EVALUATION AND MITIGATION OF HUMAN ERROR DURING LNG TANKER OFFLOADING, STORAGE AND REVAPORIZATION THROUGH ENHANCED TEAM SITUATIONAL ANALYSIS

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ABSTRACT

Human error during the offloading, storage and regasification of Liquefied Natural Gas (LNG) can lead to process upsets and possibly safety incidents within these essential steps of the LNG value chain. While unconventional gas resources in North America have recently changed the demand outlook for LNG domestically, LNG demand in Asia and Europe continue to grow. The LNG industry has grown dramatically over the past 40 years with over 100 regasification facilities and a worldwide capacity, in 2011, of 608 million tonnes per annum, (IGU, 2011). This number is expected to grow in markets where demand continues to be strong. Innovations to improve safety and the economics of LNG processing are continuous but the potential for significant events remains.

In general, major accidents in the hydrocarbon industry both onshore and offshore demonstrate that industry successes in improving occupational safety have not been mirrored in major accident performance. Many of these accidents are not the result of mechanical failure due to deficient design; but rather issues that resulted from human interaction with the process and decision making. Human error from a lack of situation awareness or understanding is often found as the root cause of process incidents. Situation awareness is the perception of elements in the process environment, the understanding of the meaning of these elements and the projection of their status in the future.

Situation awareness is a critical element of an Operator's decision making in a wide variety of operational contexts. The Deepwater Horizon Study Group, (DHSG, 2010), highlighted the risk from losing situation awareness by commenting that, "Slowly evolving developments leading to crises frequently are difficult to detect because signals of evolving degradations are drowned out by the noise of normal daily operations. We lose our ability to expect the unexpected thereby frequently losing situation awareness".

The Operator's image of system behaviour (mental model) and what will occur in the near future play an important role in the success or failure of a chosen course of action. Operators need to have an accurate understanding of system behaviour and one that adequately reflects what is happening and what may happen from their tasks within a plan of action. Improved situation awareness can benefit operational effectiveness by facilitating the planning process, improving the quality and timeliness of decisions, and providing better anticipation about the consequences of actions to be taken.

Operations personnel can face challenges from a deficiency in both individual situation awareness (ISA) and team situation awareness (TSA). In order to address this, a new technique has been developed to evaluate risk and identify mitigating opportunities where situation awareness can be enhanced through improving the real-time decision support system (DSS) that is made-up of instrumentation feedback, process control, team communication, procedures, ergonomics and work practices. The Situation Awareness Identification Technique (SAIT) utilizes hierarchical task analysis and a novel method to rate performance shaping factors (PSFs) for individuals within a framework to improve situation awareness. SAIT identifies the system variables that influence the probability of success of a task and uses the DSS to improve individuals' mental models for current and future states of the system.

This is accomplished by identifying situation awareness links between key tasks during planned simultaneous activities that have cross over effects between team members that may raise the level of risk of an individual's actions. Risk is mitigated by improving the situation awareness of each team member, that may have a limited understanding of the total situation and hence an incomplete mental model (schema) of the consequences associated with their actions. This technique provides an opportunity to reduce human error (e.g. mistakes and violations) from process operations by providing a framework that allows teams to evaluate the dynamic risk of ongoing operations. A case study within LNG regasification operations is provided as an example of how the DSS can raise situation awareness to reduce the probability of human error.

1.0 INTRODUCTION

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The study of human factors is a scientific discipline that involves the systematic approach of linking human characteristics and behaviours to the work domain (domain) in an effort to improve the performance of man-machine systems and reduce human error. Due to the relatively slow progress in the field of human reliability quantification, there is a need to advance this area of research and provide a technique that employs human factors in format to assess risk, based on situation awareness (SA). Much of the past work in human error prediction has emanated from the nuclear industry through the development of expert judgment techniques such as the Success Likelihood Index Methodology (SLIM). The need for expert judgment techniques arose from the lack of human error data and the severe consequences that may occur from nuclear accidents. Analogously, the Piper Alpha, Ocean Ranger and most recently the Deepwater Horizon, have generated a greater awareness of the impact from human error in complex operating environments. The methodology presented in this paper leverages SLIM in the evaluation of factors influencing situation awareness.

The trade in LNG has increased steadily over time reaching a demand of 250 million tons in 2012 and is expected to rise to 370 million tons by 2018 (Harrington, 2013). This trend is expected to continue to increase as large quantities of natural gas are now available from unconventional sources that have revolutionized the energy landscape. The receiving terminal is a key component in the LNG supply chain and presents an operating environment where situation awareness is a key factor in maintaining safe and efficient operations. Operational situation awareness has improved in the areas of training, procedures, regulations and operating experience, but there still exists credible scenarios in the process industries that could result in serious consequences (e.g. fire). While there has been an extensive amount of work on consequence prevention, for such events, there is a general lack of research in human factors as related to risks associated with situation awareness during work activities.

Receiving terminals are expected to operate year round and to have a high level of availability, placing significant demands on Operator performance. The focus of this paper is to present a method of assessing situation awareness among work teams and providing mitigating actions to improve situation awareness and reduce the risk from human error. An example is provided, which utilizes this technique for the start-up of an LNG high pressure (HP) Send-out Pump after maintenance work has been performed on the pump. This activity is comprised of tasks that require a high degree of team coordination and hence a high level of shared situation awareness to complete the work in a safe and efficient manner.

2.0 SITUATION AWARENESS

Operations personnel interface with a series of complex dynamic tools (e.g. process instrumentation) that provide continuous feedback. The amount of data, from this feedback, can be extensive and can change rapidly. The enhancement of an Operator's situation awareness has become a major design goal for human-machine interfaces. In most process systems large amounts of data can be produced rapidly and hence the challenge for Operators is finding what information is needed, when it is needed. The data must be accurate and discernible to allow for proper processing by the receiver and communicated, as required, between team members. Situation awareness is defined as follows:

- The continuous development of mental models based on an understanding of the work domain through the interpretation of data, information and communications, to describe and explain the current state of the domain and to predict future states.

An individual team member's situation awareness can influence the whole work team in a positive or negative manner (Smith-Jentsch, et al., 2008). The interaction between an individual and components of the work domain is not a team process. When an individual passes information, instruction or knowledge to a team member, situation awareness takes on a team process. Interaction and communication within an operations team is a critical element in developing a shared understanding of the state of the process and developing accurate mental models. Situation assessment is a team-level outcome affected by the accuracy of mental models developed through situation awareness.

There is a widening gap between the quantity of data disseminated and the Operator's ability to gather, assess and process the data in meaningful way. Distributed control systems (DCS) manage this torrent of data using algorithms to control process variables such as pressure, temperature and flow. These control systems relieve the Operator from managing process variables on a continuous basis and when optimal, perform primarily a reporting function to the Operator. In reality, due to poor control tuning, inadequate system architecture, design ergonomics, information overload and possibly a lack of experience and possibly inadequate training, these systems still present considerable risk in providing sufficient situation awareness to the Operator. Further, Operators working within the process units, removed from the DCS interface, may have a dramatically lower level of situation awareness with regards to the condition of the process any one time. The DCS design attempts to counter these performance shaping factors (PSFs) through a series of safety functions such as prioritized alarms, automatic shutdowns, and emergency plant blowdowns. DCS architecture permits the users to customize and create screens which plot key variables and display summaries of important process units, which are deemed to be central to the continued operation of the process. The DCS feedback in returning HP Send-out Pumps into operation, after maintenance, is central to many of the tasks required accomplish this work activity (e.g. monitoring cooldown temperatures).

For an Operator, situation awareness, is defined in terms of process goals and decisions to meet the objectives for optimal operation, which are twofold; continuous maximum throughput (% uptime) and optimization of the process. Endsley (2000) proposed four different levels of situation awareness that provide a definition of the level of understanding of what is occurring within the work domain.

2.1 Perception

Level 1 situation awareness addresses perception and is considered the basic level of situation awareness. Without perception of critical information the probability of developing an incorrect model of the current situation increases. Endsley (2000) reported that 76% of situation awareness errors in pilots could be traced to issues in the perception of required information. This was due primarily from either shortcomings or failures in the system or issues with cognitive processes.

2.2 Comprehension

Level 2 situation awareness encompasses how people combine, interpret, retain, and store information. Situation awareness is the integration of many pieces of process and human information and a determination of their pertinence to the individual's goals and objectives. Endsley (2000) reported that 20% of situation awareness errors were due to comprehension as opposed to just perceiving information. Meaning is an important concept in situation awareness, in the sense of interpretation and in the sense of pertinence (importance) of information.

2.3 Projection

In Level 3 the ability of an Operator to forecast a future state marks the highest level of situation awareness. The ability to construct mental models and anticipate future process events and their implications (consequences) permits for more timely decision making. Skilled Operators with a high level of experience rely on mental modeling to effectively mitigate risk through preemptive actions. Expertise is demonstrated by an ability to perceive a situation as the patterns and relationships that grew out of the past and will grow into the future, not just as cues that exist at the moment (Klein, 1998). DiMattia (2004) found that decision making skills during process plant emergencies were a crucial component in successfully reaching a platform's safe refuge during a muster.

2.4 Dynamics

An important part of situation awareness is understanding how much time is available until some process event occurs or how much time is available before an action must be taken to achieve a goal or prevent an undesirable consequence from human activity. An inadequate amount of time to complete tasks can detrimentally impact an Operators ability to achieve a level 2 (comprehension) or level 3 (projection) state of situation awareness. Real world situations are dynamic and the rate that information changes is that component of situation awareness regarding the current situation that also permits for projection of future states (Endsley, 2000). The dynamic nature of the work domain dictates that the Operator's situation awareness must also change or otherwise become outdated with their mental models possibly becoming less accurate. The operating team's domain is dynamic requiring the individual to apply a variety of cognitive strategies for maintaining a high level of situation awareness.

3.0 COGNITIVE TASK ANALYSIS

Cognitive task analysis (CTA) is used to analyze and support cognitive work a variety of methods (e.g. knowledge acquisition through procedural review). The methods for performing cognitive task analysis can utilize aspects of the work domain and the knowledge and skill individuals have developed to operate effectively (Bisantz & Roth, 2008). CTAs can produce descriptions of the of work domain (operating environment) that shape and constrain cognitive and collaborative performance in operating teams. CTAs provide descriptions of knowledge and strategies applied by individuals operating in that domain. CTAs are typically performed with an applied purpose and include recommendations related to design aspects of the work environment.

SAIT analyzes the factors of the work environment as well as individual characteristics that influence an Operators' ability to successfully complete work tasks. Task analysis (e.g. hierarchical task analysis) is a useful method in the investigation of cognitive work. SAIT utilizes hierarchical task analysis with focus on domain characteristics and personnel traits that influence the work to be conducted across an operations team through an interpretation of the individual and team level of situation awareness. Operating tasks are analyzed in SAIT from the perspective of factors that influence behaviours and decision making to provide a pathway for mitigating strategies. These strategies focus on strengthening the influence factors such as training, equipment and procedures.

