



## **Human Factors Considerations: Midstream Process Safety Integration**

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# **Human Factors Considerations: Midstream Process Safety Integration**

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## **Abstract**

Midstream oil and gas companies are coming into their own. For example, according to Deloitte (2014), “Midstream energy companies’ share of overall market value in the oil and gas industry has already risen, nearly tripling over the last six years.” Midstream operators are becoming the stars of the energy industry, investing \$26 billion on new pipelines and facilities in 2012 – a drastic increase from the seven billion spent just six years earlier [1].

Particularly in the United States due to the success of shale and the increasing possibilities for exportation along with recent accidents and fatalities, more scrutiny is being given to both process safety and the humans in the myriad of midstream systems. In the petroleum industry, midstream activities are often taken for granted. Midstream, the conduit between upstream (retrieval of crude oil) and downstream (the processing of petroleum products), is deceptively complex and risk laden. The process safety issues are many and often the integration of those issues with the elements of crude oil storage and transportation is elusive.

“Even the best designed, engineered, maintained, and operated pipelines and modes of transportation can be vulnerable to human failures and organizational complexity.” [2] Human Factors (HF) is a scientific tool that integrates humans (and their capabilities and limitations) into highly complex processes and systems. This discussion describes how the integration of human factors with process safety in crude oil storage, pipeline management, and transportation preserves human safety, organizational credibility, public goodwill, and infrastructure confidence along with investment maximization and preservation.

Each aspect and phase of midstream activities share commonalities with the others and yet each has its own unique aspects and challenges. This paper describes human factors integration with process safety in the midstream environment. Issues and considerations common to most facets of midstream enterprises are addressed. In addition, unique components of each of the midstream factors such as pipelines, transportation – rail, ship, and truck - and logistics and technology are discussed from a human factors perspective.

## 1. Introduction

Transportation links are crucial in energy markets, where supply and demand are frequently separated by large distances [3]. The transportation of crude oil has been taking place for more than a century. The first priority for transporting crude throughout North America should be safety; the second is efficiency or cost. Safety and efficiency must be predicated on known risk, meaning that experience and technical capability help determine the possibilities and they can help rank order factual, not hypothetical, conclusions [4].

All the modes of crude oil transport – pipeline, rail, vessel, barge, and truck - as well as the transshipment locations where oil is moved from one mode of transport to another, pose potential risks. Each mode of crude oil transport has advantages and disadvantages based on a range of operational, economic, and environmental factors and considerations. The risks associated with each mode of transportation must be understood in order to prepare for possible accidents, reduce risks, and to protect the public and the environment [5]. Risks are complicated by the properties of the oil being transported. Research shows that dilbit (diluted bitumen) from Canada has more corrosive properties and weathers quickly while Bakken crude oil is volatile with a low flash point and may be more explosive than conventional crude oil [6], [7].

Transportation by tanker or barge from port to port is both safe and efficient. Large quantities of transported crude oil provide efficient use of rugged vessels that transport without issues for years. Moving oil from where it is produced to ports for transport is clearly safest and efficient when it is transported by pipelines designed fit-for-purpose. Pipelines are undeniably the lowest risk and most efficient means of transport onshore for point-to-point movement. They require both regulation and ongoing inspection and maintenance and should be replaced based on predetermined age and risk factors [4].

Trains and trucks work when the distance is short and the volumes not so large. Trains can also provide a temporary longer-distance, higher-volume solution until the costs of a pipeline are justified. Facts are facts, and crude oil in tankers weighs a lot; its contents are volatile under certain conditions; rails are thin, as are train-car wheels, and possibly brittle, depending on age, construction, wear and tear, and weather. Tracks are constantly exposed to breakdown. Trucks are exposed to the same risks, including traffic and other highway conditions. Trucks are also higher risk, being subject to human factors, more so than other transport infrastructure. Hofmeister [4] advocates the use of experience and results, real data in real time, to rank the risks and decide fact-based outcomes in the order provided.

The term “human factors” applies the knowledge of human capabilities and limitations to the design, operation, and maintenance of a system. When human factors engineering is integrated into all aspects of a midstream system, the likelihood of human error is eliminated or if an error should occur, the consequences are significantly mitigated. If it was not for human error, if people were not remarkably human, there would be no need for human factors. The systematic integration of human factors into midstream activities has many benefits in addition to the elimination of human error; these include preservation and well-being of the workers, the public - perception and goodwill, the environment, and the assets as well as increased reliability, productivity, regulatory compliance, and user-acceptance.

## 2. Human Factors

Human factors engineering examines the interaction among people and all of the factors around them – the environment, the procedures, equipment (hardware and software), and other people. The discipline of human factors looks at the people, the job, the organization, the environment, and the resources. The goal is to improve the interactions. [8]

The concept of human factors to some seems extraordinarily and unnecessarily elusive. However, the breadth and scope of the scientific discipline is extremely encompassing. If one contemplates that anytime there is a human in the system, human factors should be considered – the enormity is almost incomprehensible. Admirable and worthwhile efforts toward the integration of HFE – varying in depth, application, and focus are undertaken in many industries and government agencies. At the most fulfilling extreme are the American military (which gave rise to the discipline during World War II) and some hazardous process industries. At the other end of the spectrum, some organizations and institutions adopt the principles of human factors for product design, but not the facility that produces the product. Or as often seen, human factors engineering is only applied to people’s physical well-being through ergonomics or piecemeal on a project (silo-effect) such as valve accessibility or operability of some component with no regard to consideration of a systems approach.

Midstream oil and gas is comprised of many components and many efforts that all involve humans. Even the transportation of crude oil and other related products involves the interface and integration of transportation and storage modes. Such interfaces may include: pipeline to rail, rail to truck, ship to storage, and so forth. The permutations held by each of these modes and methods all hold their own challenges for the humans in the entire system and each system individually.

This work attempts to give some consideration to humans in each of the individual systems, but also, encourages the reader to understand the overlaps among the various modes of transportation, the logistics and storage, and the myriad of often changing approaches overlap. Considerations for example, may be generalized to rail or truck. This paper addresses each separately but also provides a comprehensive look at overall human factors and ergonomics considerations.

This document is not prescriptive, but does encourage the reader to seek the prescriptive guidelines and standards because those are readily available. The “knobs and dials” era of human factors (controls, displays, labeling and other hardware issues) and the ergonomics of work postures and body positions and physical stressors are well-documented. The practice of human factors in contemporary business has grown far beyond physical dimensions and hardware interfaces, but rather, the benefit of macro-ergonomics (systematic holistic applications), organizational considerations, workload, situational awareness, reliability management, and the roles of humans in harsh and remotely handled systems.

## 3. Pipelines

Crude oil and natural gas are both already transported all over the U.S. in enormous volumes. There is a 2.5 million-mile pipeline network that moves oil and gas all over the country. That is more than 50 times the length of the U.S. Interstate Highway System. These pipelines cross through national parks, rivers, underneath cities and above the nation's aquifers—and there are pipelines crossing the U.S. border to the north and south. [9]

Unconventional oil production has transformed crude-oil supply networks in North America. New transportation modes have emerged to address logistical bottlenecks that have left crude supplies stranded. Several changes are needed, however, to resolve serious issues that have both economic and environmental consequences.

The pipeline safety statistics from 2000-09 reported 411 spill incidents from Canadian pipelines and 3,318 spill incidents from the U.S. pipelines. Within the eight Great Lakes states, 559 hazardous liquid spill incidents occurred from 2004 to 2010 resulting in property damages of over \$1.1 billion. Although data from Canada's NEB and the U.S. DOT show that pipelines result in fewer oil spill incidents and personal injuries than road and rail, this is a high-volume transmission mode and large spills in the recent past have demonstrated that the cumulative impact of a spill on the environment, economy and human health of the affected region can be serious.

The Pipeline and Hazardous Materials Safety Administration (PHMSA) has amended the pipeline safety regulations to prescribe safety requirements for controllers, control rooms, and supervisory control and data acquisition (SCADA) systems used to remotely monitor and control pipeline operations. The regulations address human factors engineering and management solutions for the purpose of enhancing the performance reliability of operator personnel that control pipeline operations. This rule generates significant benefits by reducing the number and consequences of shortfalls in control room management practices and operator errors when remotely monitoring and controlling pipelines and responding to abnormal and emergency conditions.

The “tight coupling” of a pipeline system makes it vulnerable to an unexpected event or series of events. This is one of the reasons the proposed rule includes sections on SCADA displays, communications, management of changes, alarm management, shift turnover, learning from experiences, qualifications, roles and responsibilities, validation, as well as fatigue mitigation.

### ***3.1 Pipeline Leaks and Ruptures***

Nearly all pipeline breaches are caused by human error. For example, in 2010 millions of gallons of bitumen (dilbit) leaked into Michigan's Kalamazoo River. It was one of the largest inland oil spills in United States history. The cleanup has gone on for years and has cost about 100 million dollars [10]

And, as important is the damage to the public's perception of the industry and pipelines specifically. That monumental event was directly attributed to human error and poor safety practices. In fact, after a 2 year investigation, the National Transportation Safety Board (NTSB) [10] found that there was a “complete breakdown of safety”. The NTSB report criticized the

pipeline owner for inadequate safety inspections and other human errors that resulted in the spill being ignored for 17 hours.

