipeline enterprises shall conduct regular detection and maintenance of pipelines to ensure that they are in good condition; the sections and sites with high risks shall be monitored in a critical manner, and effective measures shall be taken to prevent pipeline accidents. However, employees in the Weifang oil transportation agency did not do this work well according to the rules, and the coating overhaul for the Donghuang oil pipelines that began in 2011 had not yet been finished before the incident. The organization's nonfeasance caused the corrosion and rupture to exist for a long time, and we believe it caused the unsafe condition indirectly. Thus, this also provides an effective way to prevent some unsafe conditions, namely by turning to the elimination of corresponding unsafe acts. The flaws in individuals' safety knowledge, safety awareness, and safety habits resulted in the unsafe acts directly. As the investigation noted, Weifang oil transportation carried out a total of three flaw detections on the Donghuang oil pipelines during 2009–2013, but the staff in charge of the work failed to find the pipeline's corrosion and rupture during their inspections; therefore they might not be qualified for the technical task because of their lack of knowledge and experience. All members in the organization should attach importance to their job responsibilities, especially managers, whose poor inspection and supervision remain very important factors for the occurrence of unsafe acts. However, people who were in charge of the regular maintenance of equipment and facilities did not abide by the rules and neglected the overhaul of the pipelines in production. Based on this, we can deduce that the staff were neither aware of the adverse consequences resulting from pipeline corrosion nor had good habits to carry out the regular maintenance of the pipeline. The roots of an accident lie in the errors of an organization; moreover, individual behaviors are largely affected by organizational factors [8]. Therefore, the deficiencies in an organizational safety management system and safety culture could be inferred according to the above analysis on individual flaws. According to the Safety Specification for Crude Oil and Natural Gas Pipelines (article 8), several deficient elements, such as hazard identification, safety training and education, safety accountability, and equipment management (i.e., the maintenance and detection for oil pipelines), were identified from the safety management system of the Weifang oil transportation agency. The lack of a standard operating procedure (SOP) for hazard identification led to the staff's inadequate training and insufficient knowledge. This made them fail to identify the pipeline's hidden dangers in the process of past flaw detections (a total of three times in 2009, 2011, and 2013). Before this accident, the on-site staff had already performed regular patrol and maintenance for the oil pipelines, but the corrosion and rupture were not prevented effectively because there was no procedure or process in the safety management system to assess the effect of the implementation of engineering standards. Safety training, as one of the most important means for accident prevention, was not well conducted in the Weifang oil transportation agency. There were no adequate theoretical contents about the prevention of pipeline corrosion in the training document. Some operating skills about the pipelines' detection were not trained well in accordance with engineering standards; moreover, the specified training time for employed front-line workers was not sufficient. The flawed organizational roles caused the ambiguous assignment of responsibilities for the protection of operational safety within the Weifang oil transportation agency. The violation of regulations reflected that the post responsibility system was not valued by the operators and managers, and the organization did not establish processes to monitor its daily implementation either. The deficient safety management system indicated that members in the organization did not reach an agreement on safety beliefs such as "safety is the first priority", "the importance of safety management system", "the importance of safety training", "the importance of laws and engineering standards" or "safety performance depends on good safety awareness". Good leadership can contribute to a good safety climate. The key role for leaders and managers is to develop and drive a culture for safety management within the organization. The staff in the Weifang oil transportation agency ignored that safety should be put first in daily work and they did not pay much attention to the roles of safety awareness and the responsibility system for accident prevention. Moreover, the top management failed to demonstrate their commitment to support the implementation and audit of the safety management system. Collectively, managers and leaders should provide the organizational systems and drive the organizational culture that determines not only what people in the organization do, but more importantly, how they do it. In addition, there were several external factors related to the occurrence of the oil leaks. The local supervision department of work safety who is the lead unit for the protection of underground pipelines failed to perform its supervision duties well because the coating overhaul for the Donghuang oil pipelines was not finished within two years. Moreover, it failed to urge the pipeline enterprise to carry out the hazard identification and regular maintenance for oil pipelines and did not realize the closed-loop management of the safety inspection through the form of "reviewing". There was also some irrationality in the layout of the oil pipelines approved by the local planning and design department, which had a great impact on the occurrence of the oil leaks. As mentioned above, the oil pipeline around the accident site was installed in a closed conduit, which posed a higher risk when the leaked oil easily flowed into the conduit and caused inconvenience for the maintenance and rush repair of the installation. In view of this, the damaged pipelines located in the dangerous section are now out of use. Another two unsafe acts made the oil leaks further evolve into multiple explosions and large-scale fires. During the rush repair, the closed conduit was full of inflammable and explosive mixtures of oil and gas due to the seawater intrusion, thus causing another dangerous condition. According to the Oil and Gas Pipelines Protection Law of the PRC (article 30), it is forbidden to use mechanical tools for excavation and construction within five meters on both sides of the center line of the pipeline. The spark, a requirement for this accidental event, was just generated from drilling holes in the cover plate with a non-explosion-proof hydraulic hammer. If on-site staff performed effective gas detection for the closed conduit in accordance with the operating procedures stipulated