3.1 Decision Making

Situation awareness is the Operator's internal model of their environment and is separate from decision making and performance. Operators decide what actions are to be taken to manage the process on a continuous basis and to conduct work activities within the process. Situation awareness is the main precursor to decision making, yet an Operator having perfect situation awareness can still make an incorrect decision. The Operator may have inadequate strategies guiding their decision making or there may be constraints from a technical or organizational perspective, which impact their ability to make correct decisions. They may also not have the enough or the correct type of training and/or experience to manage the situation at hand or there may be personal factors that influence decision making in a detrimental manner.

An Operator's actions may not be executed with complete efficiency due to the PSFs influencing the individual and the team. PSFs include items such as workload, training and experience and form the essential components of strategies and plans necessary in making correct decisions and successfully completing tasks. Optimizing the PSFs allows the operating team to leverage their skill sets to the utmost, allowing for the greatest probability of success (POS) in achieving their goals. An analysis of the factors that influence individuals and the operating team decision making can help strengthen the potential for the team to generate ideas that are beyond the skill of any one team member. It is useful to consider the operating team as a single intelligent entity and analyze the factors that influence this entity. Factors that influence of the team mind have been studied by Klein (1998) in terms of team competencies, identity, cognition and metacognition. Team cognition is essentially an understanding to what level does the team share an understanding of state of their work domain. The ability of the team to look ahead, anticipate issues and manage uncertainty is directly related to their level of situation awareness.

Strengthening PSFs may also overcome a key concern in decision making, which is confirmation bias. This is the tendency for individuals to seek out information that supports a position while ignoring or minimizing inconsistent information (Cook & Smallman, 2008). There are a variety of theories for the cause of confirmation bias that include an initial anchoring by individuals that leads to biased sampling of data leading to biased decision making. Anchoring is a mental shortcut to make some form of estimate, which can then be adjusted as more information becomes available (Klein, 2009). In multifaceted operating environments Operators need to maintain a wide array of focus to interpret data and information to form accurate mental models of the current state of the process and project future states. Work teams that have effective communication and share knowledge can develop a common understanding of their domain through enhanced situation awareness, which can help overcome an individual's tendency for confirmation bias and inaccurate mental models of the domain.

4.0 PERFORMANCE SHAPING FACTORS

Performance shaping factors are parameters that influence the ability of an Operator to successfully complete a given task. The number of PSFs that may influence an individual for any given task is numerous. The degree for which any PSF influences an individual also varies. The Control Room Operator will have PSFs that are both common and unique from that of the Outside Operator. These PSFs form a construct promoting shared team situation awareness that is key to the successful and safe operation of the facility. For example, the DCS layout or color scheme could be grouped as a PSF entitled DCS ergonomics. This PSF can influence the effectiveness of the Command and Control Center (CCR) Operator to monitor and control the process and pass on accurate information to other team members, as required. The effectiveness of the DCS system to control the process may also be a PSF affecting work efficiencies and eroding the Operator's trust in the DCS or certain aspects of the DCS. This level of trust has important implications for the effectiveness of interaction strategies in a human-machine context (Merritt and Ilgen, 2008).

There are certain PSFs that are common among team members that promote effective team interaction through higher levels of situation awareness. A list of such factors is provided, in CCPS (1994), and grouped under the following subheadings; operating environment, task characteristics, operator characteristics and organizational features. These groups can be further broken down into categories (e.g. training) that help in the link the PSF to a task activity. Though there are common PSFs among team members, the skills sets among individuals are varied, resulting in different mental models of the process. A shared understanding of the surroundings, to an appropriate level, promotes an effective team approach to completing tasks and in making decisions that do not negatively impact other team members in a manner that inhibits their ability to complete those tasks successfully. A high level of shared situation awareness and communication among the work team promotes the alignment of mental models and more effective decision making.

5.0 ACQUIRING SITUATION AWARENESS

Situation awareness is derived from a variety of information sources within the work domain. For a CCR Operator situation awareness is derived primarily from DCS feedback and communication with Outside Operators and other personnel. The Outside Operator develops their sense of situation awareness from external factors such as sound, smell, touch (e.g. vibration), visual cues, local instrument feedback, equipment interface and communication with CCR Operator(s) and other outside personnel. The Outside Operator's construct is more tactile in nature and a deeper insight of the process is acquired through communication with the CCR Operator. Conversely, the CCR Operator can use feedback from the Outside Operator to help explain and rationalize DCS feedback. Figure 5.1 illustrates the connection between Outside and Inside Operators, and how their operating domains affect their situation awareness.

The CCR Operator's process is not passive in nature. Receiving displayed information creates an active environment of managing which screens are displayed and what data is being trended. There is a continuous situation assessment activity occurring, that is, an active process of seeking information from the environment, guiding the Operators' actions and decision making. The CCR Operator may also have an external interface through monitors that are trained on various part of the process such as flares. Verbal communication with Outside Operators is an important source of situation awareness information as well as knowledge transfer, which can raise the level of understanding of each Operator and improve decision making and confidence through a confirmation of comprehension. Hence, situation awareness is derived from a combination of domain feedback as well as communication between human counterparts.

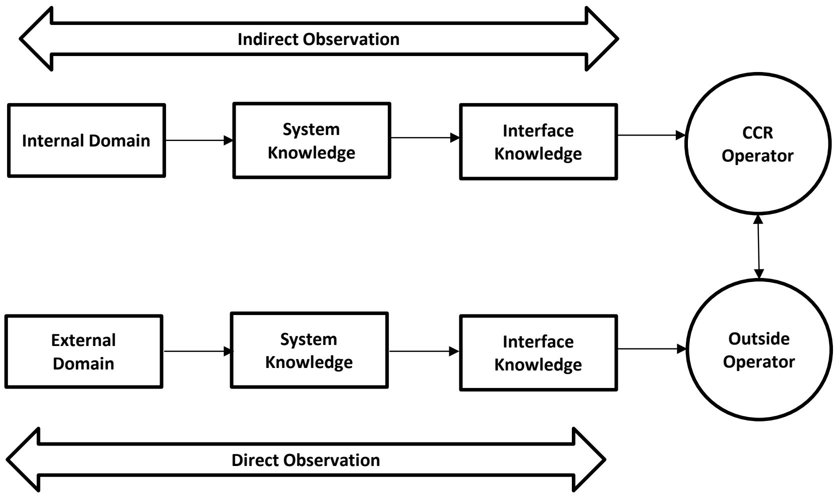

Figure 5.1 CCR and Outside Operator working domains

5.1 Managing Situation Awareness

There are several factors that can influence the completeness and accuracy of the situation awareness Operators derive from their working environment. As humans are limited by attention and working memory, it is important to understand what methods Operators use to take in competing cues, necessary in understanding what aspects of the situation will be processed, to form their situation awareness. This information needs to be integrated with other data, compared to goal states and projected into the future, placing a heavy demand on working memory. Figure 5.2, as adapted from Endsley (2000), illustrates the mechanisms (e.g. pattern matching) involved in the development of an Operator's situation awareness and how this process is continuous in nature.

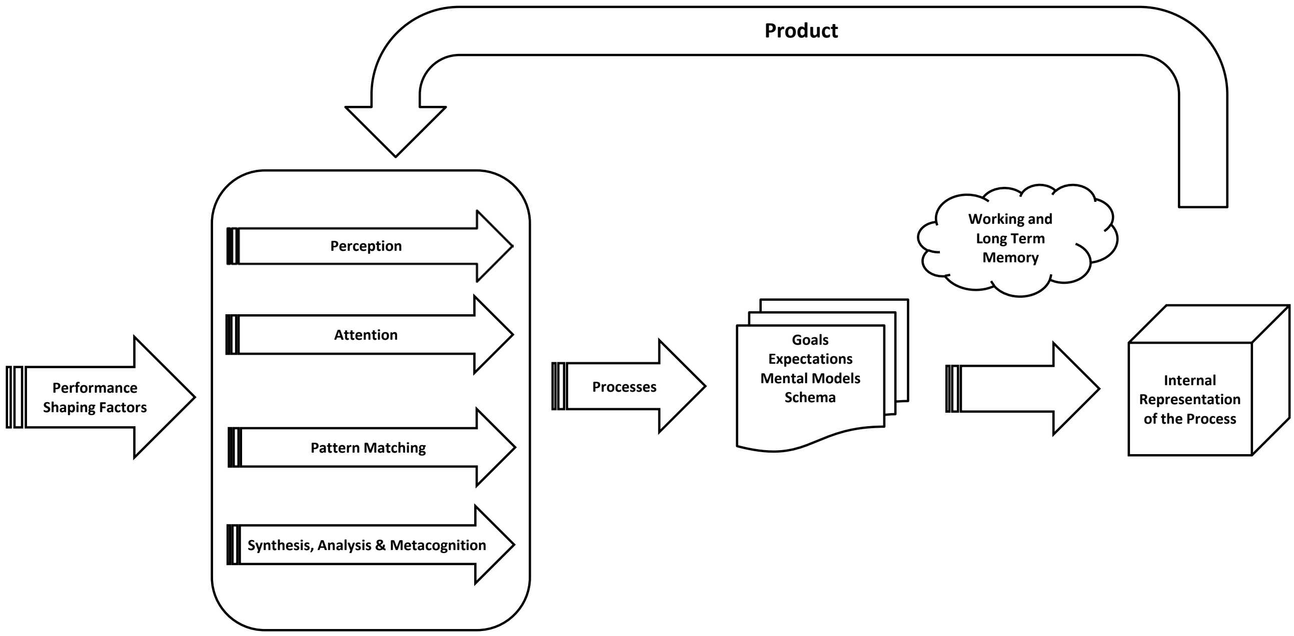

Figure 5.2 Mechanisms involved in developing situation awareness

How Operators direct their attention has an impact on which parts of the operating environment are incorporated into their situation awareness. The degree of which environmental cues (e.g. DCS feedback) draw an Operator's attention and the meaningfulness of this feedback are very important in developing an accurate mental model of the domain. Factors that influence how Operators direct their attention in acquiring information include the following:

- Learned scan patterns
- Data sampling strategies
- Goals
- Expectations
- Information already processed
- Feedback from other Operators

Endsley (2000) found that a fighter pilot's attention to targets on a tactical situation display was directly related to the importance of those targets in their tactical task. Likewise, an Operator's attention to DCS feedback will be prioritized based on the following objectives:

- Conduct operations in a safe manner – preventing process upsets that may lead to a loss of containment
- Maximize uptime – avoiding process upsets that interrupt production
- Maximize production – processing as much product as possible
- Maximize process efficiency – limit flaring

Within this list of major objectives there can be other work activities (e.g. maintenance) occurring throughout a work shift. In addition, an Outside Operator's activities that can consist of a myriad of responsibilities that may include the following items:

- Daily rounds
- Unit Start-ups
- Process management
- Troubleshooting process upsets

The Outside Operator has situation awareness factors that influence how they direct their attention in acquiring information. The Outside Operator's environmental cues are generated from the equipment itself, the surrounding external environment and communication with the CCR Operator and other Operators. Attention to information is usually prioritized on how important that information is perceived to be. Analogously, it has been shown that it is a significant challenge, for aircraft crews, to juggle competing tasks and numerous pieces of data in dynamic scenarios, Endsley (2000). Likewise, a CCR Operator manages several processes simultaneously while staying abreast of outside activities, such as maintenance work. Good situation awareness requires enough cognizance of what is happening across a wide range of activities to be capable of determining where one should focus their attention to acquire more detailed information. Attention narrowing (focus on a limited set of cues) is a well-known example of failures that can befall individuals in this type of circumstance. When attention narrowing occurs individuals will lock in on certain aspects of the domain they are trying to manage and will either intentionally or inadvertently drop their scanning behaviour (Endsley, 2006).