### 3.1.1 Human factors contributors to the accident included according to the NTSB [10]:

Organizational Accident with many human factors errors

1. Multiple contributing causes – oversight, training, and management. The operators were inadequately trained to handle such an event.
2. Erroneous assumptions about the pipeline integrity, cracks were not remediated or repaired – in part, this was a failure of training in the recognition and response to emergency situations.
3. Latent Errors – this type of error is considered a design flaw. Typically such errors are inherent, intrinsic, and often inevitable design error that given all the proper circumstances, the incident occurs. Often negative outcomes of latent errors are the cumulative effect of many smaller errors.
4. Failure to apply lessons learned from previous accidents – most process industries gather extensive operating experience data. These data if applied to new design, modifications, upgrades, and or other industry practices including procedures are proven to help avoid incidents such as pipeline accidents.
5. Flawed and incomplete procedures
6. Failure of operators to follow procedures – in the case of the pipeline fracture in Michigan, operators disregarded both alarms and procedures. Clearly, they were to shutdown the pipeline and they did not. The operators were also unduly influenced in their decision making
7. Lack of consistency and standardization – within all critical elements – communications, procedures, language among the workers,
8. Misinterpreting absent information as actual, consequential information
9. Operators knowingly failed to follow procedures; they knowingly violated the restriction on continuing flow for more than 10 minutes in a line with an unexplained alarm.
10. Organizational Culture of Deviance – coined by NASA after the space shuttle Challenger tragedy, it means an inappropriate and increasing tolerance of procedural violations
11. Lack of simulator fidelity
12. Loss of situational awareness – until a member of the public informed the control center operators of the breach, the loss of oil continued for 17 hours
13. Insufficient PHMSA oversight of integrity management programs

The pipeline industry and regulators have attempted to respond to this and similar incidents with the development, implementation, and compliance with human factors programs designed to prevent such incidents from continuing to occur in such magnitude.

### ***3.2 Pipeline Human Factors Risk Model***

Pipelines International created a pipeline human factors risk model. The different activities or processes executed throughout the lifecycle of the pipeline asset have a human intervention

component that can affect the risk level during the operation of the asset were considered during model development. [11]

### 3.2.1 Design

A complex facility has a higher potential for employee confusion and there is the potential to open the wrong valve or provide maintenance to the wrong piece of equipment. Other areas of concern are human factors considerations in design standards, which include checking the use of standards in the design phase by incorporating periodic checks on design work, and the accuracy of drawings and documents of the pipeline design.

### 3.2.2 Construction

Errors or inefficiencies introduced during construction influences the potential for human error during operation of the pipeline. Major areas of human factors' concerns during construction include: inspection quality with factors such as inspectors' capabilities, work environment, tasks performance, and procedure acceptance; performance determined by measuring effectiveness of the procedure observation program; and drawing and document accuracy, where mistakes are likely to be made in the future when employees assume inaccurate drawings are correct.

### 3.2.3 Field operation

The risk of human error varies with the way field operators communicate with each other as well as how they perform individually. The areas of concern include: the effectiveness of communication of changes in operating environments at the facilities, communications among shipper personnel delivering product and field personnel, preparation/pre-job meetings, and complexity of the facility that includes tasks such as locating components and labeling. Also, executing the proper procedure on the correct piece of equipment is susceptible to human error.

### 3.2.4 Preventative maintenance

Pipeline operations are periodically interrupted by scheduled maintenance that is essential to ensure the pipeline continues to operate properly without failure. The highest risk for human error is during the shut-down and start-up of a pipeline is due to the higher level of human intervention compared with steady-state operation. Therefore, the areas of concern include; maintenance schedule (volume and completeness), the quality of process safety management (PSM) records related to equipment maintenance, the accuracy of maintenance drawings and documents, the quality of change record keeping, the execution of maintenance procedures, and start-up and shut-down procedures.

### 3.2.5 Control center operation

The control center remotely operates the product flow for pipelines from a central location. A 12-hour shift mainly consisting of monitoring computer screens is monotonous and tedious. Distraction comes easy and vigilance is often elusive. Typical of monitoring tasks in process industries, vigilance, and situational awareness are chronic challenges. Areas to address include:



- start-up/shut-down during normal operations
- task complexity
- workload for the control room operators
- equipment layout
- design of workspace
- layout and design of SCADA
- communication among operators and maintainers and field personnel
- shift turnover and schedules
- operational information accuracy and availability including plant status
- job procedure design, availability, and completeness
- alarm presentation and management
- training
- stress and fatigue assessment and management
- alertness on the job
- automated operations
- control room design and staffing (crew complement)
- response to computer failures
- safety interlocks programmed into the computer system
- procedure verification and validation

### 3.2.6 Training and competency

Experience level and qualifications of employees is critical. Generally more experienced employees are less likely to make errors than inexperienced employees.

### 3.2.7 Management systems

Management systems include company rules, culture values, acceptable behavior, training programs, work schedules, etc. These organizational aspects give management the opportunity to influence and manage the organizational culture and accommodate the humans in the system.

### 3.2.8 Damage prevention techniques

Damage prevention techniques if they are accepted and used, are valuable in locating pipelines in construction areas such as landowner education and awareness, one-call or other notification systems, use of buried marker tape, incident investigations, and accuracy of line locators.

### 3.2.9 Encroachment detection

Encroachment detection is optimized with areas of evaluation such as effectiveness of ground and aerial patrols, and location and design of markers and signage along the pipeline.

## 3.3 *Human Factors Considerations*

Urrea [11] made the following recommendations relative to the reduction of pipeline human error.

1. Create a policy or procedure to manage process-safety information.
2. Ensure all equipment is assessed to determine which are 'safety critical' to go along with the list of 'operations-critical' equipment generated by the control center.
3. Standardize policies to ensure operators and field staff are using the most up-to-date and efficient systems such as process-safety information procedures and processes, and safety training and observations.
4. Write a human factors' standard that defines the company position with respect to human factors and provides design principles and operation guidelines to ensure the potential for human error is mitigated through the pipeline and facility lifecycle.

#### **4. Rail**

Rail has traditionally been a secondary crude-transportation mode because it costs two to three times as much as pipelines. In 2009, 10,000 carloads of crude oil were carried on Class I railroads. By 2013, this traffic had grown to 400,000 carloads—a 40-fold increase. This explosive growth has resulted in rail congestion and service delays, which often impact transportation of grain and other commodities. It has also led to an increase in rail accidents.

According to the Association of American Railroads, 434,000 carloads of crude oil moved by rail across United States in 2013, roughly 45 times the amount shipped in 2008, and the volumes continue to rise [12]. The reason that oil shipping by rail has expanded is due to the ability of rail to quickly respond to increased production in the oil fields. However, the increased volume of rail transport has also led to a surge in oil spill incidents via this mode. Rail has historically been a safe and efficient way for suppliers to transport oil. Over the period 1996-2007, railroads statistically spilled less crude oil per ton-mile than either trucks or pipelines. However, in 2013 alone, the total volume of oil spilled by rail was more than the combined total from 1975-2012 [12], [13].

The incident at Lac-Mégantic, Quebec, which left 47 dead, is the most notable such accident. There have also been accidents in Lynchburg, Virginia and Casselton, North Dakota, as well as Alabama and South Carolina, and many other small incidents throughout the U.S. There have also been tank-car failures, spills, and derailments.

Even though rail is not the ideal transportation mode, it is and will remain a reality. This is especially true for shipments to the East and West Coasts, because no pipeline projects are in the works. It is also true for bitumen, a very heavy, viscous grade of crude oil, which can be transported by rail without dilution. Railroads have invested billions of dollars to increase capacity and improve maintenance. But congestion remains, and accidents continue.

According to Thurber [3], "What is needed is an effective and swift rollout of improved standards for railcars, improved risk identification and mitigation processes, and better availability of information to support improved emergency response. Regulators are taking action. But with several of them involved, cooperation and swift action are needed to enable an appropriate response from railroad operators and tank car manufacturers."

Rail transport of crude oil is generally more expensive per barrel than pipeline transport, and it can present larger safety risks if not adequately regulated. Better regulation of rail transport of crude oil is a necessary but not sufficient improvement in North America's energy transportation network. A major reason for the surge in rail transport of crude oil has been the difficulties associated with timely construction of needed pipelines [3]. Part of the solution to traffic problems for rail companies has been to make single shipments much larger so they can transport more goods in one go and free up more time for other products. The only expense for this has been in adding extra cars to trains. There are economic and other considerations relative to this practice that lie beyond the scope of this writing; however, the fact remains that more and more trains are conveying crude oil and other petroleum products.

#### ***4.1 Tank Car Design***

The DOT-111/Class 111 tank car is most frequently used to ship crude oil in the U.S. and Canada. Several problems have been identified with this tank car model. These tank cars are prone to structural failure and rupture upon impact. Studies from the Transportation Safety Board (TSB – Canada) [14] and the National Transportation Safety Board (NTSB – United States) [10] show that the DOT-111/Class 111 car's wall thickness (7/16 inch) might not be sufficient to withstand impact during an accident [10]. The topfittings, used for loading and unloading of content, may burst open in a derailment or rollover. The head shields, at the front of the cars, are prone to puncture in a collision. The three bottom valves, facilitating quick unloading at the terminals, can break on impact and release oil. Out of the 63 oil-filled tanker cars that derailed in Lac-Mégantic, 60 cars (95%) spilled oil due to tank car damage – puncture of shell and front/rear heads were identified as the major structural points of failure [15].