in Safety Specification for Crude Oil and Natural Gas Pipelines (article 8.4) before the excavation, this explosion could have been avoided. Indeed, this disaster was classified as an "accountability accident" by the SAWS and almost all unsafe acts violated regulations or engineering standards; therefore, identifying and eliminating those specific unsafe acts is of crucial importance for the prevention of such similar mistakes. Safe acts or unsafe acts, by the accident causation model, are directly determined by individuals' habitual behaviors such as competence, awareness, thought, habit, etc. The two unsafe acts above were produced by the staff involved in the oil pipeline's rush repair. As the investigation report noted, the management and employed front-line workers at the scene were not trained adequately and lacked the experience to rush repair the underground pipelines. They did not know how inflammable and explosive gases formed, nor did they understand why the mixture spread and accumulated in the closed conduit. According to the survey, most people did not even have the theoretical knowledge about the chemical property of crude oil and did not think that it could be easily detonated like refined oil (e.g., gasoline, diesel oil, etc.). Also, the staff was not aware of the consequences of using non-explosion-proof tools and developed bad habits in the process of daily operations since accidental events had not occurred in the past. It is therefore no wonder that unsafe acts appeared in this event. The poor disposal of the oil leak indicates that there are also lots of flaws in some elements of the Weifang oil transportation agency's safety management system, such as equipment management (i.e., the regulation for repair), risk assessment and mitigation, safety training and education, emergency response planning, etc. The repair of underground oil pipelines is a high-risk task and the organization must establish a comprehensive SOP in the management system according to related engineering standards for managers and operators. The personnel allocation (operators and supervisors), tools selection, job steps, and protective measures should be detailed in this procedure. However, the Weifang oil transportation agency was not aware of the risks in the repair of leaked oil pipelines and neglected the importance of safety procedures. This also caused deficiencies in other systems or plans. Some contents about the SOP, especially the danger of using non-explosion-proof tools in the repair of oil pipelines, were not given in the safety training system, and the occurrence of the explosions also had a lot to do with peoples' lack of knowledge and bad treatment in the rush repair. As we know, the leaks of oil pipelines can easily trigger domino events once disposed improperly. According to the survey, there was no procedure or process in the safety management system to assess the risk of the area where the pipeline leaked, and protective measures were not taken by the organization, either. Additionally, emergency plans about the pipeline leaks need to be mastered and exercised by all concerned but the management failed to ensure that emergency training was provided as intended. According to the investigation, the regular exercise for pipeline leaks was actually carried out by the Weifang oil transportation agency, but there was no procedure or process in the safety management system to assess the effect of its implementation and the emergency response plan was not performed and audited all the time. There are no significant differences in the deficiencies of organizational safety culture elements between the analyses of the two critical events; thus, analyses in this section will be simplified. The occurrence of explosions indicated that the members' inadequate consensus on safety beliefs such as "safety is the first priority", "the importance of safety management system", "the importance of safety training", "safety performance lies on good safety awareness", "the importance of laws and engineering standards", etc. could be inferred as poor safety culture. The quality of leadership and commitment to safety can drive or limit the safety culture of an organization. However, the leaders and managers in the Weifang oil transportation agency failed to deeply understand the process safety management (PSM) program—its importance for maintaining both safe operations and compliance, its key roles and responsibilities, as well as current issues and challenges the organization faced in its implementation. As mentioned above, improper disposal of the oil leaks triggered the multiple explosions; clearly, Weifang oil transportation agency neglected the importance of emergency management for the PSM. The management should promote all staff to master the emergency plan and supervise its implementation and regular audit. In addition, there were several external factors contributing to the explosion and serious casualties. The local administration committee of the development zone failed to fully understand the severity of the crude oil leakage and initially classified it as a general emergency (total four levels: particularly serious, serious, major, and general) based only on the report of the pipeline enterprise. This led to a poor command and coordination for the emergency: warning and road closure measures were not taken on the site; the nearby masses were not notified and evacuated in a timely manner; and problems such as violations of regulations from on-site emergency personnel were not found and stopped. Moreover, the local office of emergency management did not organize experts to carry out the research and assessment on the development trend of the oil leaks and thus failed to raise the level of the emergency response timely. Therefore, it was not surprising that the multiple explosions occurred, and the casualties and property losses were so severe. This article presents an improved accident causation model and its application in accident analysis through a specific case, the oil leaks and explosion of the Sinopec Donghuang pipelines. The main purpose of this study was to generalize a universal method for accident analysis, and meanwhile, it is significant to help people learn lessons from this catastrophic event through this model. The accident causation model provides a pathway for accident analysis from the individual level to the organizational level. A timeline of events is a primary step for the task and further determining the critical ones is of vital importance. For every critical event, unsafe acts and unsafe conditions, which are considered as the immediate causes, should be identified first. On this basis, unsafe behaviors (i.e., individuals' safety knowledge, safety awareness, safety habit, psychological status, and physiological status), deficiencies in organizational safety management system, and safety culture elements can be further deduced one by one. Finally, external factors influencing the occurrence