Fracker (Endsley, 2000) showed that the limits of working memory can pose a constraint on situation awareness. Working memory issues come in the form of information that is initially perceived and then is forgotten as time passes. Operators with limited experience that are presented with novel or complicated scenarios, typically in the form of a process upset or an emergency, need to combine information, interpret it within a limited time period and attempt to make projections within limited working memory. Under such circumstances situation awareness can degrade rapidly. Contrary to this process, experienced Operators have several mechanisms in their toolbox to overcome this bottleneck (Endsley, 2000). Strategies that experienced Operator's leverage, to reduce working memory load, include the following:

- Information chunking
- Information prioritization
- Information gistification (summarization)
- Restructuring the environment to provide external memory cues

Despite these strategies, Operators can be faced with information overload such that working memory constraints become problematic when attempting to complete tasks successfully. Process information is transferred from sensory memory to long term memory, which is required for pattern recognition and coding. The information that is salient stays in working memory as a subset of long term memory through automatic activation or localized attention. In this manner, information from the process environment can be managed and stored in terms of an activated mental model helping to establish Level 2 and Level 3 situation awareness. In this sense, an Operator's situation awareness is a unique product of acquired external information, working memory processes, and long term memory stores that are activated based on the information of the internal representation of the process.

5.2 Long Term Memory, Mental Models and Situation Awareness

Cowan (Endsley, 2000) developed a model of cognition that illustrated how information proceeds directly from sensory memory to long term memory. This process is needed for good pattern recognition and coding. Those parts of the environment, that are relevant, stay in working memory, as a subset of long term memory, by either localized attention or automatic activation. In this way information relevant to the process can be managed and stored in terms of a mental model (schema). This allows Operators to achieve Level 2 and 3 situation awareness and attempts the infill of missing data or information. Situation awareness is a product of acquired external information and activated internal long term memory that are used in the formation of an internal representation of the domain.

Long term memory stores in the form of mental models are thought to play a significant role in managing the limitations of working memory (Endsley, 2000). With experience and training Operators can develop mental models of the process that help direct limited attention in more efficient ways, providing a means of integrating information (data) without loading working memory and supplying a means for generating a projection of future states of the process. Key process information is matched to mental models to identify prototypical situations that provide situation classification and comprehension.

The concept of mental models of a processing environment is very useful. It allows a means for guiding Operator's attention to relevant aspects of the process. The mental model helps integrate perceived information to form an understanding of its meaning and to project future states of the process based on its current state as well as an understanding of the system dynamics that comes in the form of process reaction and control mechanisms. The ability to see the past and the future rests on understanding root causes and the ability to apply these factors to run mental simulation (Klein, 1998). Mental models can also present a problem, by forming biases in the Operator's selection and interpretation of information provided by process instrumentation and other team members. These biases can create errors in situation awareness that lead to actions being completed incorrectly or not within some time limitation. The definition of a mental model is as follows:

- Mental models are adaptive belief constructs used to describe, explain and predict situations (Burns, 2000).

Pattern matching is utilized in mental models to help facilitate the development of situation awareness. There is evidence that experienced Operators (decision makers) use pattern matching to recognize information as an archetype of known process scenarios. In addition to pattern matching, conscious analysis, story building, mental simulation and metacognitive processes are all leveraged to some degree at various times to form situation awareness.

Goals are essential to the development of situation awareness. Information processing, in operations, alternates between data driven (bottom-up) and goal-driven (top-down) treatments. In goal-driven processing the Operator's attention is directed across the operating environment in accordance with active goals. Information is sought for goal attainment while simultaneously the goals work as a filter in the interpretation of information. In data driven processing, cues in the form of DCS feedback and person-person communications may create a situation where new goals are developed, which become higher in priority. The dynamic switching between these two forms of treatment is instrumental in successfully completing tasks to achieve goals.

The CCR and Outside Operator will have multiple goals that may change in importance throughout their shift and into accompanying shifts and teams. At any one time only a subset of these goals are actively pursued. The critical functions of an Operator's goals can be represented through a mental model (Figure 5.3) with the following main characteristics (Endsley, 2000):

1. The active goals direct the selection of the Operator's mental model.
2. That goal and the associated mental model are used to direct attention in selecting information from the environment (digital and verbal).
3. Goals and their associated mental models are utilized to interpret and integrate the information to achieve a level of comprehension.

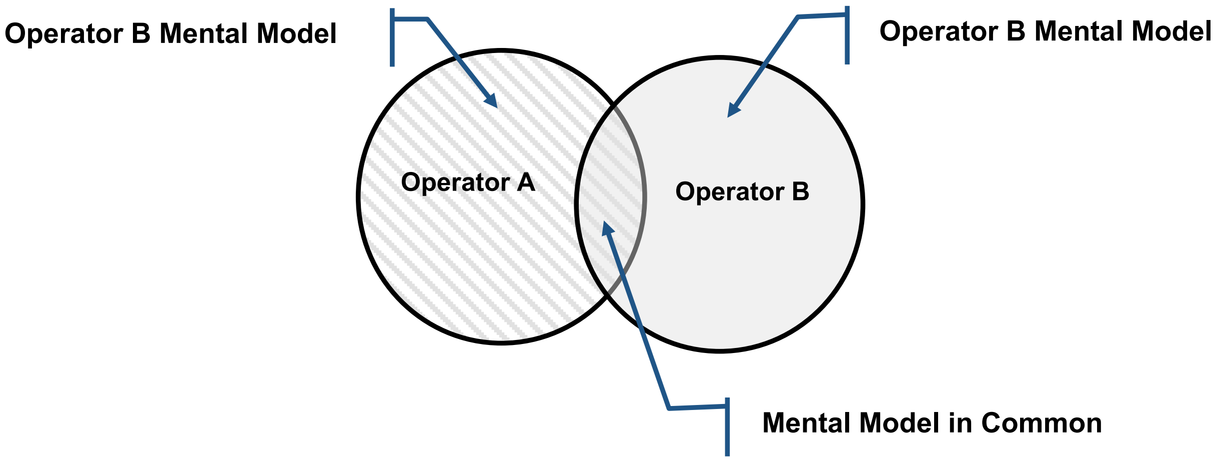

Figure 5.3 Operators' mental model and shared understanding within work teams

These top-down process goals actively guide information selection and processing. Simultaneously, a bottoms-up process is occurring as information is received causing the formation of new goals. For example, an Operator starting up an LNG HP Send-out Pump is driven by top down goals of a safe and efficient start-up within a specified period of time for which this is a common goal between CCR and the Outside Operator. As actions are carried out, feedback from process instrumentation and the Outside Operator may generate a new set of goals that are bottom driven due to issues experienced in the field. This process is dynamic and can shift at any time during the work activity. Team plasticity (flexibility) to adapt to changing conditions is enhanced through high situation awareness. A clear understanding of the shared goals of the operations team provides meaning to the information feedback to both Inside and Outside Operators.

Preconceptions or expectations can also influence situation awareness. Operators' expectations on what should happen through process manipulation are a result of their mental models, prior experiences, instructions and communications. Expectations set by these factors provide a mechanism for filtering information (data). These expectations motivate people to see what they expect to see or hear and can form a type of bias. Another mechanism that can affect situation awareness is automaticity. That is, when pattern recognition and action sequences become very routine, a level of automaticity is said to develop. This can be considered to be a skill based type of behaviour that is more "unconscious" in nature. This mechanism provides good performance with a low level of attention demand in well-understood environments when tasks are done at a high frequency or where tasks are performed by well-trained individuals with experience in performing the actions.

Automaticity can be a positive influence on situation awareness by reducing the demand on limited attention resources (Endsley et al., 2003). Conversely, automaticity of cognitive processes can be detrimental due primarily to a reduction in responsiveness to information that is outside of the routine, when that information may be important in forming a better assessment of the situation. Operators working under automaticity may be less receptive to novel events and errors may occur when a change is required from the learned pattern. The Operator may have difficulty moving from skill based behaviour to either rule or knowledge based behaviour, when needed. Operators must combine available information and anticipate events that may be beyond their normal experience to achieve their goals.

Situation awareness is a state of knowledge about a dynamic environment. An Operator's goals, expectations, mental model and current situation model combine to affect the processes employed and this process determines the resulting level of situation awareness. An individual's current level of knowledge influences the process of acquiring and interpreting new knowledge in an ongoing cycle. Hence, situation awareness is up-to-the minute comprehension of a task's relevant information that enables appropriate decision making under stress. Each Operator may use different information acquisition methods to arrive at the same state of knowledge or may arrive at different states of knowledge based on the same processes due to differences in the comprehension of acquired information as applied to their different mental models.

Process designs that promote situation awareness increase the probability that Operators will make effective decisions. Designs should avoid producing data overload, data confusion, non-integrated data, and complex systems that are difficult to control and understand, requiring excessive attention demands. The relationship between situation awareness and performance may be considered a probabilistic one, as Operators can still make poor decisions despite having good situation awareness.

The method in which an Operator deploys their attention in acquiring and processing information has a fundamental impact on situation awareness, when managing complex processes. Operations typically involve multiple sources of information feedback. Greenfield design and brownfield modifications that influence attention distribution can have a notable impact on situation awareness. Processes often expand over time to manage either additional production throughput or to enhance production efficiency. These additional processes layered onto existing systems require careful management to be integrated seamlessly into the existing process configuration. The additional procedures required to manage larger processes can tax Operator's attention. Experienced, skilled Operators carry procedures in long term memory and bring them into working memory when they are required. Workload is affected by process design, yet situation awareness may improve or worsen depending on increased or decreased workload. However, if workload exceeds an Operator's capacity to manage the process effectively, for example in managing a problematic piece of equipment, the quality of the Operator's general situation awareness may be at risk.