#### ***4.2 Additional Rail Car Safety Considerations***

The coupling and assembly of rail cars makes a significant difference relative to their safety and possible derailment. Not does the proper and correct coupling of the cars have to be considered, but also, the order of the cars according to content, weight, empty or loaded, and train length. Research shows that improperly assembled trains are more susceptible to derailment [16]. The aforementioned variables related to the distribution of cars affects the train's ability to negotiate track routes while subjected to "stretching" and "compressive forces" that may result in derailment. In addition to train assembly, other factors like track grades and turning radius affect train maneuverability which may result in derailment.

#### ***4.3 Federal Railroad Administration Rulemaking – Human Factors***

In August 2001, the Federal Railroad Administration (FRA) issued the notice of proposed rulemaking: Standards for Development and Use of Processor-Based Signal and Train Control Systems (49 Code of Federal Regulations Part 236). This rule addresses the design and implementation of processor-based train control systems. Under the proposed rule, a railroad wishing to implement a positive train control (PTC) system in revenue service must develop and submit a product safety plan (PSP) and assess the risk associated with the new system.

Submitting this information requires knowledge of the human-machine interface (HMI) and its impact on human performance. Similarly, FRA will require knowledge of HMI and its impact

on human performance to evaluate the safety of the new system. The first system expected to fall under the proposed rule was the North American Joint Positive Train Control (NAJPTC) system.

This PTC system differs significantly from train control systems that have come before it. The NAJPTC system is a complex train control system that significantly alters the current method of operation and the way railroad employees interact with the train control system and may create the potential for a variety of new failure modes.

The current report provides guidance to the railroad industry, specifically to those people who must submit human factors analyses of HMI as part of the PSP and to FRA staff, which must evaluate those analyses. The challenge for the railroad is to identify how these new systems or components effect human performance, identify new failure modes, and address how to prevent or mitigate these failure modes. FRA must decide whether the human factors analysis has identified all the potential human factors-related safety risks and addressed them in a satisfactory way. [17]

#### ***4.4 Human Factors Considerations***

It can readily be seen that there are human factors concerns around the operation of railroads and the operation and maintenance of trains, as well as the impact of embracing new technologies. As with the other modes of transportation some of the human factors issues around railroads are concerned with minimally the following [18]:

##### **4.4.1 Engineer-Related Safety Concerns**

- Changes in Operating Practices - whenever there are changes made to work practices, modifications, upgrades, new equipment or processes, those should be reviewed by HF. They are often a source of human error especially when changes are not well broadcast. Positive train control is one such are where locomotive engineers have expressed concern. There are new interfaces which impact the operation of the train as well as new human system interfaces that deliver new information and alerts.
- Other Sources of New Problems
  - Reliance on Manually Entered Data - PTC systems generally require manually entered inputs at the start of a trip and after a shutdown of the system during train operations. The train crew must enter information that the system will use as parameters for safe operation. These data entry tasks provide another source of workload and distraction. In addition, manual entry errors can have safety implications. [18]
  - Changes in Mode of Operations – it stands to reason that train locomotive engineers may have to drive some trains with contemporary PTC and at other times operate trains that are not operate with the new PTC, thus error-likely. The transition between the two can cause difficulties.
  - Impacts on Teamwork Processes – as with any system that is upgraded and new human interfaces are introduced, particularly if that system is poorly designed or over gimmicked, there are process safety implications and increased likelihood of human error.

##### **4.4.2 Training**

With something as sophisticated and new as train PTC, hands-on training as well as classroom is requisite. In addition, all human factors elements – training, procedures, simulators, hardware, software, labeling, color coding, abbreviations/acronyms, and so forth must be perfectly consistent and standardized.

#### 4.4.3 Maintenance-Related Safety Concerns

- Availability and Quality of Support - Maintainers must have adequate support. This support includes adequate and sufficient testing and maintenance equipment, vendor and supplier dialogue, current manuals, and requisite training.
- New Sources of Workload - New systems can introduce new sources of workload that can divert attention and resources. This can result in increased error or sources of risk in other safety areas. Safety analyses should identify additional sources of workload associated with the operation and maintenance of the new PTC system. The potential for increased error or risk in other safety areas should be addressed [18].
- New Technology Issues - The new PTC systems incorporate digital technologies that differ from more traditional relay logic systems. This imposes new human performance requirements (e.g., new knowledge and skills), as well as introducing new opportunities for improved performance (e.g., better diagnostics). Test and maintenance of PTC systems require general knowledge of electronics that maintenance personnel who have worked on traditional relay logic systems may not possess.
- New Sources of Extreme Exposure - New technologies can result in added exposure to risk. In particular, unreliable equipment that requires signalmen to spend more time on the track troubleshooting wayside equipment can increase their exposure to risk. Safety analyses should explicitly consider any added exposure to risk that result from operating or maintaining the systems. In particular, safety analyses should explicitly address issues relating to the reliability of the equipment and impact on risk to the maintenance personnel responsible for testing and fixing the equipment.

#### 4.4.4 System Operation-Related Safety Concerns

- Impact on Operations – According to Wreathall, et. al. [18] PTC systems can impact the overall safety and productivity of a railroad since the delays or stoppages by one train in the system can spread to create blockages for other trains, and these can have impacts beyond the simple delays to a single train. This is particularly true for high- density operations, such as the NEC and for commuter operations (because of scheduling constraints), but other locations may exist where system delays and interruptions can be significant. For example, if a long heavy coal train were to stall on an upgrade while the traffic density may be low, the inconvenience of having to repeatedly send out helper locomotives could be a source of operational frustration.

While problems like these may not be in themselves safety concerns, they can become sources of pressure for operators to find ways to overcome these problems. Some of these may lead to the system being switched out (and therefore the expected level of protection

from its operations being reduced) or other ways of bypassing the enforcement components of the PTC system.

- Integration with Existing Systems – similar to any system that upgrades, increases components, changes work practices, or any alterations to a process system must be accompanied by an assessment of the interface, interactions, and impacts of the integration of the old with the new.
- Interoperability Issues – includes human factors issues such as the movement of personnel between upgraded equipment and the more familiar existing equipment. Also considerations of upgrades of equipment and interfaces that differ from one system to another. That is, if one process integrates a new HMI or HSI and a similar process used by the same operators adopts a different HMI or HSI, it becomes extremely error likely and generalization is not possible.

#### 4.4.5 Systems Development and Implementation Process

- User Involvement in the Design Process – It is the case whenever process aspects of any nature are changed or are new, operator and maintainer input is critical. Gathering their input can be done in the form of workshops, task analysis, and gathering data from lessons learned. It is essential in any human factors development program that users be involved in the design process early and continues to be involved in evaluating and improving the design as it progresses [19]. Interviews with users of all the systems currently in use shows that everyone with operating experience knows that, with their input very early on, the designs would be more effective, development and deployment would take less time, and acceptance by the users would be better. Theory and/or engineering design are often at best are only loosely coupled to the practical applications of implementation of new work practices, processes, and associated hardware and software.
- Person-in-the-Loop Testing - is the process by which developers continue to include representatives of user communities in the system tests as the design progresses, rather than simply performing hardware and software tests in an isolated manner. The idea behind testing is that there should be no user-related surprises when the system goes into operation. Tests that explicitly evaluate the ability of train crews to understand and use the in-cab displays being designed and to operate a train with the PTC control algorithms under development should be conducted throughout the PTC development process to provide rapid feedback to inform the design process. In practice, the railroad may implement person-in-the-loop testing. However, this testing frequently takes place during the latter phases of the system implementation, as the systems become installed in locomotives. Making changes at this stage is more expensive, more likely to delay the rollout of the system, and less likely to remove (rather than moderate) user problems. Performing person- in-the-loop testing early in the design process makes easier to adjust the design before irreversible or costly decisions has been made [18].
- Gradual Implementation Process – Wreathall, et al., [18] state: “Even if the system design evolves using feedback from person-in-the-loop testing with user groups (discussed above), surprises can still occur as the system becomes deployed in operational settings. Examples include the following:

- Finding areas where signal strength to the PTC system is suddenly weak (most PTC system users described this experience)
- Operational settings where equipment difficulties exist (such as the approach signal problem)
- Maintaining a minimum train speed in particular locations to prevent power phase through pantograph and catenary equipment
- Locations where frequent changes in speed limits occur (and engineers become preoccupied with PTC displays) are also often areas where there are frequently trespassers (e.g., urban locations)
- Maintenance staff or equipment may be needed to overcome initial weaknesses in the design”

To avoid these and other new problems causing loss of credibility of the PTC system and pressure to remove or isolate it, the deployment of the system should be done gradually and preferably in locations where the consequences can be isolated from the entire operating system. Solutions can then be developed before the PTC system is deployed more widely.

While these details are relative to railroad PTC integration, the human factors principles contained herein are completely appropriate for generalization and application to any of the transportation modes.

## **5. Ships**

Special risks arise from the nature of ship and barge operations, which differ in significant ways from surface transportation modes and are not always fully controllable through regulatory measures. Weather conditions, for instance, are a much greater risk management factor for water transportation than for truck, rail or pipeline. Severe weather in the form of high winds and waves, ice and diminished visibility – particularly when combined with equipment failure and/or human error – can substantially increase the risk of catastrophic events. There is also greater responsibility placed on a single human operator for ship and barge operations than in surface transportation modes. While commercial shipping lanes linking cargo ports on the Great Lakes are well established in open waters and tightly regulated in restricted and high-traffic areas, ultimate navigation routing decisions and ship handling maneuvers are still controlled by the vessel master on U.S. and Canadian flag vessels, or by a licensed pilot on foreign flag vessels operating in the Great Lakes via the St. Lawrence Seaway [5].