of the events could be determined in detail. In this study, the accident was divided into two sequential events (i.e., the oil leaks and explosion), and causal factors involved in each one were analyzed by this model. Thus, several important lessons for the PSM can be summarized as follows. Front-line workers' unsafe acts or nonfeasance often results in the facility's unsafe conditions, which may spawn severe consequences directly. Thus, it is necessary for the management to strengthen the field supervision and inspection. Adequate safety training and education for individuals is conductive to improving their safety knowledge, safety awareness, safety habit, or even psychological status, and most unsafe acts may be avoided with it. The SOPs for some dangerous works, such as hazard identification, flaws detection, emergency disposal, etc. are of the essence, and procedures for the monitoring of their implementation effects should be given at the same time. Periodic safety audits must be performed with rigor to identify the weaknesses of the safety management system before an incident occurs. If any issues were found, all should be reported and corrected. The quality of leadership and commitment to safety can drive or limit the safety climate of an organization. Managers must develop and sustain a sound culture that embraces both process safety and occupational safety. External causes from other organizations, such as unreasonable design and planning, inadequate supervision and inspection, poor command and coordination, etc., also had significant impacts on the occurrence and development of the accident. The government agencies shall perform their duties well. Admittedly, the accident causation model is not perfect and still needs to be improved constantly. The present study intends to promote a universal method for accident analysis, especially in the process safety domain, but it is difficult to offer a convincing fact with only one case study. Thus, continued research needs to be carried out in the future. Conceptualization, J.W.; formal analysis, M.Y.; investigation, J.W.; methodology, J.W.; writing—original draft, M.Y.; writing—review and editing, J.W. This work was supported by the National Natural Science Foundation of China (grant no. 51534008). 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Safety Management System Failures of Chinese Hazardous Chemical Accidents. China University of Mining & Technology; Beijing, China: 2018. [Google Scholar] 28.Hale A.R. Culture's confusions. Saf. Sci. 2000;34:1–14. doi: 10.1016/S0925-7535(00)00003-5. [DOI] [Google Scholar] 29.Mearns K., Kirwan B., Reader T.W., Jackson J., Kennedy R., Gordon R. Development of a methodology for understanding and enhancing safety culture in Air Traffic Management. Saf. Sci. 2013;53:123–133. doi: 10.1016/j.ssci.2012.09.001. [DOI] [Google Scholar] 30.Ma Y. Study on the Construction Method of Enterprise Safety Culture. China University of Mining & Technology; Beijing, China: 2017. [Google Scholar] 31.Stewart J.M. Managing for World Class Safety. John Wiley & Sons; New York, NY, USA: 2002. [Google Scholar] 32.Stewart J.M. The turn-around in safety at the Kenora pulp paper mill. Prof. Saf. 2011;46:34–44. [Google Scholar] 33.State Administration of Work Safety Accident Investigation Report of Qingdao '11-22' Oil Leaks and Explosions of Sinopec Donghuang Pipelines. [(accessed on 1 May 2019)]; Available online: . Articles from International Journal of Environmental Research and Public Health are provided here courtesy of Multidisciplinary Digital Publishing Institute (MDPI) This article examines the role of human factors in the accident causation process and reviews the various preventive measures (and their effectiveness) by which human error may be controlled, and their application to the accident causation model. Human error is an important contributing cause in at least 90 of all industrial accidents. While purely technical errors and uncontrollable physical circumstances may also contribute to accident causation, human error is the paramount source of failure. The increased sophistication and reliability of machinery means that the proportion of causes of accidents attributed to human error increases as the absolute number of accidents decreases. Human error is also the cause of many of those incidents that, although not resulting in injury or death, nevertheless result in considerable economic damage to a company. As such, it represents a major target for prevention, and it will become increasingly important. For effective safety management systems and risk identification programmes it is important to be able to identify the human component effectively through the use of general failure type analysis. The Nature of Human Error Human error can be viewed as the failure to reach a goal in the way that was planned, either from a local or wider perspective, due to unintentional or intentional behaviour. Those planned actions may fail to achieve the desired outcomes for the following four reasons: 1. Unintentional behaviour: The actions did not go as planned (slips). The action was not executed (lapses). 2. Intentional behaviour: The plan itself was inadequate (mistakes). There were deviations from the original plan (violations). Deviations can be divided in three classes: skill-, rule- and knowledge-based errors. At the skill-based level, behaviour is guided by pre-programmed action schemes. The tasks are routine and continuous, and feedback is usually lacking. At the rule-based level, behaviour is guided by general rules. They are simple and can be applied many times in specific situations. The tasks consist of relatively frequent action sequences that start after a choice is made among rules or procedures. The user has a choice: the rules are not automatically activated, but are actively chosen. Knowledge-based behaviour is shown in completely new situations where no rules are available and where creative and analytical thinking is required. In some situations, the term human limitation would be more appropriate than human error. There also are limits to the ability to foresee the future behaviour of complex systems (Gleick 1987; Casti 1990). Reason and Embrey's model, the Generic Error Modelling System (GEMS) (Reason 1990), takes into account the error-correcting mechanisms on the skill-, rule- and knowledge-based levels. A basic assumption of GEMS is that day-to-day behaviour implies routine behaviour. Routine behaviour is checked regularly, but between these feedback loops, behaviour is completely automatic. Since the behaviour is skill-based, the errors are slips. When the feedback shows a deviation from the desired goal, rule-based correction is applied. The problem is diagnosed on the basis of available symptoms, and a correction rule is automatically applied when the situation is diagnosed. When the wrong rule is applied there is a mistake. When the situation is completely unknown, knowledge-based rules are applied. The symptoms are