CCR and Outside Operators require system awareness and simultaneously need a team awareness that functions in a common framework of information in which the team shares their information and interpretation of the current state of the process. Situation awareness is important as it is essential to an Operator's performance and can form the basis for decision making. Situation awareness is tied to limitations in working memory, attention and one's expertise. System controls, when designed effectively, can counter these limitations and reduce the probability of human error and subsequent consequences.

The difference between the actual situation awareness provided by the work domain, as it is designed, and an ideal level of situation awareness is called the available situation awareness. The difference between these two levels of situation awareness presents an opportunity to improve the PSFs that impact Operator performance. The achievable ideal reflects the ultimate level of success designers can strive for to create processes, procedures and training programs in an attempt to have work tasks completed correctly. If the achievable situation awareness is not realized it provides opportunity for improvement in designs and managements systems.

Individual tasks (subgoals), within a team framework, overlap to achieve an overall team goal (Figure 5.4). An improvement in an individual's situation awareness improves the overall team situation awareness through more accurate shared mental models. When this occurs the area of overlap as shown in Figure 5.3 becomes larger, and the probability of human error decreases. In this context, situation awareness and process operations are dynamic and the level of Operator's experience and skill varies based on the state of the process (e.g. normal operations or upset conditions).

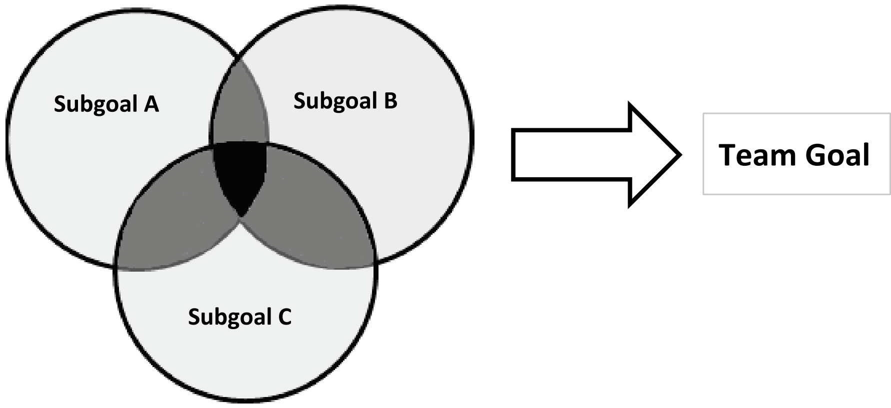

Figure 5.4 Illustration of the intersection of subgoals as part of the overall team goal

6.0 HUMAN ERROR

An improvement in the understanding of human error and its consequences can be realized through the application of predictive human error models. SAIT does not calculate the probability of human error but does provide a measure of the likelihood of success and can be extended to predict human error probability through an expert judgment technique such as SLIM (DiMattia, 2004). In order to achieve this, human error needs to be placed within a systems perspective. The factors that can influence human error, through a systems perspective, can be identified and managed, in a tangible manner, to reduce the overall risk associated within that system through an improvement in human reliability.

Human reliability is the probability of successfully performing a task or an element of a task by a human (McCormick and Sanders, 1987). Human factors that impact human reliability play a major role in daily operations and in the successful completion of work tasks. The importance of human factors in the process industries has been recognized through previous works that range from human error probability prediction to the assessment of human factors in safety critical tasks. On a regulatory basis there remains a lack of clear definition or specific requirement for the inclusion of human error considerations in management systems or risk assessments. A method that incorporates the identification and assessment of situation awareness, within a system, can be a used as a means of applying human factors to assess the likelihood of completing tasks successfully.

Human error plays a significant role in accident causation, from a systems perspective, and can be treated as a natural consequence arising from a discontinuity between human capabilities and the demands of processes and procedures. The human error potential of a system is a function of the properties of the system which includes human and machine components. Changes that increase the disorder in that system can increase the probability of human error and the severity of its consequences. Systems must strive to be error tolerant and provide predictive and reactive measures to mitigate the risk from human error. In certain cases Operators may receive immediate feedback that an action was in error, while in other circumstances the results of an incorrect human action may not be apparent for some time after the action has been performed (CCPS, 2001). Though there is a wide variation in data associated with losses resulting from human error, as a causal factor, it has been reported to be significant. Despite this, it is not unreasonable to state that human error plays a significant role in accidents through either inadequate design or direct human action.

Applying a consistent definition to human factors and human error may help reduce confusion when assessing human error potential from a lack of situation awareness and generate more consistent human reliability assessments. Human factors, in terms of situation awareness, is defined as follows:

- Environmental, organizational and job factors, system design, task attributes and human characteristics that influence behaviour and decision making.

A definition for human error within a situation awareness context is as follows:

- Any human action or lack thereof, based on an understanding of the current and future state of the system in question that exceeds or fails to achieve some limit of acceptability, where limits of human performance are defined by the system.

The intermediate steps in decision making are shown in Figure 6.1. The structure of this model assumes a serial nature to completing each task, with each subfunction receiving an input with subsequent processing and an output to act as input for the next subfunction. SAIT follows this process in analyzing tasks and applying risk mitigation steps that can improve both individual and team situation awareness.

6.1 The Success Likelihood Index Methodology

The Success Likelihood Index Methodology is a rating oriented model originally developed with the support of the U.S. Nuclear Regulatory Commission and has been applied in other industries such as chemical and transport (Embrey et al., 1984). Technology and experience associated with the nuclear industry has influenced developments in safety systems for offshore platforms and has ready application across the process industries. Components of SLIM are utilized in SAIT, in order to weigh and rate PSFs, which leads to a calculation of the success likelihood index (SLI) for each task.

The key premise behind SLIM is that the probability of a human error associated with a task is a function of the PSFs associated with that task. PSFs used to analyze ISA and TSA can be developed by a person knowledgeable in human factors or through a cross functional team that can develop a list of the most pertinent PSFs. There is no limit to the number of PSFs used in a situation awareness assessment though a list of 10 or less PSFs is usually adequate for a given action. SAIT leverages the weighing and rating of PSFs used in the SLIM technique only and does not attempt to predict the probability of human error in completing tasks through the logarithmic relationship proposed in SLIM (DiMattia, 2004). The level of task decomposition ranges for each goal and should be sufficient enough to allow for an adequate assessment of the action in terms of an Operator's situation awareness. The application of SLIM within SAIT is depicted in Figure 6.2.

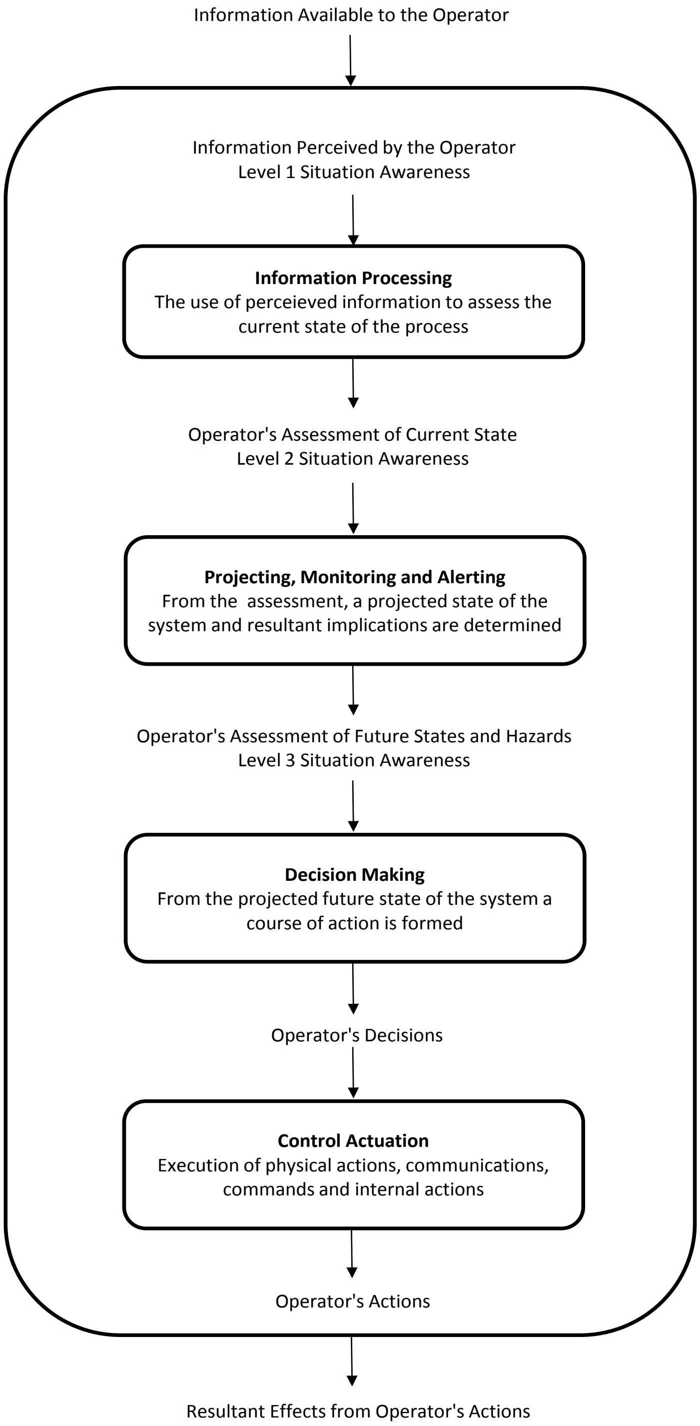

Figure 6.1 Intermediate steps in decision making (Prichett and Hansman, 2000)

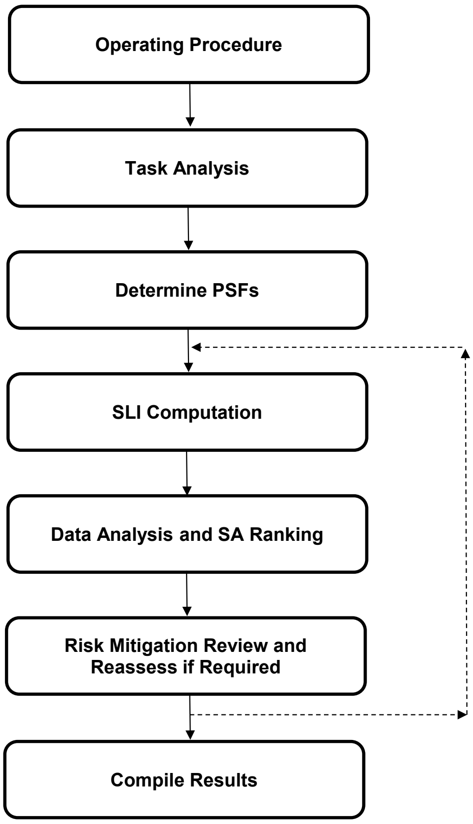

Figure 6.2 Applying SLIM to assess PSFs within SAIT

6.2 Behavior Modes

Each action within a task sequence can be classified by the type of behavior which governs its action. These modes of behavior are known as skill (S), rule (R) and knowledge (K) based and form what is referred to as the SRK model developed by Rasmussen (Reason, 1990). This model describes the error mechanisms (e.g. omission of a task step due to being unaware of the need for action) based on level of conscious effort required to complete a task successfully. For example, with skill-based actions an individual operates in what is referred to as an unconscious mode where the likely error mechanism is a slip due to inattention. Slips are defined as errors in which the intention is correct, but a failure occurs when carrying out the activity (CCPS, 1994). In this behaviour mode Operators are typically highly skilled in relation to the task requirements and do not expend any significant amount of mental energy to successfully complete the task. These tasks are given to the lower levels of the brain and are not continuously monitored by the conscious mind (Kletz, 1991). In rule-based mode Operators need to apply a known rule to complete the action and this requires a greater level of consciousness. The rules that are applied are influenced by the level of situation awareness achieved by the Operator as an individual and through team interaction.