### **5.1 Oil Tankers**

An oil tanker, also known as a petroleum tanker, is a merchant ship designed for the bulk transport of oil. There are two basic types of oil tankers: the crude tanker and the product tanker. Crude tankers move large quantities of unrefined crude oil from its point of extraction to refineries. Product tankers, generally much smaller, are designed to move refined products from refineries to points near consuming markets [20].

Tankers have grown to gargantuan proportions. The Prelude floated in 2013 is 5 football fields long - the sheer size defies the imagination. Like an airliner accident, incidents with tanker ships grab the news headlines. And while generally viewed as safe, the magnitude of an accident is typically huge - with environmental impact and often, loss of life. There have been noteworthy accidents over the last several decades.

### **The Amoco Cadiz March, 1978**

One of the single worst oil tanker disasters close to the British Isles occurred when super-tanker Amoco Cadiz ran aground off the coast of France in bad weather in March 1978, en route from the Persian Gulf to Le Havre. The environmental impact was catastrophic. Attempts to save the ship's cargo and oil were waylaid when storms caused the Amoco Cadiz to split in two, releasing all the oil on board into the Atlantic Ocean, just off the Brittany coast.

### **Torrey Canyon March 1967**

In March 1967, the Torrey Canyon supertanker struck Pollard's Rock and spilled 31 million gallons of oil into the Cornish sea. Desperate rescuers, in a bid to minimize the oil slick and the environmental impact used napalm and petrol to try and burn off the oil on the sea's surface. The ship's entire cargo approximately 860,000 barrels either ended up in the sea or were burnt off over the next twelve days.

### **Braer January 1993**

The Braer runs aground off Shetland, Scotland while travelling from Norway to Canada in January 1993, the Liberian-registered supertanker Braer encountered hurricane-force winds off the Shetland Islands and ran aground. Though all the crew was evacuated via rescue helicopter, 85,000 tons of crude oil spilled. The North Sea is fierce in January and the clean-up operation was severely hampered by a month-long storm that made access to the ship and the site difficult.

Additionally, there have been other newsworthy and infamous tragedies involving ships. These include the Zeebrugge Ferry, Costa Concordia, Exxon Valdez, Overseas Reymar, Cosco Busan, and many more.

All of these incidents were directly attributable to human error. Rothblum [38] indicates that ship design and construction are improving. She indicates that "the shipping industry has focused on improving ship structure and the reliability of ship systems in order to reduce casualties and increase efficiency and productivity." Nonetheless the casualty rate and risk of incidents is still high. She goes on to say: "About 75-96% of marine casualties are caused, at least in part, by some form of human error. Studies have shown that human error contributes to:

- 84-88% of tanker accidents
- 79% of towing vessel groundings
- 89-96% of collisions
- 75% of allisions
- 75% of fires and explosions"



The first and foremost goal of human factors is to eliminate the possibility of human error and if an error does occur to mitigate the consequences. Regardless of the midstream mode or transport of crude and other oil products, the application of human factors guidelines, principles, and methods are paramount. Typically not one misstep, error, or latent design flaw creates a catastrophic event. Most of the time, there is a gestalt (the sum is greater than the whole) that leads to an event of catastrophic proportions. That is, many many small errors, flaws, mistake or inappropriate action contribute to the event. A Dutch study (TSBC, 1994) found that human error contributed to 96% of the 100 marine accidents that they studied. And while that is not particularly surprising, they found that in 93 of the accidents at least 2 human errors apiece were committed by at least 2 different people. The study states, "...every human error that was made was determined to be a necessary condition for the accident."

*"That means that if just one of those human errors had not occurred, the chain of events would have been broken, and the accident would not have happened. Therefore, if we can find ways to prevent some of these human errors, or at least increase the probability that such errors will be noticed and corrected, we can achieve greater marine safety and fewer casualties."*

## **5.2 Human Factors Considerations**

In a study by Lema [39] human error related causes of shipping accidents include:

- pressure (organizational culture) on personnel due to specific management practices or trade agreements,
- manning levels - insufficient or surplus personnel based on regulation for the specific ship type
- education - insufficient education or training
- inappropriate professional behavior - errors related to lack of situational awareness, unprofessional behaviors, or willful misconduct
- workload and fatigue
- equipment problems - operation and maintenance

Among all human error types classified in numerous databases and libraries of accident reports, failures of situation awareness and situation assessment overwhelmingly predominate, being a causal factor in about 45% (offshore) to about 70% (ships) of the recorded accidents associated with human error [21]. Human factors is not about either blaming or fixing people. In fact, leading human factors experts maintain that typically design flaws, particularly latent design flaws, lead to human errors [40], [41], [42].

ABS, in its March 2004 [43] review and analysis of ship accident databases 1991-2002, found that human error continues to be the dominant factor in maritime accidents. In particular, lack of situation awareness and errors in situation assessment were factors in up to 70% of the recorded accidents attributed to human error. Fatigue and task omission are closely related to lack of situation awareness. ABS also noted that considering the billion tons of material shipped on the high seas every year, the millions of miles of wake left behind, and the apparent infrequency of major accidents, shipping might be said to be a rather safe industry, generating a steadily

declining trend in marine accidents leading to loss of property, life and environmental damage over the last decade.

Most human errors tend to occur as a result of technologies, work environments, and organizational factors which do not sufficiently consider the abilities and limitations of the people who must interact with them, thus “setting up” the human operator for failure. Even the best designed, engineered, maintained and operated assets and facilities are still vulnerable to human failings and organizational complexity [2].

### ***5.3 Human Factors to Address***

Human factors risk issues include:

1. Multi-factorial risks
2. Complexity of new technologies, new work processes, and human-machine interfaces (HMI) leading to increased mental and emotion strain
3. Poor ergonomic design of non-office video display unit workplaces
4. Poor design of human-machine interfaces (excessively complex or requiring high forces to operate)

## **6. Trucks**

- Trucking is a very dangerous profession, about 600 drivers a year die in highway accidents.
- Driving certain types of rigs like tankers and flatbeds is probably the most dangerous major occupation in the country.
- About 55% of all class 8 (semis) driver fatalities occur in rollover accidents.
- Another 10% occur in fuel oil fires.

Many accident causation systems currently focus much of their attention on the road user and their “human errors” which resulted in the accident occurring. By so doing, these “errors” or failures are treated as the main cause of accidents, while the reasons behind them (i.e. the “factors” of human failures) are often given little consideration. Also, “factors” are often confused with their resultant “failures” in the analysis of accidents. [22]

Tanker trucks are among those with the highest fatality rates. This is due to both fires and to rollovers. Truck cabs built in the United States are not as accident or crush resistant as those built in Europe. Thus a rollover is more likely to result in a fatality. Additionally, many drivers do not understand the severe demands put on the brakes by long downhill runs. Many seasoned drivers were taught long ago that continuous braking was the preferred method of slowing. Unfortunately that is not the best method but rather snubbing (intermittent braking pressure) is best. But many drivers have not been informed of this fact [23].

Sloshing – running a tanker truck less than  $\frac{3}{4}$  full - increases risk of rollovers greatly. And diesel fuel is difficult to ignite – rolled over truck fires are not caused typically by a diesel leak, ruptured tank or sparks. The typical cause of rolled tank truck fires is the ignition of the battery

box. Placement of the battery box (HF design consideration) behind the cab in front of the fifth wheel or inside the frame rails prevents the batteries from being crushed and/or shorted out in an accident.

It is the peculiar case that relative to vehicular accidents, either single vehicle or multiple vehicles, there are well known cases where no driver did anything wrong, but accident and subsequent fatalities were inevitable. These again are related to the latent design flaws discussed earlier. Roadway design, posted speeds, roads in disrepair, hidden intersections, and other variables contributed to fatalities when no driver was at fault and did nothing wrong. These line up with the Reason “Swiss cheese” model.

## ***6.1 Highest incident of Human Error***

As long as the terms human error, human factors, and human behavior are used as synonyms, the chance of reducing over-the-road oil truck accidents is diminished. Humans are human and they are going to be part of the driving system. Thus more consideration is being given to enhancing driving efficiency with less blame on the driver. Human factors is not about fixing people, rather how can the person in the system have optimum conditions in spite of the obvious variable associated with traffic... both single vehicles and multiple vehicle accidents?

### **6.1.1 Human Factors of Driving**

The term 'human factors' in the ergonomic literature generally stands for all the human aspects involved in any activity, whether they are positive or negative. This is a catch-all term that covers notably the science of understanding the properties of human capability. This conception is well represented by the international 'Human Factors' Journal. And when analyzing road accidents, it is worth remembering that the driving system is relying a lot on the capacity of human beings to adapt to situations which are often complex, variable, and insufficiently defined where no other devices than human factors are able to operate and to adapt efficiently, even if this adaptation capacity is subject to limits. The problem behind such a label is that it is too often confused with its homonymous qualifying the human contributing causes of accidents, figuring only the negative aspects of human factors.

### **6.1.2 Human factors of accidents**

Accidents are explained by multi causal factors characterizing the wrong state of a system, i.e. the defects of its components (human or other such as technical defects) and the defects in the interactions between these components. Accident factors correspond to the main parameters of the driving context (relating to the road, the driver, other users, the conditions in which the task is performed) that contributed to the user's inability to adapt to a road situation that had to be negotiated and its particular demands. And it has to be borne in mind that in the majority of cases it is at the interface between the human component and the other components of the system that the problem is found to originate. Thus, human factors of accidents refers to the inadequacy of the variables characterizing the human component (such as level of experience, of fatigue, of attention, etc.), and which combine with the inadequacy of the variables characterizing the other components (road layout, vehicle, environment, traffic) to produce 'human errors'.