examined in the light of knowledge about the system and its components. This analysis can lead to a possible solution the implementation of which constitutes a case of knowledge-based behaviour. (It is also possible that the problem cannot be solved in a given way and that further knowledge-based rules have to be applied.) All errors on this level are mistakes. Violations are committed when a certain rule is applied that is known to be inappropriate: the thinking of the worker may be that application of an alternative rule will be less time-consuming or is possibly more suitable for the present, probably exceptional, situation. The more malevolent class of violations involves sabotage, a subject that is not within the scope of this article. When organizations are attempting to eliminate human error, they should take into account whether the errors are on the skill-, rule- or knowledge-based level, as each level requires its own techniques (Groeneweg 1996). Influencing Human Behaviour: An Overview A comment often made with regard to a particular accident is, "Maybe the person did not realize it at the time, but if he or she had not acted in a certain way, the accident would not have happened." Much of accident prevention is aimed at influencing the crucial bit of human behaviour alluded to in this remark. In many safety management systems, the solutions and policies suggested are aimed at directly influencing human behaviour. However, it is very uncommon that organizations assess how effective such methods really are. Psychologists have devoted much thought to how human behaviour can best be influenced. In this respect, the following six ways of exercising control over human error will be set forth, and an evaluation will be performed of the relative effectiveness of these methods in controlling human behaviour on a long-term basis (Wagenaar 1992). (See table 1.) Table 1. Six ways to induce safe behaviour and assessment of their cost-effectiveness No. Way of influencing Cost Long-term effect Assessment 1 Don't induce safe behaviour, but make the system "foolproof". High Low Poor 2 Tell those involved what to do. Low Low Medium 3 Reward and punish. Medium Medium Medium 4 Increase motivation and awareness. Medium Low Poor 5 Select trained personnel. High Medium Medium 6 Change the environment. High High Good Do not attempt to induce safe behaviour, but make the system "foolproof" The first option is to do nothing to influence the behaviour of people but to design the workplace in such a way that whatever the employee does, it will not result in any kind of undesirable outcome. It must be acknowledged that, thanks to the influence of robotics and ergonomics, designers have considerably improved on the user-friendliness of workplace equipment. However, it is almost impossible to anticipate all the different kinds of behaviour that people may evince. Besides, workers often regard so-called foolproof designs as a challenge to "beat the system". Finally, as designers are human themselves, even very carefully foolproof-designed equipment can have flaws (e.g., Petroski 1992). The additional benefit of this approach relative to existing hazard levels is marginal, and in any event initial design and installation costs may increase exponentially. Tell those involved what to do Another option is to instruct all workers about every single activity in order to bring their behaviour fully under the control of management. This will require an extensive and not very practical task inventory and instruction control system. As all behaviour is de-automated it will to a large extent eliminate slips and lapses until the instructions become part of the routine and the effect fades away. It does not help very much to tell people that what they do is dangerous - most people know that very well - because they will make their own choices concerning risk regardless of attempts to persuade them otherwise. Their motivation to do so will be to make their work easier, to save time, to challenge authority and perhaps to enhance their own career prospects or claim some financial reward. Instructing people is relatively cheap, and most organizations have instruction sessions before the start of a job. But beyond such an instruction system the effectiveness of this approach is assessed to be low. Reward and punish Although reward and punishment schedules are powerful and very popular means for controlling human behaviour, they are not without problems. Reward works best only if the recipient perceives the reward to be of value at the time of receipt. Punishing behaviour that is beyond an employee's control (a slip) will not be effective. For example, it is more cost-effective to improve traffic safety by changing the conditions underlying traffic behaviour than by public campaigns or punishment and reward programmes. Even an increase in the chances of being "caught" will not necessarily change a person's behaviour, as the opportunities for violating a rule are still there, as is the challenge of successful violation. If the situations in which people work invite this kind of violation, people will automatically choose the undesired behaviour no matter how they are punished or rewarded. The effectiveness of this approach is rated as of medium quality, as it usually is of short-term effectiveness. Increase motivation and awareness Sometimes it is believed that people cause accidents because they lack motivation or are unaware of danger. This assumption is false, as studies have shown (e.g., Wagenaar and Groeneweg 1987). Furthermore, even if workers are capable of judging danger accurately, they do not necessarily act accordingly (Kruysse 1993). Accidents happen even to people with the best motivation and the highest degree of safety awareness. There are effective methods for improving motivation and awareness which are discussed below under "Change the environment". This option is a delicate one: in contrast with the difficulty to further motivate people it is almost too easy to de-motivate employees to the extent that even sabotage is considered. The effects of motivation enhancement programmes are positive only when coupled with behaviour modification techniques such as employee involvement. Select trained personnel The first reaction to an accident is often that those involved must have been incompetent. With hindsight, the accident scenarios appear straightforward and easily preventable to someone sufficiently intelligent and properly trained, but this appearance is a deceptive one: in actual fact the employees involved could not possibly have foreseen the accident. Therefore, better training and selection will not have the desirable effect. A base level of training is however a prerequisite for safe operations. The tendency in some industries to replace experienced personnel with inexperienced and inadequately trained people is to be discouraged, as increasingly complex situations call for rule- and knowledge-based thinking that requires a level