In knowledge-based mode, individuals are faced with an unfamiliar task for which they lack adequate knowledge or training. In this behavior mode Operators may gather data, formulate new rules and apply them in an attempt to complete the task successfully. In this mode, individuals are considered to be fully conscious. It is difficult for Operators to work for extended periods in this behaviour as mental fatigue may set-in relatively quickly, generating a higher potential for human error. Mistakes can either be rule based, if the task involves following a set of procedures, or knowledge based when the task involves evaluation within a new or changing situation (Wells, 1996). A third class of human error is violations, which are the intentional departure from an accepted practice. A violation may occur, in either rule based or knowledge based modes of behaviour, most commonly to overcome a lack of knowledge about the situation and may be in response to time pressures to complete the task. Understanding the different modes of behavior associated with each action can aid in the development of more meaningful measures to help increase the probability of success of completing a task through better situation awareness.

6.3 Hierarchical Task Analysis

Hierarchical task analysis (HTA) is a well-known and frequently utilized technique that represents tasks through goal-subgoal activity decomposition (Bisantz & Roth, 2008). Information used to support an HTA can be derived from a variety of sources. This includes the following:

- document analysis (e.g. operating procedures or guides)
- interview with subject matter experts (e.g. experienced Operators)
- observation (e.g. in field work observation of tasks)

Tasks are described in terms of operational activities that meet operating goals and subgoals. The tasks are considered in terms of the operating scenario and conditions at the time the work is being conducted. The scenario description is central to the evaluation of the PSFs for individual Operators and the Operations Team. The level of detail applied within SAIT is adaptable, depending on the level of task decomposition and analysis required. The descriptive components of an HTA are often represented in an annotated tree structure as applied in SAIT. HTAs have been applied in variety of applications such determining human error potential (DiMattia, 2004). SAIT uses this form of HTA in order to organize goals and subgoals in manner that allow for the evaluation of factors (e.g. training) that influence the likelihood of success of completing the task in an acceptable manner.

6.4 Weighting and Rating of PSFs in SAIT

The weighting (importance) and rating (quality) of the PSFs is conducted in the manner followed by DiMattia, (2004) and is as follows:

- For each work action consider the associated PSFs to be as severe as possible for the given task. Firstly, a PSF is identified that, if improved, provides the greatest possibility of completing the task successfully. That PSF is given a value of 100 (PSF_{100}). In increments of 10, the remaining PSFs are weighted against $PSF_{100.}$ For example, if PSF(i) is deemed to be 50% as important as PSF_{100}, then PSF(i) is given a weight (ω_{ijk}) of 50 and so on for the remaining PSFs. The weighting of the remaining PSFs do not need to be unique and can have the same weight relative to PSF_{100}. The weights are summed for each action as shown by equation [6.1]. The PSF weights are then normalized for each action as shown in equation [6.2].

$$\theta_j = \sum_{i=1}^{n} \omega_{ijk} \qquad [6.1]$$

where:
i = PSFs (1 to n)
j = PSF category
k = Situation Awareness Action Component
ω = weight for each PSF
θ = sum of PSF weights for action (j)
n = number of PSFs for action (j)

For the given action a rating (δ_{ijk}) is determined for each PSF. A PSF Rating Table is utilized as a guide to establish the rating value, which is on a scale from 0 to 100, in increments of 10. A rating of 100 indicates that the PSF is optimal while a rating of 0 indicates the PSF has no effect. The rating for each PSF does not have to be unique.

$$\sigma_{ijk} = \frac{\omega_{ijk}}{\theta_j} \quad [6.2]$$

where:
σ_{ijk} = normalized weight of PSF(i)
ω_{ijk} = weight of PSF(i)
θ_j = sum of PSF weights

The sum of the normalized weights (σ_{ijk}) is unity as shown in the following equation [6.3].

$$\sum_{i=1}^{n} \sigma_{ijk} = 1 \quad [6.3]$$

The Success Likelihood Index (SLI) is the product of normalized weight and rating for each PSF, as shown in the following equation [6.4].

$$\beta_{ijk} = \sigma_{ijk} * \delta_{ijk} \quad [6.4]$$

where:
δ_{ijk} = rating for each PSF(i)
β_{ijk} = SLI for PSF(i)

The SAIT process allows for its application on a wide basis across operating procedures in whole or in part, focusing on specific goals. Though not part of SAIT, as previously noted, the SLIM process allows for the calculation of human error probabilities for each action based on two known data points for calibration purposes as applied to a logarithmic relationship (DiMattia, 2004). A graphical description of the work flow for SAIT is shown in Figure 6.3.

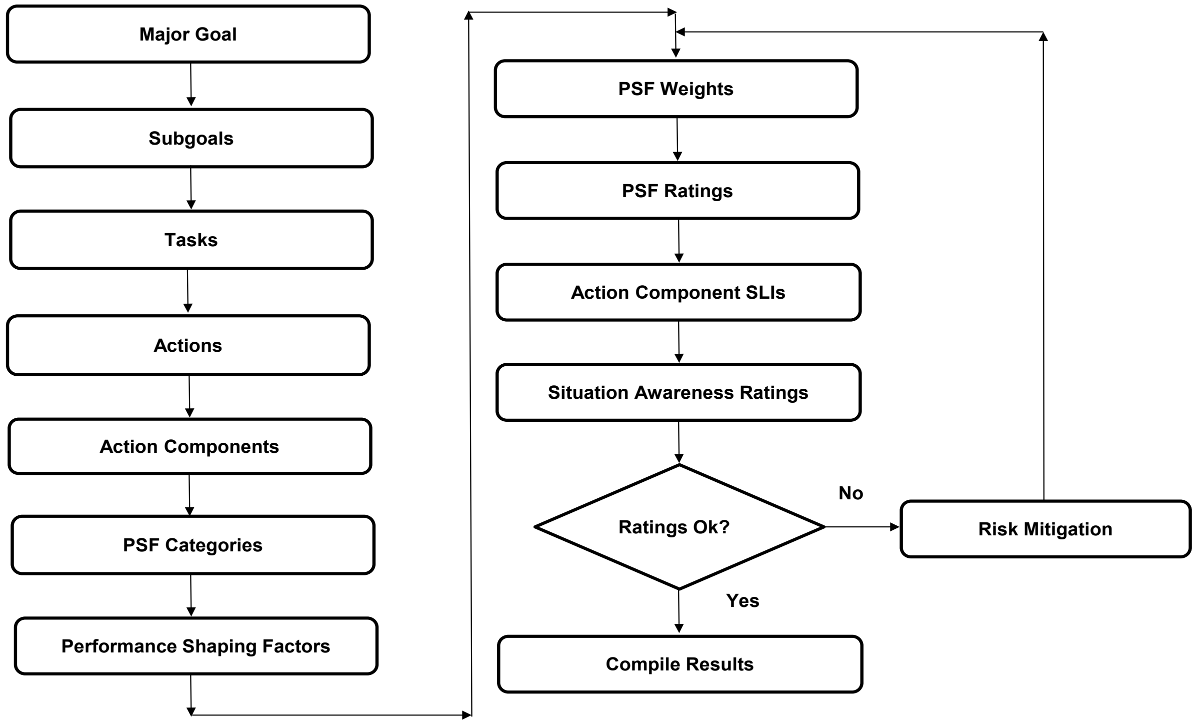

Figure 6.3 SAIT Work Flow

The SAIT technique is flexible and allows users to work in cross functional teams and permits the inclusion of any PSFs deemed pertinent and judgments on the acceptability of the calculated SLIs. The nomenclature used in the tables presented hereafter applies the following format:

- X.Y%.W.Z.R.Q

where:

- X = Major Goal
- Y = Subgoal
- % = Subgoal Task (A,B,C…)
- W = Situation Awareness Action (SAA)
- Z = Situation Awareness Action Component (SAAC)
- R = PSF Category
- Q = PSF

Firstly, a situational analysis defines an overall goal and its components (Major Goals - X) as shown in Figure 6.4. This breakdown can be accomplished by using existing operating procedures at any stage from development to brownfield operations. Each Major Goal is broken down into Subgoals (Y) and then into its respective Tasks (%), as shown in Figure 6.5 Once the Subgoals and Tasks are defined, the Situation Awareness Actions (W) required to complete each task are determined. These actions are generic in nature and are defined by the SAACs (Z) that make-up these actions, as illustrated in Figure 6.6.

Once the Components of each Action are finalized, the PSF Categories are listed (Figure 6.7). The PSFs (Q) are split into the appropriate Categories at this point in the SAIT process (Figure 6.8). The PSFs chosen for each category can be distilled from a larger list by using the Pairwise Comparison method (DiMattia, 2004) that generates a ranked list of PSFs, allowing the SAIT user to choose the most pertinent PSFs. It is helpful to tabulate the PSFs to manage and categorize according to the applicable Situation Awareness Action Component (Table 6.1). Guidance on the rating of each PSF for the applicable category can be a useful tool for assessment teams, as shown in Table 6.2. Each PSF is rated based on its ability to positively affect the action in question.