### 6.1.3 Human errors

In its common sense definition, human error is most often considered as the main -and more or less fatalistic- cause of the problem considered: Humans are by nature subject to errors, and it is the reason why problems occur. Another implicit aspect of this common sense is that 'error' is confused with and taken as synonymous of 'fault'. In such a way that each time a human error is noticeable in a process, it becomes the fault of the human being involved in this process. And as being a fault, the only way to fight against it is the punishment of its perpetrator. This implicit common sense becomes misleading when applied to the scientific analysis of a phenomenon such as road accidents, leading analysts to confuse human errors and human factors of accident [22].

The problem with such confusion is that it loses any potentiality of solution, apart from fatalism and punishing. A scientific analysis of accidents needs a precise characterization of these 'human errors', clearly differentiated from the factors that produce them, whether they are human, environmental, vehicular, etc. Such a differentiation allows for more efficient solutions directed toward preventing well understood human errors by acting on the well-identified causes, and by promoting a better ergonomics of the driving system in accordance with human capacities and limitations.

## 6.2 *Human Factors Considerations*

Section 6 brought some human factors considerations relative to crude oil transport by truck to the surface that may not be adequately considered. In addition, below a couple of other well know human factors variables contribute to crude truck transport generally.

### 6.2.1 Fatigue

There is much available in the literature regarding shiftwork, crew rotation, shift rotation, circadian rhythms, and variable that impacts the extent to which a human can perform optimally under less than optimal conditions. It is true that the department of transportation and some state and federal government agencies have created regulations regarding the amount of time a driver is supposed to be on the road.

### 6.2.2 Whole Body Vibration

According to CCOH [24], NSC [25], OSHA [26] and other sources, whole body vibration may be experienced by truck drivers. Whole-body vibration can cause fatigue, insomnia, stomach problems, headache and "shakiness" shortly after or during exposure. The symptoms are similar to those that many people experience after a long car or boat trip. After daily exposure over a number of years, whole-body vibration can affect the entire body and result in a number of health disorders.

Sea, air or land vehicles cause motion sickness when the vibration exposure occurs in the 0.1 to 0.6 Hz frequency range. Studies of bus and truck drivers found that occupational exposure to

whole-body vibration could have contributed to a number of circulatory, bowel, respiratory, muscular and back disorders. The combined effects of body posture, postural fatigue, dietary habits and whole-body vibration are the possible causes for these disorders.

Studies show that whole-body vibration can increase heart rate, oxygen uptake and respiratory rate, and can produce changes in blood and urine. East European researchers have noted that exposure to whole-body vibration can produce an overall ill feeling which they call "vibration sickness." Many studies have reported decreased performance in workers exposed to whole-body vibration.

There are a number of human factors interventions that aid in the management of worker exposure to whole body vibration. Vibration dampening, time of exposure, frequency of exposure, activities and rest subsequent to vibration exposure, and a number of others that can be implemented toward containment of driver, operator, and user risk.

### 6.2.3 Training

The literature reports that often truck drivers are unaware of circumstances that can lead to accidents. Approaches taught or used in the past to control trucks are proven to be obsolete. Rather today, with contemporary roadway design, modernized cockpits, improved/enhanced vehicle construction, tires, and so forth, it makes practical HF sense to train drivers in new theories, applications, and approaches to vehicle recovery when at risk and accident avoidance wherever possible.

## **7. Transshipment - Logistics, Storage, and Support**

The surge in crude oil production from the western United States and Canada is changing the ways in which oil is moved in both countries and the geography of oil transport lines, networks and nodes. Transshipment facilities are being expanded in some instances and new ones are being planned and created. These include truck transfer sites at the point of extraction to connect with pipelines; loading and off-loading sites at rail spurs and in rail yards; and transfer and storage sites at refineries and ports.

While some transshipment facilities are becoming more important because of their proximity to booming oil fields or have other geographic advantages, some transshipment facilities and their facilities are less economically viable because they are linked to older and now declining direct sources of oil. This is an inherent feature of the boom-bust cycle of resource extraction-based economies. To cope with uncertainties, oil companies use multiple modes of transport to link key production sites and refineries. They also utilize makeshift facilities, as has happened in North Dakota, to provide immediate services. These temporary facilities are likely to create more risks than those that have been planned carefully and fully vetted by regulators [27].

Corson and Fisher [28], suggest adopting the following activities, all of which have direct human factors implication and lead to fewer incidents and less possibility for human error.

### **7.1 Storage**

1. Regularly inspect fixed and mobile tanks, transfer equipment and piping for drip marks, tank discoloration, puddles of leaked liquid, puddles of water with a sheen (indicating petroleum product), corrosion, localized dead vegetation and stains on the ground, leaks/seepage from valves and seals, deformities (e.g., bulges, cracks, bends) in pipes and tanks;
2. Regularly inspect secondary containment structures for cracks, discoloration, corrosion, erosion (of inside walls and outside perimeter), valve leaks, loose mortar, sealer, sizing or grouting used to construct walls, presence of leaked or spilled material within the containment area, debris within the containment area, and the operational status of drainage valves [closed];
3. Periodically conduct integrity testing of above ground storage tanks and leak testing of valves and piping;
4. Ensure that secondary containment holds the volume of the largest storage container plus sufficient freeboard for precipitation;
5. Inspect and record inspection results of stormwater released from any drainage system in the bulk tank storage area directly to waterways;
6. Regularly inspect and test liquid level sensing devices and audible alarms on each storage tank to ensure proper operation;
7. Inspect valves that permit the outward flow of tank or secondary containment contents to ensure that they will remain closed when not operating;
8. Prepare a spill prevention and emergency response plan for the facility and all storage/transfer operations and submit it to the federal and/or state/provincial environmental regulatory authority for approval;
9. Provide initial and follow-up training to employees responsible for facility operations and for emergency spill response;
10. Locate spill clean-up materials and equipment in known and convenient locations.  
Transfer (Loading/Unloading)

## **7.2 *Transfer (loading/unloading)***

1. Inspect starter controls for pumps within secondary containment to ensure that they will remain locked in “off” position when not operating;
2. Inspect loading/unloading connections of pipelines to ensure that they are securely capped or blank flanged when not in service;
3. Inspect valves and valve operation, piping, flange joints, expansion joints, valve glands, catch pans, pipeline supports and metal surfaces;
4. Ensure that the loading/unloading area drains to a catchment basin or other similar containment structure; the capacity of the containment structure must be equivalent to the largest compartment of a tank car or truck loaded/unloaded;
5. Use physical barriers, warning signs, wheel chocks or vehicle brake interlock systems to prevent tank cars/trucks from departing before complete disconnection of transfer lines;
6. Inspect drains and outlets on tank cars/trucks prior to filling and departure and tighten, adjust or replace as necessary;
7. Use pans or containers to catch drips/spills when making or breaking connections with hoses, nozzles or other transfer equipment;

8. Ensure that buried piping has protective wrapping or coating and is cathodically protected or otherwise meets corrosion protection requirements;
9. Install and maintain vapor recovery systems for product transfer to bulk tanks;
10. Ensure that transfers are supervised by facility employees who are thoroughly familiar with normal and emergency operations procedures.

Always consider how someone could do something wrong...and prevent it! For example there are many incidents with the coupling of nozzles or manipulation of valves. Give design input to engineers and/or vendor suppliers that things can only be hooked up one way, the right way!

## **8. Human Factors Applications Relevant to all Midstream Activities**

Heretofore, some of the major components or systems of midstream and their interfaces have been discussed. Each mode provides some unique aspects; however, all the principles suggested herein can be generalized and applied to all modes. There is much guidance available about the physical well-being of people found in the ergonomic literature. Moreover, along with process safety the “knobs and dials” era of human factors and ergonomics is well-recognized in the engineering community. Thus these contents are not prescriptive, clear guidance is readily available for the prescriptive aspects of design optimization and the accommodation of people in the midstream environments. Contemporary human factors closely parallels process safety and takes into account people in systems, their safety, preservation of the asset, and public goodwill along with regulatory compliance. Process safety can be undermined by human error when engineers and specialists working in groups have the tendency to normalize risk because they believe that a certain problem has already been solved or because they have collectively come to understand that the risk is within an acceptable limit [2].

Conventional wisdom says “we work in a dangerous industry and will always have accidents in the normal course of business.” Pundits go on to believe that rule-of-thumb individual employees are not exposed to jail time in the course of their daily business.

Conventional wisdom has been turned on its head! Clearly, individual employees are being held accountable for action in the criminal court system; regardless of their attorneys’ belief that charges should not have been filed. Moreover, permits to operate have been revoked and substantial fines are likely. New models of high reliability management techniques are challenging the normal accident theory. [44]

This wake-up call should reverberate across the global industry boundaries. Field operations decision makers at all levels realize that asset integrity management and its governance model require human factors systems that do NOT try to abridge complex situation, but enable individuals and teams to understand the full dimension of the issue at hand. Organizations must simplify the decision making process without losing high fidelity. Human factors in the myriad of midstream environments can help to achieve that goal.