of experience that such lower-cost personnel often do not possess. A negative side-effect of instructing people very well and selecting only the highest-classified people is that behaviour can become automatic and slips occur. Selection is expensive, while the effect is not more than medium. Change the environment Most behaviour occurs as a reaction to factors in the working environment: work schedules, plans, and management expectations and demands. A change in the environment results in different behaviour. Before the working environment can be effectively changed, several problems must be solved. First, the environmental factors that cause the unwanted behaviour must be identified. Second, these factors must be controlled. Third, management must allow discussion about their role in creating the adverse working environment. It is more practical to influence behaviour through creating the proper working environment. The problems that should be solved before this solution can be put into practice are (1) that it must be known which environmental factors cause the unwanted behaviour, (2) that these factors must be controlled and (3) that previous management decisions must be considered (Wagenaar 1992; Groeneweg 1996). All these conditions can indeed be met, as will be argued in the remainder of this article. The effectiveness of behaviour modification can be high, even though a change of environment may be quite costly. The Accident Causation Model In order to get more insight into the controllable parts of the accident causation process, an understanding of the possible feedback loops in a safety information system is necessary. In figure 1, the complete structure of a safety information system is presented that can form the basis of managerial control of human error. It is an adapted version of the system presented by Reason et al. (1989). Figure 1. A safety information system Accident investigation When accidents are investigated, substantial reports are produced and decision-makers receive information about the human error component of the accident. Fortunately, this is becoming more and more obsolete in many companies. It is more effective to analyse the "operational disturbances" that precede the accidents and incidents. If an accident is described as an operational disturbance followed by its consequences, then sliding from the road is an operational disturbance and getting killed because the driver did not wear a safety belt is an accident. Barriers may have been placed between the operational disturbance and the accident, but they failed or were breached or circumvented. Unsafe act auditing A wrong act committed by an employee is called a "substandard act" and not an "unsafe act" in this article: the notion of "unsafe" seems to limit the applicability of the term to safety, whereas it can also be applied, for example, to environmental problems. Substandard acts are sometimes recorded, but detailed information as to which slips, mistakes and violations were performed and why they were performed is hardly ever fed back to higher management levels. Investigating the employee's state of mind Before a substandard act is committed, the person involved was in a certain state of mind. If these psychological precursors, like being in a state of haste or feeling sad, could be adequately controlled, people would not find themselves in a state of mind in which they would commit a substandard act. Since these states of mind cannot be effectively controlled, such precursors are regarded as "black box" material (figure 1). General failure types The GFT (general failure type) box in figure 1 represents the generating mechanisms of an accident - the causes of substandard acts and situations. Because these substandard acts cannot be controlled directly, it is necessary to change the working environment. The working environment is determined by 11 such mechanisms (table 2). (In the Netherlands the abbreviation GFT already exists in a completely different context, and has to do with ecologically sound waste disposal, and to avoid confusion another term is used: basic risk factors (BRFs) (Roggeveen 1994).) Table 2. General failure types and their definitions General failures Definitions 1. Design (DE) Failures due to poor design of a whole plant as well as individual items of equipment 2. Hardware (HW) Failures due to poor state or unavailability of equipment and tools 3. Procedures (PR) Failures due to poor quality of the operating procedures with respect to utility, availability and comprehensiveness 4. Error enforcing conditions (EC) Failures due to poor quality of the working environment, with respect to circumstances that increase the probability of mistakes 5. Housekeeping (HK) Failures due to poor housekeeping 6. Training (TR) Failures due to inadequate training or insufficient experience 7. Incompatible goals(IG) Failures due to the poor way safety and internal welfare are defended against a variety of other goals like time pressure and a limited budget 8. Communication (CO) Failures due to poor quality or absence of lines of communication between the various divisions, departments or employees 9. Organization (OR) Failures due to the way the project is managed and the company is operated 10. Maintenance management (MM) Failures due to poor quality of the maintenance procedures regarding quality, utility, availability and comprehensiveness 11. Defences (DF) Failures due to the poor quality of the protection against hazardous situations The GFT box is preceded by a "decision-maker's" box, as these people determine to a large extent how well a GFT is managed. It is management's task to control the working environment by managing the 11 GFTs, thereby indirectly controlling the occurrence of human error. All these GFTs can contribute to accidents in subtle ways by allowing undesirable combinations of situations and actions to come together, by increasing the chance that certain persons will commit substandard acts and by failing to provide the means to interrupt accident sequences already in progress. There are two GFTs that require some further explanation: maintenance management and defences. Maintenance management (MM) Since maintenance management is a combination of factors that can be found in other GFTs, it is not, strictly speaking, a separate GFT: this type of management is not fundamentally different from other management functions. It may be treated as a separate issue because maintenance plays an important role in so many accident scenarios and because most organizations have a separate maintenance function. Defences (DF) The category of defences is also not a true GFT, as it is not related to the accident causation process itself. This GFT is related to what happens after an operational disturbance. It does not generate either psychological states of mind or substandard acts by itself. It is a reaction that follows a failure due to the action of one or more GFTs. While it is indeed true that a safety management