A straightforward set of criteria as shown in Table 6.3 can be utilized to instigate a review based on the level (adequacy) of situation awareness for a given task. This review would consider methods to improve the quality of the PSFs to allow for a greater likelihood of success in completing the each action. The results from the SAIT process can then be compiled in a spreadsheet for review and analysis as shown in Table 6.4. Compiling the data in this manner allows for a review of the SLI on a PSF by PSF basis for each PSF Category for a given SAAC. Weaknesses within the system can be flagged and addressed accordingly in promoting a higher level of situation awareness on an individual and team basis.

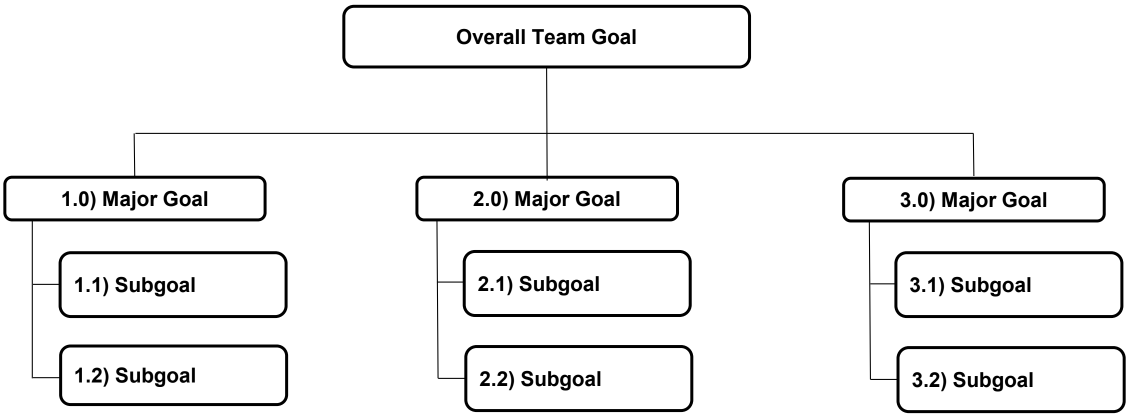

Figure 6.4 Example of overall team goal hierarchy of Major Goals and Subgoals (Endsley et al., 2003)

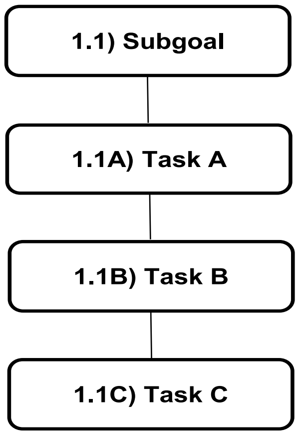

Figure 6.5 Example of Tasks associated with a Subgoal

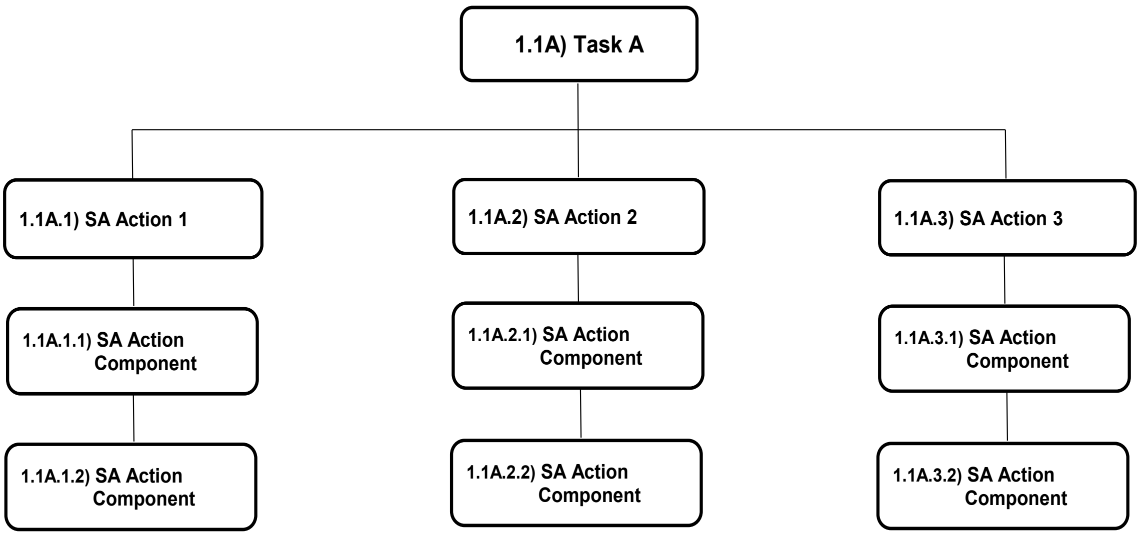

Figure 6.6 Example of a Task's decomposition into Situation Awareness Actions and SA Components

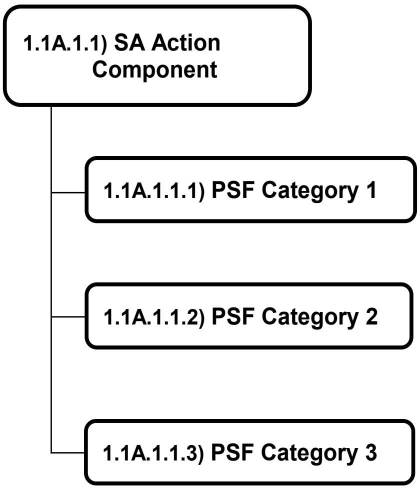

Figure 6.7 Example of Performance Shaping Categories associated with each SA Action Component

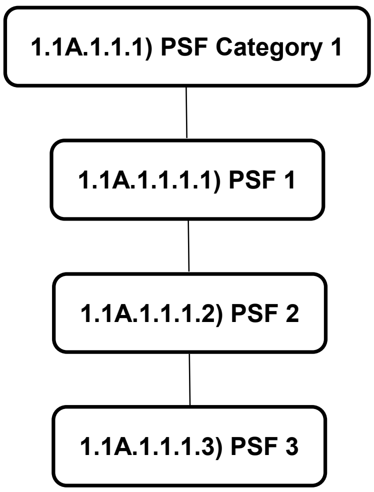

Figure 6.8 Example of Performance Shaping Factors associated with each PSF Category

Table 6.1 Example of a Performance Shaping Factors Description Table for each Situation Awareness Action Component based on the PSF Categories

SAAC	PSF Category	PSF #	PSF Description
1.1A.1.1	1	1	Description of how each Performance Shaping Factor affects situation awareness as related to the SAAC for a given Task and Action. Description must be detailed enough to allow the weighting and rating of each PSF in order to determine the Success Likelihood Index of each PSF.
		2	
	2	1	
		2	
	3	1	
		2	
		3	

Table 6.2 Example of a Performance Shaping Factor Rating Table

SAAC	1.1A.1.1	Peformance Shaping Factor Category		
Rating Scale		PSF 1	PSF 2	PSF 3
100		Optimal Effect	Optimal Effect	Optimal Effect
50		Some Effect	Some Effect	Some Effect
0		No Effect	No Effect	No Effect

Table 6.3 Example of a SLI Rating Table

SLI %	SA Criteria
a to b	Not Applicable
c to d	Needs Improvement
e to f	Adequate
g to h	Enhanced

Table 6.4 Generic SLI Table for each Task associated with a Subgoal

Major Goal	1.0	Success Likelihoof Index																		
Subgoal	1.1	PSF Cat. 1						PSF Cat. 2						PSF Cat. 3						Total
Task	1.1A	PSF 1	PSF2	PSF3	PSF4	PSF5	SLI-1	PSF 1	PSF 2	PSF 3	PSF 4	PSF 5	SLI-2	PSF 1	PSF 2	PSF 3	PSF 4	PSF 5	SLI-3	SLI-T
SA Action	1.1A.1																			
Component	1.1A.1.1																			
	1.1A.1.2																			
SA Action	1.1A.2																			
Component	1.1A.2.1																			
	1.1A.2.2																			
SA Action	1.1A.3																			
Component	1.1A.3.1																			
	1.1A.3.2																			
Task	1.1B	PSF 1	PSF2	PSF3	PSF4	PSF5	SLI-1	PSF 1	PSF 2	PSF 3	PSF 4	PSF 5	SLI-2	PSF 1	PSF 2	PSF 3	PSF 4	PSF 5	SLI-3	SLI-T
SA Action	1.1B.1																			
Component	1.1B.1.1																			
	1.1B.1.2																			
SA Action	1.1B.2																			
Component	1.1B.2.1																			
	1.1B.2.2																			
SA Action	1.1B.3																			
Component	1.1B.3.1																			
	1.1B.3.2																			
Task	1.1C	PSF 1	PSF2	PSF3	PSF4	PSF5	SLI-1	PSF 1	PSF 2	PSF 3	PSF 4	PSF 5	SLI-2	PSF 1	PSF 2	PSF 3	PSF 4	PSF 5	SLI-3	SLI-T
SA Action	1.1C.1																			
Component	1.1C.1.1																			
	1.1C.1.2																			
SA Action	1.1C.2																			
Component	1.1C.2.1																			
	1.1C.2.2																			
SA Action	1.1C.3																			
Component	1.1C.3.1																			
	1.1C.3.2																			

7.0 LNG OFFLOADING, STORAGE AND SEND-OUT

Operations begin, at an LNG import terminal, by LNG being transferred from the tankers by the onboard ship pump into on-site storage tanks which can have a capacity of up to 200,000 m3. The time it takes to offload a tanker varies but it can take over a day-shift to offload a 135,000 m3 ship. LNG flows from the ship through a series of offloading lines, during which the vapour generated in the storage tank is returned to the ship's cargo tanks through a vapour return line to maintain a positive pressure in the ship (Figure 7.1).

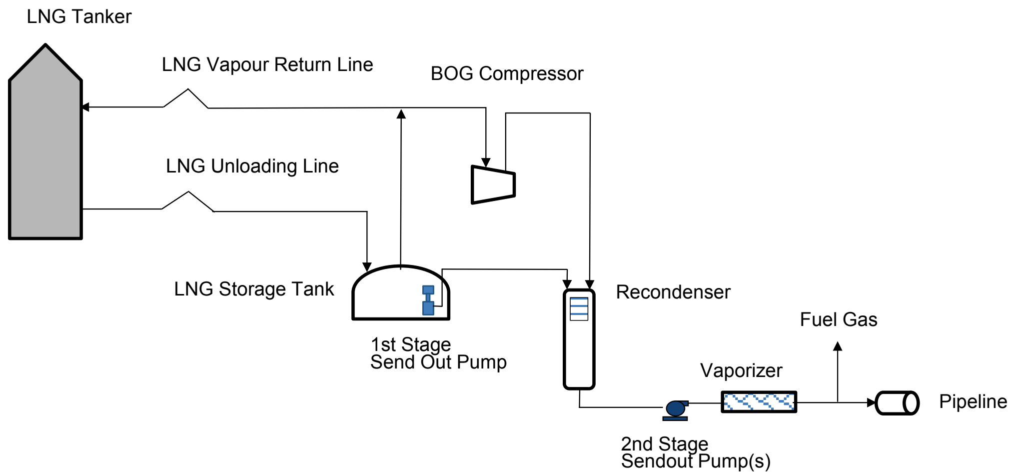

Figure 7.1 Simplified depiction of a LNG Receiving and Regasification Terminal

During normal operation, boil of gas (BOG) is produced within the storage tanks due to heat transfer. The vapour is routed to a compressor which feeds the Recondenser. During ship offloading the amount of vapour in the tank can be notably higher, flash vapour generated by pressure difference between the ship and the storage tanks and vapourization from heat transfer in the offloading and transfer lines. BOG can be routed back to the ship for pressure maintenance or directed to the Recondenser.