### **8.1 Operability and Maintainability**

While looking at humans in complex systems, the observations have been that the operator and maintainer all too often forgotten. To achieve the reliable, safe, error-free, and risk-managed organization, process, system, or mode, the humans can never be an afterthought. A culture where those most intimate with the system are involved in its design and operation is one that is likely to contain incidents and the productivity is enhanced and unplanned downtime is minimized. There are many variables and interfaces in the midstream environments. None can be taken for granted, including the humans. Optimization is always sought to deliver, transfer, store, and manage by whatever mode the crude oil products. Systematic integration of human factors which parallels and overlaps process safety compensates for error-prone humans and the unpredictability of the environment.

## **8.2 High Reliability Management**

**Benjamin Franklin once said: “By failing to prepare, you are preparing to fail.”**

High reliability organizations have not only taken their place at the table but have emerged as leading-edge front-runners to businesses that are successful in today's world. The management of highly reliable organizations has foresight and attends to trends, to safety, and to regulatory compliance. There are tools and methods that are part and parcel of high reliability management. Human factors is one of those tools that is successfully integrated by high reliability management, particularly in process industries.

Human factors engineering has proven “value-added” merit when applied systematically top-down, starting with requirements definition in the concept and select phases with defined strategies through operations to decommissioning. Timely and appropriate integration of human factors into capital projects with full commitment of management yields all the desired advantages which are often elusive in capital projects. This discussion has focused on the role of human factors in the domain of highly reliable management and risk containment in the midstream environment.

### **8.2.1 High Reliability Defined**

Reliability is the ability to maintain performance during complexity, uncertainty, and the unexpected. Reliability is managing complexity. Reliability is decision making. Reliability is managing errors. Reliability is learning. Reliability is managing the unexpected. [29]

Virtually all modern organizations have exposure to risks that threaten to their ongoing viability. High Reliability Organizing (HRO) is the process of managing organizations to allow them to successfully deal with these threats. The principles of HRO used to identify risk and threat and then develop an effective response are similar across different types of organizations and industries.

Highly reliable organizations build people rather than trying to fix them and have the goal of building agile, resilient members of the organization. Therein lies an overarching commonality with human factors and that is: neither approach intends to “fix people” but rather systematically attend to those design flaws (particularly latent ones) that set people up and create inevitable



human errors. Organizations typically that understands and embraces high reliability and human factors concepts are those that are risk laden. Missteps can have dire consequences.

Successful organizations – those that are high reliability and have integrated human factors to manage risk have demonstrated that high risk and high effectiveness do co-exist. Clearly, there can be no latitude for ease of structure or any room for complacency. That is, vigilance, effort, and attention to operations and quality do not diminish over a plant or project's lifecycle.

Perhaps a sign of management that is not highly reliable is one where the management is rigid, inflexible, and lack innovation. The organizations that fall under such management are going to be left far behind those organizations that embrace reliability and human factors concepts and make workers primary in the workplace. That is not to say that credence and concern have not been taken with worker health and safety. But the complexion of work is so highly changed that risk is greatly magnified. Consideration of humans in systems is paramount in a changing international world. Highly reliable management recognizes this fact.

### 8.2.2 Staggered but Solid

In the recent past, there have been organizations that had highly reliable management that took the brunt of economic downturns, acts of malice, or incidents that were misunderstood and misconstrued by the media and/or the public. Those organizations are well known. The highly reliable management of those organizations reeled, even stumbled, or took a step backward, but those organizations thrive successfully today. That is no accident.

Corporate crises are common and nearly all organizations go through at least one crisis in its lifetime [30]. “If symptoms of crisis are not recognized in due time or are ignored, or if there is a lack of judgment and decisions required to resolve the crisis, valuable time is lost.” Highly reliability management recognizes and confronts crisis, analyzes the causes (not the symptoms), and the need for action. They develop corrective actions and assertively pursue solutions. Max Frisch said, “A crisis is a productive state. You simply have to get rid of its aftertaste of catastrophe.”

### 8.2.3 Shock Absorbers

Planning and managing for the unpredicted, readiness for undesired events, and keen awareness of trends, and, clear and open communications allows for highly reliable management to act quickly and decisively. Highly reliable management sustains public goodwill through transparency and the absence of guile. Even the best of the best, the benchmarked organizations, those found as highly reliable, safe, and “prepared” can be blindsided by the unpredicted and unexpected. The Black Swan theory in essence describes those events that cannot and have not been predicted. Highly reliable management is prepared for both the unlikely and the unimagined.

### 8.2.4 Black Swans: Improbable Risks – the Unexpected CAN Happen

Incidents with very substantial consequence, which most people never considered or thought to be too unlikely but which can typically be explained with hindsight are known as “black swans”. The black swan was traditionally a metaphor for the impossible or completely improbable. The term black swan has acquired increasing relevance as the world has shrunk and societies have become more complex. Even in an age of information and infinite strides in knowledge acquisition where people have control over what happens and what is about to happen, one type of knowledge exists which does not allow for predicting the future and that is, the awareness that the unexpected can happen. Calculating probabilities is based to a great extent on the expectation that what will happen tomorrow is something that can probably be expected today. What seems less likely is also less probable. But that does not account for unimagined – those things that never happened before. Those are not completely improbable. The completely improbable is also possible. What cannot be imagined can obviously happen. Black-swan logic has been demonstrated well and often. There are countless things that a decade ago could not have been imagined and there was no reason to expect them to actually occur. There was no way to give consideration to the likelihood of something improbable.

Overenget [31] maintains that one way to meet the future is to think that no one can predict what will happen with certainty, but that what will occur is one of several likely possibilities that can be imagined today. He states, “But why should things actually be like that? It might be equally likely that the completely improbably will happen, the things nobody has any reason to expect today.”

This thinking represents a challenge for all forms of safety, reliability, and risk work. Process operations involve risks and there are many examples of major accidents. Regardless of how serious such incidents might be, eliminating risk is impossible. Strenuous efforts are undertaken to eliminate the possibility of an accident; however, what can be done about improbable incidents? Can the inconceivable be controlled?

Humans possess a faculty for imagining that the world can be completely different: this is the ability that underlies development and change. Even though people can make mistakes, one must never stifle this ability through fears of human error.

Good safety work calls for robust systems and reliable organizations which pick up the errors and safety breaches which occur. But interaction between the system and the people must not reduce the latter to pawns in the former – and the system cannot be expected to take care of safety. Overenget maintains that, “we must also give room for the individual’s silent, experience-based knowledge, which enables it to smell danger.”

System designers in highly reliable organizations address attention explicitly to human factors. One main reason according to Control Engineering [32] is that a skilled designer knows that a better working environment can reduce an operator’s stress, which in turn substantially increases the operator’s performance and effectiveness for handling abnormal situations, as well as reduces health issues and turnover of resources.

### ***8.3 Design for Usability***

Give consideration to the design of hardware and software. There is much guidance available regarding the ease with which people can interact with both equipment (accessibility, operator feedback, parameters status, etc.) as well as proper design of displays, controls, and software interfaces that are intuitive, easy to use, and are proven to be user-centric.

#### ***8.4 Workload, Situational Awareness, and Vigilance***

Today humans in process systems are relegated to monitoring for extended periods of time. Cognitive workload – too much or too little – can lead to human error or the loss of situational awareness. There are many commercially available instruments available to assess workload. A straightforward commonly used human factors tool is a task analysis. There are a number of strategies to help with not only workload assignment but also to help maintain vigilance.

#### ***8.5 Remote work and intelligent overseers...***

Today, the human in many process systems are far removed from the device, the apparatus, or the process that they are controlling. This presents new and different challenges for the human in the system. Today's operators take the role of monitors and intelligent overseers. They monitor processes that are accomplished by robots, automation, and components such as drones and automatic guided vehicles. As such the input regarding the human is quite different and it impacts all aspect of their work environment. This includes control rooms design, human computer interfaces, and the management of automation. It is often the case that the human backs up the automation and indeed the automation backs up the human and in either case the automation essentially functions as a peer. Thus it is a challenge to ensure that the human is aware at all time of where the automation is in the process.

#### ***8.6 Human Factors Integration***

Human factors integration (HFI) is a systematic method of incorporating all aspects of human factors into the appropriate stages of an engineering or system design process. The concept was first applied in the defense industry but its success has meant that it is now being applied in other sectors. This is particularly the case in industries with a major hazard potential.

Human Factors Integration is a systematic method of incorporating all aspects of human factors and ergonomics into the appropriate stages of the engineering process. The integration of human factors into engineering design was originally made systematic by defense procurement, first in the US and shortly afterwards in the UK. Contractors are required to consider human factors in the design and modification of defense systems. This is to ensure total system effectiveness by recognizing the capabilities and limitations of the system operators, maintainers, and repairers.

The success of these programs, together with generally increased awareness of human factors issues and their impact on the potential safety and efficiency of a system, has given rise to recognition within non-defense sectors of the need for human factors integration. This is particularly the case in safety critical industries such as petro-chemical and the transportation of products.

The objective of HFI is to ensure that human factors methods and principles are applied appropriately and consistently during systems development in order to achieve a safe and effective design for the users. Given the increasing emphasis on safety, it is ever more important that human factors are taken into account in the design, upgrades, modification, storage, and transportation processes.