system should focus on the controllable parts of the accident causation chain before and not after the unwanted incident, nevertheless the notion of defences can be used to describe the perceived effectiveness of safety barriers after a disturbance has occurred and to show how they failed to prevent the actual accident. Managers need a structure that will enable them to relate identified problems to preventive actions. Measures taken at the levels of safety barriers or substandard acts are still necessary, although these measures can never be completely successful. To trust "last line" barriers is to trust factors that are to a large extent out of management control. Management should not attempt to manage such uncontrollable external devices, but instead must try to make their organizations inherently safer at every level. Measuring the Level of Control over Human Error Ascertaining the presence of the GFTs in an organization will enable accident investigators to identify the weak and strong points in the organization. Given such knowledge, one can analyse accidents and eliminate or mitigate their causes and identify the structural weaknesses within a company and fix them before they in fact contribute to an accident. Accident investigation The task of an accident analyst is to identify contributing factors and to categorize them. The number of times a contributing factor is identified and categorized in terms of a GFT indicates the extent to which this GFT is present. This is often done by means of a checklist or computer analysis program. It is possible and desirable to combine profiles from different but similar types of accidents. Conclusions based upon an accumulation of accident investigations in a relatively short time are far more reliable than those drawn from a study in which the accident profile is based upon a single event. An example of such a combined profile is presented in figure 2, which shows data relating to four occurrences of one type of accident. Figure 2. Profile of an accident type Some of the GFTs - design, procedures and incompatible goals - score consistently high in all four particular accidents. This means that in each accident, factors have been identified that were related to these GFTs. With respect to the profile of accident 1, design is a problem. Housekeeping, although a major problem area in accident 1, is only a minor problem if more than the first accident is analysed. It is suggested that about ten similar types of accidents be investigated and combined in a profile before far-reaching and possibly expensive corrective measures are taken. This way, the identification of the contributing factors and subsequent categorization of these factors can be done in a very reliable way (Van der Schrier, Groeneweg and van Amerongen 1994). Identifying the GFTs within an organization pro-actively It is possible to quantify the presence of GFTs pro-actively, regardless of the occurrence of accidents or incidents. This is done by looking for indicators of the presence of that GFT. The indicator used for this purpose is the answer to a straightforward yes or no question. If answered in the undesired way, it is an indication that something is not functioning properly. An example of an indicator question is: "In the past three months, did you go to a meeting that turned out to be cancelled?" If the employee answers the question in the affirmative, it does not necessarily signify danger, but it is indicative of a deficiency in one of the GFTs—communication. However, if enough questions that test for a given GFT are answered in a way that indicates an undesirable trend, it is a signal to management that it does not have sufficient control of that GFT. To construct a system safety profile (SSP), 20 questions for each of the 11 GFTs have to be answered. Each GFT is assigned a score ranging from 0 (low level of control) to 100 (high level of control). The score is calculated relative to the industry average in a certain geographical area. An example of this scoring procedure is presented in the box. The indicators are pseudo-randomly drawn from a database with a few hundred questions. No two subsequent checklists have questions in common, and questions are drawn in such a way that each aspect of the GFT is covered. Failing hardware could, for instance, be the result of either absent equipment or defective equipment. Both aspects should be covered in the checklist. The answering distributions of all questions are known, and checklists are balanced for equal difficulty. It is possible to compare scores obtained with different checklists, as well as those obtained for different organizations or departments or the same units over a period of time. Extensive validation tests have been done to ensure that all questions in the database have validity and that they are all indicative of the GFT to be measured. Higher scores indicate a higher level of control - that is, more questions have been answered in the "desired" way. A score of 70 indicates that this organization is ranked among the best 30 (i.e., 100 minus 70) of comparable organizations in this kind of industry. Although a score of 100 does not necessarily mean that this organization has total control over a GFT, it does mean that with regard to this GFT the organization is the best in the industry. An example of an SSP is shown in figure 3. The weak areas of Organization 1, as exemplified by the bars in the chart, are procedures, incompatible goals, and error enforcing conditions, as they score below the industry average as shown by the dark grey area. The scores on housekeeping, hardware and defences are very good in Organization 1. On the surface, this well-equipped and tidy organization with all safety devices in place appears to be a safe place to work. Organization 2 scores exactly at the industry average. There are no major deficiencies, and although the scores on hardware, housekeeping and defences are lower, this company manages (on the average) the human error component in accidents better than Organization 1. According to the accident causation model, Organization 2 is safer than Organization 1, although this would not necessarily be apparent in comparing the organizations in "traditional" audits. Figure 3. Example of a system safety profile If these organizations had to decide where to allocate their limited resources, the four areas with below average GFTs would have priority. However, one cannot conclude that, since the other GFT scores are so favourable, resources may be safely withdrawn from their upkeep, since these resources are what have most probably kept them at so high a level in the first place. Conclusions This article has touched upon the subject of human error and accident prevention. The overview of the literature regarding control of the human error component in accidents yielded a set of six ways by which one can try to influence behaviour. Only one, restructuring the environment or modifying behaviour in order to