The 1st stage LNG send out pumps are typically installed within these LNG tanks. These pumps operate fully submerged within pump wells and can be removed for maintenance, as required. These pumps are designed to deliver the send out flow rate and circulate LNG through the ship offloading piping to maintain temperature between ships offloading. LNG from the intank pumps is routed to the Recondenser. The boil off vapours generated during normal send out operations are routed to this vessel and mixed with the subcooled LNG to be condensed.

The second stage send-out pumps route LNG into a high pressure distribution system. In order to accomplish this send out multi-staged high-head pumps are required. These pumps accept LNG from the Recondenser and feed into LNG vapourizers that operate at slightly above pipeline pressure. LNG vapourizers are commonly in the form of Open Rack Vapourization (ORVs) units where seawater free falls, as a film, over aluminum panels and collects in a trough before being disposed of. LNG vapourizes within the panels due to the exchange of heat with the continuous falling seawater before entering the natural gas distribution system.

7.1 Start-up of HP Send Out Pumps after Maintenance Activities

The start-up of the second stage LNG send out pumps, after maintenance, occurs in several steps that requires very good coordination between the CCR and Outside Operators, Table 7.1. It is a team based activity that requires continuous assessment of the situation to avoid making errors in the field or in the control room that could lead to either operational upsets at pump start-up or a loss of containment due to possible brittle fracture from an improper cool down. The valve preparation and cool down work can take more than a 12 hour shift to accomplish. Table 7.1 provides a representation of the steps to accomplish this goal.

7.2 Goal Directed Task Analysis

Based on the procedure shown in Table 7.1, a task analysis is conducted to breakdown and categorize the actions that make-up the goals of the given procedure. The overall goal, in this case, is to return the facility to full functionality or possibly restart of the plant after planned maintenance work. One of the Major Goals within this this Overall Team Goal of restarting the plant is to return the HP Pumps back to service. Figure 7.2 illustrates the 5 Subgoals (1.1 to 1.5) that make up this Major Goal (1.0). From this initial step each Subgoal is broken down into Tasks. For example, Subgoal 1.2 (Cooldown of Pump Suction and Caisson) has 4 associated Tasks (1.2A through 1.2D), as shown in Figure 7.3. These tasks are sequential in nature and require close coordination between the CCR and the Outside Operator. Each task is then broken down into broad Actions, which in turn are further detailed by the following Situation Awareness Action Components (Figure 7.4):

Table 7.1 Representation of an HP Send-Out Pump start-up procedure after maintenance

No.	Action	Comment
1	Remove car seal certificates	Removal of car seals that permitted maintenance work
2	Open valves to permit Nitrogen purge to the electrical & instrumentation connections of the pump	Purge air from system
3	Set-up valves in the field in preparation for pump start-up	Valve set-up for pump start-up
4	Resinstate car seal valves to their normal positions	Open remaining isolation valves to CSO position
5	Stop Nitrogen purge	Air purge complete
6	Maintain nitrogen positive pressure in pump section and associated piping	Nitrogen maintained in system
7	Set-up valves in preparation of cool down and venting to flare for pump suction	Valve preparation for pump suction system
8	Start cool down process targeting a specific temperature for a maximum cooldown rate	Requires manipulation of valves based on cool down rate
9	Fill-up pump caisson at specified rate while achieving target temperatures	Preparation of pump for start-up
10	Once cooldown is achieved set-up valves accordingly	Manual valves in that section are in position for start-up
11	Set-up valves in preparation of cool down and venting to flare system for pump discharge and recycle	Valve preparation for pump discharge system
12	Start cool down process targeting a specific temperature for a maximum cooldown rate	Requires manipulation of valves based on cool down rate
13	Liquid fill discharge header and recycle line at specified rate while achieving target temperatures	Preparation of pump for start-up
14	Once cooldown is achieved set-up valves accordingly in discharge and recycle lines	Manual valves in that section are in position for start-up
15	Set-up valves and pressurize HP pump in preparation for start-up	Prepare pump for start-up
16	Reset and open unit shutdown valves	Reset SDVs for start-up
17	Car seal valves as indicated on P&IDs	Set-up car seals in the field
18	Update Car Seal Log	Ensuring CS log matches valve position in the field
19	Allow pump to cool down for specified period	Pump cool down time is several hours before start-up
20	Remove electrical isolatons	Prepare pump with electrician
21	Ensure flow control logic is set-up in auto mode	Ensure pump controls are set-up accordingly for start-up
22	Test pump	Monitor amps, vibration, pressure build-up
23	Start pump	

- Assess and Monitor
- Manage and Control
- Communicate and Coordinate

Table 7.2 lists the pertinent PSFs that are applicable to these action components. Techniques such as Pairwise Comparison utilized by DiMattia (2004) can be leveraged as means of choosing the most significant PSFs either as a single practitioner or within a team format. Figure 7.5 illustrates how the Action Component is broken down into the following PSF Categories:

- Work Status
- External Factors
- Field Team

Each PSF has associated attributes, which are noted to aid in the determination of the PSF's SLI for a given action. As the same PSF may be applied to different action components, within the Overall Goal, it is important to clearly define the PSF for each application for proper assessment of the weight and rating of each PSF. The PSFs provided in Figure 7.5 apply on team basis, that is, to both Outside and Inside Operators, to facilitate a team perspective when assessing these PSFs. These PSFs are essential to an Operators situation assessment, promoting accurate mental models that are shared by the Operations Team. PSFs that have a high rating (quality) promote higher levels of situation awareness, which allow Operators to move to higher levels of SA (i.e. Level 1 - Perception, Level 2 - Comprehension, Level 3 - Projection).

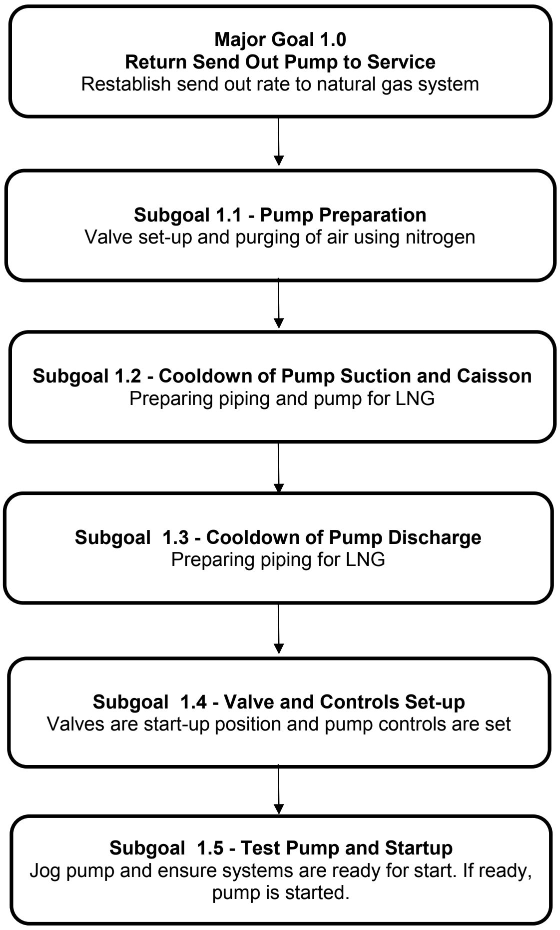

Figure 7.2 Major Goal and Subgoals for restart of HP Send-out Pump after maintenance

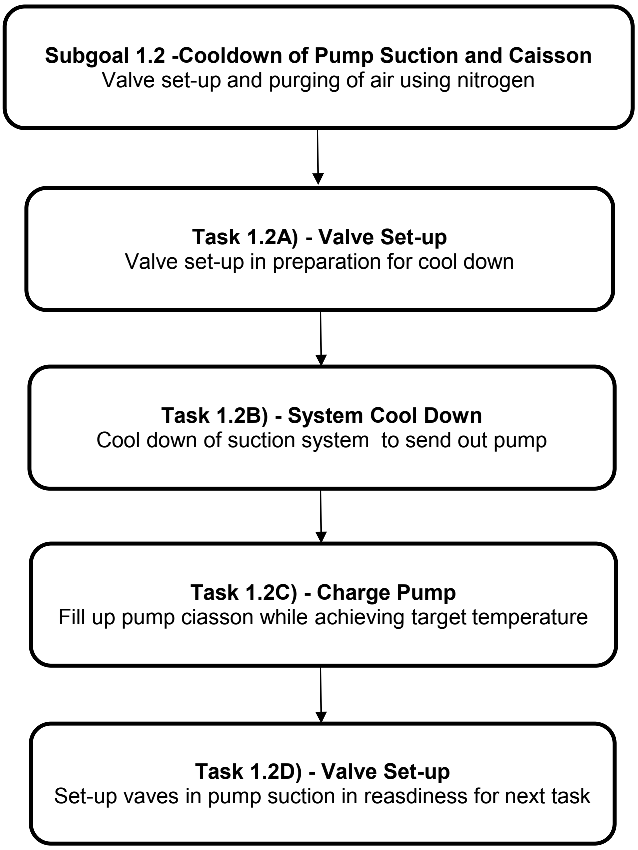

Figure 7.3 Associated Tasks for the cooldown of the HP Pump and caisson (Sub-goal 1.2)