Adherence to good human factors principles not only improves the safety and productivity of workers, but also reduces the risk of injury and damage to equipment. The inclusion of HFI in a project may also provide a commercial/competitive advantage. To cover the full range of human factors issues, HFI encompasses the following six elements, known as domains. They are:

- Manpower
- Personnel
- Training
- Human Factors Engineering
- System Safety
- Health Hazard Assessment

Early human factors integration means that human reliability can be designed into a system while under development. This is much more effective than addressing human reliability issues in a completed system. Ultimately, the benefits of human factors integration can be realized in terms of improved safety and reduced life cycle costs. Failure to apply human factors and ergonomics may result in an increase in the likelihood of accidents occurring. A recent example of ergonomics deficiencies contributing to an accident is the explosion and fire at the Milford Haven Texaco refinery in 1994. [33]

In July 1994 an explosion and a number of fires occurred at the Texaco Refinery in Pembroke, where hydrocarbon fuels are produced from crude oil. A severe electrical storm caused plant disturbances and resulted in all but one of the cracking units being shut down. Approximately 20 tons of flammable hydrocarbons were released forming a drifting cloud of vapor. The vapor was ignited and the resulting force of the explosion was equivalent to four tons of high explosive. However, it was a combination of failures in safe working procedures, equipment and control systems during the plant upset that directly caused the explosion some five hours after the initial storm:

- a control valve was in fact shut when the system indicated that it was open
- a modification had been carried out on the flare drum pump-out system without assessment of all its consequences,
- control panel graphics did not provide necessary process overviews,
- attempts were made to keep the unit operating when it should have been shut down
- inefficient classification of alarms overwhelmed the operators as the incident developed

The occurrence of the incident figured prominently in the media and was notified to the European Union. The Health and Safety Executive brought legal proceedings against the Partners involved, which resulted in a fine of £200,000 plus payment of £144,000 costs. The consequent business interruptions seriously affected the UK refining capacity and the damaged refinery cost approximately £48 million to rebuild. The use of HFI before the incident could have identified most of the contributory factors, whereupon the necessary ergonomics intervention could have been applied. For instance, when considering the HFI domain of human engineering, the requirement for the process overview screens, mass and volumetric balance

summaries and efficient alarm design would have been identified. The training requirements for the operators during unplanned events would also have been addressed when considering the HFI domain of training.

### **8.7 Human Error**

According to Lifetime Reliability Solutions [45], “human error in anticipating failure continues to be the single most important factor in keeping the reliability of engineering designs from achieving the theoretically high levels made possible by modern methods of analysis and materials. ...nine out of ten recent failure (in dams) occurred not because of inadequacies in the state of the art, but because of oversights that could and should have been avoided.” Lifetime Reliability [45] maintains that poor reliability, poor maintenance, poor production and performance are under the auspices of management, the designers and managers of business processes and run and maintain system processes.

Human error cannot be prevented. It is part of human nature to make mistakes. They will always happen because human brains and bodies have limits [34]. But it does not mean that a mistake must lead to a failure. There is a better way to control failure that is to ensure failure cannot happen by using error-proofing. Error-proofing means to change the design of a thing so that mistakes have no effect on the outcome. 100% reliability in an error-proofed process is achieved. In all situations and circumstances no human error leads to failure. Error-proofing does not mean mistakes are not allowed, they are inevitable; rather, when mistakes are made they will not fail the job. Examples of the practice of error proofing equipment include changing designs of parts so they can assemble only one way, and providing parts with tell-tale indication of correct positioning. In information collection, transcription problems can be greatly reduced simply by changing the layout of forms to promote clear writing and easy reading.

In machines designed where maintenance and operating tasks are completely error-proofed, there are no failures from human error. The work and parts are designed in ways that allow human error to occur, but the errors cannot progress to equipment or job failure. Human error cannot be stopped. But machines and work processes that do not allow human error to cause failure can be created. The right outcomes then result first-time-every-time.

### **8.8 Macroergonomics**

Macroergonomics is the sub-discipline of ergonomics that focuses on the design of the overall work system. Conceptually, a top-down sociotechnical systems approach to the design of work systems and carry through of the overall work system design characteristics to the design of human-job, human-machine, and human-software interfaces to ensure that the entire work system is fully harmonized.

The top-down, macroergonomic approach – systemizing functions – i.e., standardization and consistency across the organization (within and among plants) parallels the classic system engineering approach. High reliability management is intolerant of piecemeal solutions. "If you take a microergonomic approach and look at the research results over the years, successful programs tend to get a 10-25 percent improvement, whether it is in productivity or

accident reduction. But when you get the macroergonomic level in there and 50-90 percent improvement is seen. Associated benefits include better productivity and quality, and improved job satisfaction and employee commitment.” [35]

### ***8.9 Power of Intuition***

Intuition is the way experience is translated into action [36]. It is how people make good decisions without performing deliberate analysis. Intuition is the natural extension of experience and preparation. It is “acting without apparent consideration.” It is illustrated by those senior people (such as firefighters) who jump into action and solve a problem without conscious or apparent deliberation. In their minds, there is only one course of action. And, it is the correct action.

Albert Einstein said, “The intuitive mind is a sacred gift and the rational mind is a faithful servant. We have created society that honors the servant and has forgotten the gift.”

The experienced leader, decision maker, or that person who determines a course of action relies on subtle cues without conscious awareness. These trustworthy judgments rely on informed skilled intuitive decisions as well as analytical strategies. Intuition and analysis are both necessary.

In an era of increasing complexity, new technology, remote operations, and automated functions, it is that leader who intuitively controls, contains, and resolves mishaps and incidents that avoid or mitigate the effects of missteps. In contemporary consideration of the role of the human in systems... this competency among decision-makers is an imperative.

### ***8.10 Process Improvement Paradox***

In these times of incredible technological advancements, issues around aging plants, and adoption of processes that are far removed from the operator as well as the diminishing pool of competent workers, a powerful paradox emerges that is a challenge to all process industries. On one hand, that there is a perception that technological advances, increasing knowledge, and enhanced production through automation gives rise to increased safety and reliability while risk is presumably reduced.

However, the evidence shows that there is conflict between formal design and technology and operational skills, experience, and knowledge. Moreover, infrastructure vulnerability exists, that is the management of business continuity (goals) and public security (safety and goodwill). Efforts at improvement can seriously challenge control operators to manage essential systems reliably and safely. Again only high reliability management with their fingers on the pulse of their organization, their plant, and the industry can brave the onslaught of a paradox of heretofore unknown proportions.

Shemwell [37] points out that today’s business faces a new risk environment. His book *Culture of Safety* defines and delineates five contributors to increased magnitude of risk. These are:

- 1) Escalation of consequences

- 2) Single point failure
- 3) Demanding stakeholders
- 4) Multitude of partners (and international collaboration)
- 5) Executive responsibility (and accountability)

Only high reliability management can face and successfully overcome these new risks. Their impetus is to use every tool as their disposal and to be proactive in their stance and actions.

### ***8.11 Operator Competence***

Control Engineering [32] indicates that when operators interact with processes, their action often have huge business consequences, especially when the process is in an exceptional situation and operators need to understand and manage complex operations to support recovery.

They continue, in view of rapid technological evolution, generational shifts in workforces, and increasing complexity of operations, there is an explicit need to address operator effectiveness directly throughout the whole life-cycle of a process-control system.

### ***8.12 Reliability Threats***

#### ***8.12.1 When technology goes wrong***

Highly reliable management as aforementioned is steeled against inevitable reliability threats. Technology does not always serve society or people in the workplace well. Technology can go wrong. For example, often software and hardware fail to work as intended – which leads to work-arounds. Work-arounds may be acceptable in the short term but they often become a long term means of accomplishing tasks. As such work practices are adopted that violate or do not maintain bases of design – and may be highly susceptible to human error.

In addition, people are thrown into systems to do tasks that were never intended for people – the tasks were supposed to be automated or in some fashion only involve people as either monitors or remote operators. When the technology fails – having made the investment and the processes begun – such failures typically result in people doing what machines were meant to do. Process efficiencies, worker well-being – safe injury-free activities and reliability preservation are lost. When the temporary becomes permanent, therein lies a recipe for disaster – extremely error likely. Another paradox lies in the fact that if an event occurs, it will be attributed to human error and as a result, unreliable management will frantically once again attempt to “fix people” – blame, train, displace, same song, different verse.

Highly reliable management however responds differently to technological failures. And while some work arounds are entirely acceptable with vigilant oversight, they are not allowed to become permanent; status quo is restored as quickly as possible. That is, the source of technological failures are identified and solved; highly reliable management gets to the root of the technological failures. They do not cavalierly allow for people to function in the place of the machine that failed. At the design onset, tasks are carefully allocated to humans and to machines by the human factors specialists. When intended machine performance fails, then engineering is

revisited for the causes. Such conditions are not just accepted. The risks are simply too great. The outcomes are negative and defeat the project goals and objectives.

A set up for both human and technological failure is when a “digital face” is put on analogue thinking. In the design of new processes, plants, or systems and/or their upgrades and modifications, human factors is thoroughly integrated from the onset. It is a matter of practice that the human factors specialists involve operations and maintenance staff as well as management and engineering disciplines. Among the valuable approaches used by HF specialists to ensure reliability and effectiveness, is operating experience (lessons learned and experience transfer), in addition however, is the due diligence associated with organizational history and cultural behaviors. It is those seasoned operators who well know what was successful and that which need addressed.

High reliability management embraces the tribal knowledge, but also disallows acceptance of inferior design or burdensome tasking simply because “we always did it that way”. A powerful example lies in the modification of a European power plant. Upgrading the plant, particularly the control room was justifiably costly; however, those from the utility who were giving design input insisted that the new controls and displays that allowed for operations and monitoring and provided the requisite operator feedback, look exactly like the old operator interfaces. That was extremely error-likely and put the plant stability at risk.