reduce the number of situations in which people are liable to commit an error, has a reasonably favourable effect in a well-developed industrial organization where many other attempts have already been made. It will take courage on the part of management to recognize that these adverse situations exist and to mobilize the resources that are needed to effect a change in the company. The other five options do not represent helpful alternatives, as they will have little or no effect and will be quite costly. "Controlling the controllable" is the key principle supporting the approach presented in this article. The GFTs must be discovered, attacked and eliminated. The 11 GFTs are mechanisms that have proven to be part of the accident causation process. Ten of them are aimed at preventing operational disturbances and one (defences) is aimed at the prevention of the operational disturbance's turning into an accident. Eliminating the impact of the GFTs has a direct bearing upon the abatement of contributing causes of accidents. The questions in the checklists are aimed at measuring the “health state” of a given GFT, from both a general and a safety point of view. Safety is viewed as an integrated part of normal operations: doing the job the way it should be done. This view is in accordance with the recent “quality oriented” management approaches. The availability of policies, procedures and management tools is not the chief concern of safety management: the question is rather whether these methods are actually used, understood and adhered to. The approach described in this article concentrates upon systemic factors and the way in which management decisions can be translated into unsafe conditions at the workplace, in contrast to the conventional belief that attention should be directed towards the individual workers who perform unsafe acts, their attitudes, motivations and perceptions of risk. An indication of the level of control your organization has over the GFT “Communication” In this box a list of 20 questions is presented. The questions in this list have been answered by employees of more than 250 organizations in Western Europe. These organizations were operating in different fields, ranging from chemical companies to refineries and construction companies. Normally, these questions would be tailor-made for each branch. This list serves as an example only to show how the tool works for one of the GFTs. Only those questions have been selected that have proved to be so “general” that they are applicable in at least 80% of the industries. In “real life” employees would not only have to answer the questions (anonymously), they would also have to motivate their answers. It is not sufficient to answer “Yes” on, for example, the indicator “Did you have to work in the past 4 weeks with an outdated procedure?” The employee would have to indicate which procedure it was and under which conditions it had to be applied. This motivation serves two goals: it increases the reliability of the answers and it provides management with information it can act upon. Caution is also necessary when interpreting the percentile score: in a real measurement, each organization would be matched against a representative sample of branch-related organizations for each of the 11 GFTs. The distribution of percentiles is from May 1995, and this distribution does change slightly over time. How to measure the “level of control” Answer all 20 indicators with your own situation in mind and beware of the time limits in the questions. Some of the questions might not be applicable for your situation; answer them with “n.a.” It might be impossible for you to answer some questions; answer them with a question mark“?”. After you have answered all questions, compare your answers with the reference answers. You get a point for each “correctly” answered question. Add the number of points together. Calculate the percentage of correctly answered questions by dividing the number of points by the number of questions you have answered with either “Yes” or “No”. The “n.a.” and “?” answers are not taken into account. The result is a percentage between 0 and 100. The measurement can be made more reliable by having more people answering the questions and by averaging their scores over the levels or functions in the organization or comparable departments. Twenty questions about the GFT “Communication” Possible answers to the questions: Y = Yes; N = No; n.a. = not applicable; ? = don’t know. In the past 4 weeks has the telephone directory provided you with incorrect or insufficient information? In the past 2 weeks has your telephone conversation been interrupted due to a malfunctioning of the telephone system? Have you received mail in the past week that was not relevant to you? Has there been an internal or external audit in the past 9 months of your office paper trail? Was more than 20% of the information you received in the past 4 weeks labelled “urgent”? Did you have to work in the past 4 weeks with a procedure that was difficult to read (e.g., phrasing or language problems)? Have you gone to a meeting in the past 4 weeks that turned out not to be held at all? Has there been a day in the past 4 weeks that you had five or more meetings? Is there a “suggestion box” in your organization? Have you been asked to discuss a matter in the past 3 months that later turned out to be already decided upon? Have you sent any information in the past 4 weeks that was never received? Have you received information in the past 6 months about changes in policies or procedures more than a month after it had been put into effect? Have the minutes of the last three safety meetings been sent to your management? Has “office” management stayed at least 4 hours at the location when making the last site visit? Did you have to work in the past 4 weeks with procedures with conflicting information? Have you received within 3 days feedback on requests for information in the past 4 weeks? Do people in your organization speak different languages or dialects (different mother tongue)? Was more than 80% of the feedback you received (or gave) from management in the past 6 months of a “negative nature”? Are there parts of the location/workplace where it is difficult to understand each other due to extreme noise levels? In the past 4 weeks, have tools and/or equipment been delivered that not had been ordered? Reference answers: 1 = N; 2 = N; 3 = N; 4 = Y; 5 = N; 6 = N; 7 = N; 8 = N; 9 = N; 10 = N; 11 = N; 12 = N; 13 = Y; 14 = N; 15 = N; 16 = Y; 17 = N; 18 = N; 19 = Y; 20 = N. Scoring GFT “Communication” Percent score = (a/b) x 100 where a = no. of questions answered correctly where b = no. of questions answered “Y” or “N”. Your score % Percentile % Equal or better 0-10 0-1 100 99 11-20 2-6 98 94 21-30 7-14 93 86 31-40 15-22 85 78 41-50 23-50 79 50 51-60 51-69 49 31 61-70 70-85 30 15 71-80 86-97 14 3 81-90 98-99 2 1 91-100 99-100 Back The Swiss cheese model has become the dominant paradigm for analyzing human