#### 8.12.2 Locomotive momentum

*If you do what you always did, you will get what you always got. Albert Einstein*

Oddly enough, the laws of physics apply to organizations as well as the momentum of the universe. There are well known organizations that have failed or nearly faced demise. In retrospect, there are always the Monday quarterbacks that proclaim that they could have (or should have) predicted the events that transpired. Perhaps no one could predict how the public would embrace computing or social media. Remember the president of IBM, who firmly believed no one would want a home computer... Consider the obsolescence of those items that at one time were leading edge (rotary phones, Polaroid cameras, mimeograph and facsimile machines for starters).

When an organization is very large – it has momentum due to size, similar to a locomotive... the perils of derailment may be readily apparent; however, without highly reliable management that organization will fail. Sometimes the light at the end of the tunnel is sought more than the tree across the tracks.

It is hard to stop a train (to paraphrase a well-known commercial). The momentum afforded by physics and the laws of science, often give a false impression of well-being. Variables like lack of communication, intolerance of change, “being an ostrich” – ignoring trends, and taking success for granted accelerate what inevitably becomes failure. There is false security in the momentum achieved but ultimately not sustained by management that are not highly reliable or those who did not embrace the proven tools at their disposal.



Forward motion is not always progress. The path to sustained success is not always linear. Forward motion is not *always* a good thing. It kind of depends on what lies in front. What if moving forward means falling off a cliff or crashing into the car in front? Before moving forward is celebrated, the destination must be diligently scrutinized.

Progress, like forward motion, is not always good. It can cause problems, admittedly sometimes unforeseen (remember the Black Swan?). For instance, the industrial revolution was progress. It gave society some good things, but it also created problems that are still present today.

Harvard Business Review states, “It’s tough when markets change and your people within the company don’t.” Because a strategy or method worked in the past, that does not mean it is viable for the highly reliable organization of today, needless to say, tomorrow. Somehow somewhere along the line, engineering seems to have become synonymous with “cut-and-paste”.

Professionally irresponsible and morally reprehensible... and is not characteristic of a highly reliable organization. Neither is the mantra, “we always did it that way”. Ironically, at a recent technology forum, a featured speaker of renown indicated that the process industries are so preoccupied with production, that they are unwilling to embrace technology. It is apparent if they are unwilling to stop long enough to implement that which would enhance productivity and ultimately profits, they cannot be considered high reliability managers.

#### 8.12.3 The Evil Assumptions (Demise of Critical Thinking)

Life today is chaotic and stress filled. All too often even the most consummate professionals get caught up in the media bias and hype. Too breathless to search out the facts and apply nonbiased and well-informed critical thinking, too often conclusions are drawn and based on assumptions – not facts. *Just cause you think it (or hear it), that doesn't make it so.*

Consider in risk laden hazardous industries, when there are incidents of nearly any magnitude, a root cause analysis of some sort is performed. Too often the apparent is readily selected as a cause when in reality, more thorough, deeper investigation is warranted. When the apparent is accepted as fact, the likelihood of repeated and perhaps worse incidents can be expected.

#### 8.12.4 Hear no evil, see no evil

High reliability management demands transparency. Killing the messenger is not feared in such organizations and the imperative to human factored communications - in all practices, at all levels is the mode. Human factors inputs are requisite relative to plans, programs, procedures, work instructions, and process philosophies.

#### 8.12.5 Close-minded Parochialism

Terminal uniqueness is an illusion. In some industries (and some more than others), the principles described herein are waved off with an attitude of “you don’t understand us”. Sadly the parochialism within some process industry sectors is so staid that lessons learned even within their own industry are disregarded. Even within a company with multiple plants, one plant does

not communicate lessons learned among themselves. And while there are some industry groups, little experience transfer occurs. But the worst case is when some process industries learned their lessons well, whether it is design, operations, or human interfaces, and yet other industries fail to take heed and learn.

People are people regardless of the systems where they are found. People while incredibly complex, are also extremely fragile and vulnerable and they make mistakes. People do err and within spectrum of human capabilities and along the continuum of human limitations, there are predicted and reliable human attributes – some negative or detrimental, that are manifest under stress (physical and psychological). Human error is a symptom not a cause. The human factors support of highly reliable management entails the knowledge of what people can and cannot reasonably, reliably, safely do and has the tools to design out the possibility of human error.

## **9. Solutions and Strategies**

Human factors cannot be ignored in any system and even more so when hazards and risks are inherent. In process safety the integration of human factors and a holistic approach gives rise to safer and more efficient midstream activities.

### ***9.1 Developing a Human Factors Program***

The written human factors program and therefore, the guidance document, must at least address the following:

- The inclusion of human factors in the Process Hazards Analysis process;
- The consideration of human systems as causal factors in the incident investigation process for major accidents or releases or for an incident that could reasonably have resulted in a major accident or release;
- The training of employees in the human factors program;
- Operating procedures;
- The requirement to conduct a Management of Change (MoC) prior to staffing changes for changes in permanent staffing levels/reorganization in operations or emergency response. Employees and their Representatives are consulted in such Management of Changes;
- The participation of employees and their representatives in the development of the written human factors program;
- The development of a program that includes, but is not limited to, issues such as staffing, shiftwork, and overtime; and
- The inclusion of a human factors program description in the Safety Plan.

## **10. Conclusions**

This discussion demonstrates that human factors – systematically applied in an integrated way – parallels process safety concerns and that full consideration of humans in systems, processes, and all modes and interfaces have many elements that must be embraced by all concerned with midstream endeavors. Phenomenal growth of course is of great economic benefit. Exponential

growth inevitably causes consternation and often undesired consequences. Many systems and components are challenged and put to the test.

The science of human factors, successfully applied in process industries, offers many tools and considerations for the containment of human error, mitigation of consequences, preservation of public goodwill and the assets, regulatory compliance, and overall safety and worker well-being.

With the surge in crude oil transportation, there are important issues that need to be properly understood in order to develop a more comprehensive approach to reduce the risks of spills. It is clear that human factors should play a significant role in each individual mode and systematically among all midstream endeavors.

## 11. Regulatory Requirements

- 40 CFR Part 112.7, EPA Oil Pollution Prevention (General requirements for Spill Prevention Control and Countermeasures Plan) ([www.gpoaccess.gov/cfr/retrieve.html](http://www.gpoaccess.gov/cfr/retrieve.html))
- 40 CFR Part 280 (Technical Standards and Corrective Action Requirements for Owners and Operators of Underground Storage Tanks) ([www.gpoaccess.gov/cfr/retrieve.html](http://www.gpoaccess.gov/cfr/retrieve.html))
- 33 CFR Part 154, “Facilities Transferring Oil or Hazardous Materials in Bulk” ([www.gpoaccess.gov/cfr/retrieve.html](http://www.gpoaccess.gov/cfr/retrieve.html))
- “Storage Tank Systems for Petroleum Products and Allied Petroleum Products Regulations” (SOR/2008-195), pursuant to Section 209 of the Canadian Environmental Protection Act (1999) (<http://laws.justice.gc.ca/en/ShowFullDoc/cr/SOR-2008-197///en>) 22
- “Response Organizations and Oil Handling Facilities Regulations” (SOR/95-405), pursuant to the Canada Shipping Act (1995) ([www.tc.gc.ca/actsregulations/GENERAL/C/csa/regulations/100/csa101/csa101.html](http://www.tc.gc.ca/actsregulations/GENERAL/C/csa/regulations/100/csa101/csa101.html))
- <http://www.dot.gov/briefing-room/us-dot-announces-comprehensive-proposed-rulemaking-safe-transportation-crude-oil>
- <https://www.aar.org/todays-railroads/what-we-haul/crude-oil-by-rail>
- Regulatory Update on Transportation of Crude Oil by Rail, <http://www.steptoe.com/assets/htmldocuments/Transportation%20of%20Crude%20Oil%20By%20Rail.pdf>
- Emergency Order Establishing Additional Requirements for Attendance and Securement of Certain Freight Trains and Vehicles on Mainline Track or Mainline Siding Outside of a Yard or Terminal, FRA Emergency Order No. 28, Notice No. 1, 78 Fed. Reg. 48218 (Aug. 7, 2013); Advance Notice of Proposed Rulemaking, Hazardous Materials: Rail Petitions and Recommendations to Improve the Safety of Railroad Tank Car Transportation (RRR), Docket No. PHMSA-2012-0082, 78 Fed. Reg. 54849 (Sept. 6, 2013)
- Notice of Safety Advisory, Recommendations for Tank Cars Used for the Transportation of Petroleum Crude Oil by Rail, Docket No. PHMSA-2014-0049, 79 Fed. Reg. 27370 (May 13, 2014). 2 Notice of Proposed Rulemaking, Hazardous Materials: Enhanced Tank Car Standards and Operational Controls for “High-Hazard Flammable Trains,” Docket No. PHMSA-2012-0082 (released on July 23, 2014) (hereinafter 2014 NPRM).

- Advance Notice of Proposed Rulemaking, Hazardous Materials: Oil Spill Response Plans for “High-Hazard Flammable Trains,” Docket No. PHMSA-2014-0105 (released on July 23, 2014) (hereinafter 2014 ANPRM).
- <http://www.bsee.gov/Regulations-and-Guidance/index/>
- <https://www.ihs.com/products/api-standards.html>
- [http://www.shalegas.energy.gov/resources/071311\\_api.pdf](http://www.shalegas.energy.gov/resources/071311_api.pdf)
- <http://www.ogp.org.uk/pubs/454.pdf>

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