errors and aviation accidents & incidents. It illustrates that accidents involve successive breaches of multiple defenses. These breaches are triggered by many enabling factors such as equipment failures or operational errors. The Swiss-Cheese Model contends that complex systems - such as Aviation- are well defended by layers of defenses (otherwise known as barriers). A single-point failure is rarely consequential. Breaches in safety defenses can be a delayed consequence of decisions made at the higher levels of the organization, which may remain dormant until their effects or damaging potential is activated by certain operating conditions (known as latent conditions). However, under such specific circumstances, human failures - or Active Failures - at the operational level act to breach the final layers of safety defense. The Swiss-Cheese Model proposes that all accidents include a combination of both active failures and latent conditions -Latent failures. The distinction between the hands-on human failures and those made by other aspects of the organization is described by The Swiss-Cheese Model as active and latent failures. Active Failures have an immediate consequence and are usually made by front-line people such as ground support equipment operators, maintenance technicians, and aircraft pilots. These immediately preceded and are the direct cause of the accident. Latent failures are those aspects of the organization which can immediately predispose Active Failures. Common examples of latent failures include (HSE, 1999): Poor design of plant and equipment;Ineffective training;Inadequate supervision;Ineffective communications; andUncertainties in roles and responsibilities. Latent Failures are important for accident prevention, for two reasons: 1. If not resolved, the probability of repeat (or similar) accidents remains high, regardless of what other action is taken. 2. As one latent failure often influences several potential errors, removing Latent Failures can be a very cost-effective route to accident prevention. Is it complicated to understand the Swiss Cheese Model? Let me facilitate this by explaining the classification of Human Failures. The term human failures can include a great variety of human behavior. Therefore, in attempting to define human Failures, different classification systems have been developed to describe their nature. Identifying, why these Failures occur will ultimately assist in reducing the likelihood of such errors occurring. Regarding the classification of Active Failures, Reason distinguishes between intentional and unintentional Errors. Intentional errors are described as violations. Unintentional errors are classified as either slips/lapses or mistakes. A- Skilled-Based Error - Slips and Lapses These occur in routine tasks with a person who knows the process well, and holds experience in his work: They are action errors that occur at the time of performing the task; They often involve missing a step out of a sequence or applying steps in the wrong order and frequently arise from a lapse of attention; Operating the wrong control through a lapse in attention or accidentally selecting the wrong gear are typical examples. B- Mistakes They are decisions that are found to be wrong, although, at the time, the person would have believed them to be correct. There are two types of mistakes (HSE, 1999). - Rule-based mistakes It occurs when the operation at hand is governed by a series of rules. The mistake occurs when an inappropriate action is tied to a particular event. - Knowledge-based mistakes Knowledge-based mistakes occur in entirely novel situations when you are beyond your skills, beyond the provision of the rules. And you have to rely entirely on adapting your basic knowledge and experience to deal with a new problem. Violations are any deliberate deviation from the rules, procedures, instructions, and regulations which are necessary for the safe or efficient operation and maintenance of a plant or equipment. Breaches in these rules could be accidental/unintentional, or deliberate. Violations occur for many reasons and are seldom willful acts of sabotage or vandalism. The majority stem from a genuine desire to perform work satisfactorily given the constraints and expectations that exist. Violations are divided into three categories: routine, situational and exceptional (HSE,1999). A- Routine Violations Are violations where breaking the rule, or procedure has become the normal way of working. The violating behavior is normally automatic and unconscious. But the violation is recognized as such by the individual(s) if questioned. It can be due to cutting corners and saving time. Or be due to a belief that the rules are no longer applicable. B- Situational Violations Occur because of limitations in the employee's immediate workspace or environment. These include the design and condition of the work area, time pressure, number of staff, supervision, equipment availability, and design and factors outside the organization's control, such as weather and time of day. These violations often occur when a rule is impossible or extremely difficult to work to in a particular situation. C- Exceptional Violations Violations that are rare and happen only in particular circumstances, often when something goes wrong. They occur to a large extent at the knowledge-based level. The individual in attempting to solve a novel problem violates a rule to achieve the desired goal. Swiss Cheese Model Example In this example, I will represent the threats to safety by the holes in the slices. Slice 1: Management level Expanding the operation network decision was taken three months ago (Expanding the operation network with the current human power and current maintenance capabilities). Slice 2: Reliable Maintenance The airline suffers from a " Missing Component" of reliable maintenance. Slice 3: Unsafe Acts Undocumented Procedures. Slice 4: Human Failures Flight crew deliberately deviating from standard operating procedures followed by a lack of communication, leading to a loss of situational awareness coupled with a non-assertive behavior causing an incident or accident. Do you think the accident is the flight crew's responsibility? or Many contributing factors that led to this accident. Summary Human Error is more than front-line personnel error. Everyone can make errors no matter how well trained and motivated they are. It is important, for accident investigators and safety experts to distinguish between active and latent failures. Active Failures are those hands-on front-line personnel errors that immediately precede an accident. Latent failures are the factors or circumstances within an organization (which increase the likelihood of Active Failures). Latent Failures lie hidden until they are triggered in the future. Further reading : - ICAO Doc 9859- Safety Management Manual - Reason J (1990) Human Error, Cambridge University Press - HSE (1999), Reducing Error and Influencing Behaviour, HS(G)48, HSE Books