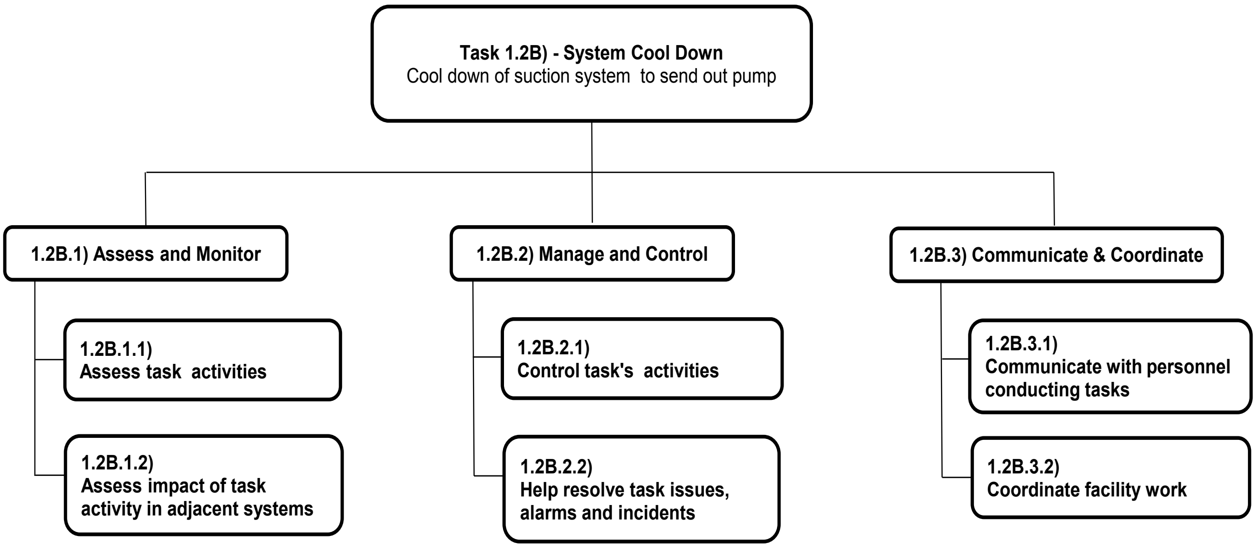

Figure 7.4 Cooldown of suction system to HP Pump with Actions and Components (Task 1.2B)

Table 7.2 Example of Performance Shaping Factors for a given Task

PSFs	Description
Complexity	Intricacy of the action and sub-actions for either CCR or Outside Operator. This PSF in conjuction with stress can make actions that a are simplistic in nature more difficult to accomplish successfully. Can promote short cuts while following procedures (e.g violations).
Weather	Impact of weather conditions such as rain, wind and temperature on ability of team to effectively communicate and complete outside tasks in a safe and efficient manner. May impact an individuals ability to work in effectively and may cause delays or promote improvisation to compensate.
Experience	Experience as related to the task to be completed. Individuals with less experience may perform tasks at a slower pace and may work under greater level of stress. Individuals with greater levcels of experience may form biases and may not as responsive to certain cues.
Training	Training as related to working in a manner that accomplishes tasks in a safe and responsible manner. Training in understanding equipment operation and process knowledge. Contract personnel involved in operating duties may have different training backgrounds.
Automation	Quality of instrumentation may impact amount of information and the accuracy of the information. The location of instruments may also impact accuracy and efficacy of feedback. The ergonomic set-up of equipment, displays from local instrumentation. Process control, alarm set-up and emergency shutdown activation.
Ergonomics	Equipment layout and access. Labelling and signage of valves, pipipng and vessels. DCS layout, color scheme, information provided, ease of maniplulation.
Stress	Work load and conditions under which actions take place. Adverse weather conditions may impact outside actions. Competing task may raise stress levels as well as time constraints. Inexperience or personal factors may generate elevated levels of stress impacting the quality of decision making.
Communication	Ability for effectively communicate as required among team members during work activities. Type of quipment and availability. Communication potocols and procedural requirements to communicate statis of work. Creates shared understanding of work activities and process status. Promotes common mental models of current and future system states.

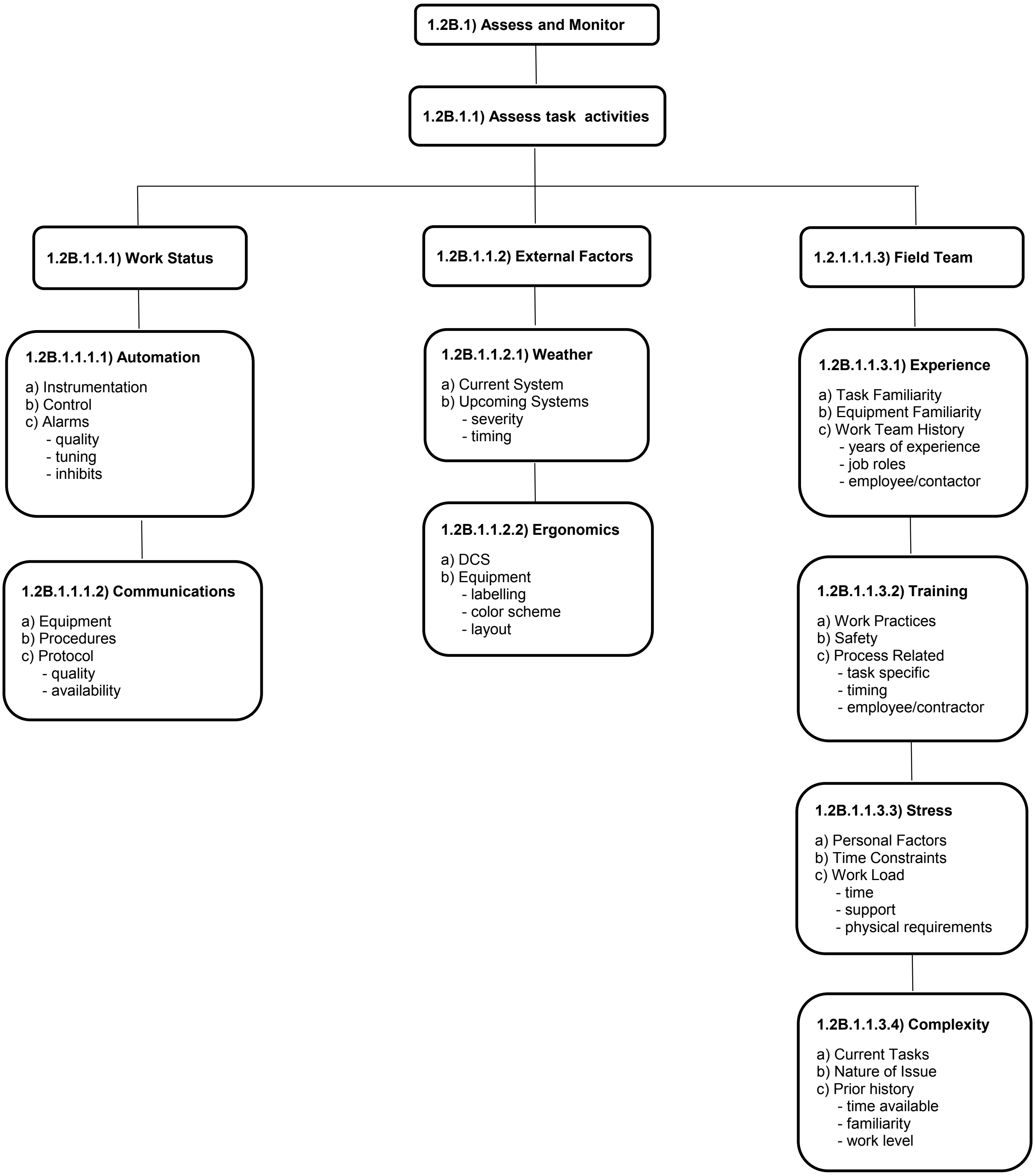

Figure 7.5 Task Action and related PSF Categories and corresponding Performance Shaping Factors

8.0 SLI DETERMINATION

For each action a PSF weight is determined ranging from 0 to 100, with a value of 100 representing a maximum PSF weight. An example of a PSF the weight determination is as follows:

- Subgoal – 1.2) Cooldown of Pump and Caisson
- Task – 1.2B) System Cooldown
- Action – 1.2B.1) Assess and Monitor
- Action Component – 1.2B.1.1) Assess Task Activities

Taking into consideration the PSF category of External Factors (1.2B.1.1.2), two PSFs are listed:

- Weather (1.2B.1.1.2.1) – Impacts ability of Outside Operator to complete tasks efficiently and may create distractions.
- Ergonomics (1.2B.1.1.2.2) – Impacts both Inside and Outside Operators. In the field, access to valves, labeling and spacing are considerations. For the CCR Operator, DCS colors, layout and control room design are factors that affect performance.

The ergonomics PSF is deemed the most important of the two PSFs considered in this example. As per the SLIM procedure ergonomics is chosen as the PSF_{100} and hence has a PSF weight of 100. Weather is given a relative weighting to Ergonomics of 40. The sum of the weights is 140 and the subsequent normalized weights (Equation [6.3]) for each PSF are as follows:

- Weather – 0.286
- Ergonomics – 0.714

The sum of the normalized weights is unity as a check on the calculation. The operating scenario is a key factor when deciding the PSF ratings. For this scenario the pertinent components are:

- Task is completed in sunny warm weather and the upcoming forecast is for continued good weather.
- Valve access is poor in some cases forcing the outside Operator to climb onto pipe or erect some form of step.
- Some valve tags have fallen off over time.
- Method of car sealing valves is not robust and can be easily defeated in the field.
- DCS layout, color scheme, and information provided has been optimized over time and is currently not requiring modification for the equipment and controls associated with this task.

The rating of the PSFs is a measure of their quality. The optimal rating for any given PSF is 100 and a 0 value is the minimum value or in other terms the quality of the PSF is low as the rating approaches 0. Using this scale each PSF was given a rating as per Table 8.1. Sensitivity analysis can be performed by varying the scenario to produce a range of SLI results creating a map of situation awareness for a given set of tasks.

Table 8.1 PSF Rating Table

Rating Scale	Weather	Ergonomics
100	No effect	High quality
50	Some effect	Mid quality
0	Large Effect	Low quality

The ratings on a scale of 0 to 100, for the two PSFs, based on this scenario, are predicted to be as follows:

- Weather – 100 – Conditions are optimal for conducting work in the field.
- Ergonomics – 30 – Design issues in the field. The quality of the PSF can influence the Outside Operator's effectiveness in completing tasks and influences the CCR Operator's monitoring and control actions.

The Success Likelihood Index for this Action Component is the product of the normalized weight and the corresponding rating for each PSF. The SLI determined from Equation [6.4], for each PSF is as follows:

- Weather – 100 * 0.286 = 28.6
- Ergonomics – 30 * 0.714 = 21.4

When considering the individual SLIs, the SLI for weather has a potential score of 28.6. Since work is being conducted in optimal weather conditions, this PSF is given full value. In this case no mitigation is immediately required to permit the Operator a greater probability of success in completing this task under the current weather conditions. The SLI for external ergonomics (21.4) is well below the potential SLI of 71.4 (0.714 * 100). The rating is 30% of the optimal value and based on the scale, as provided in Table 8.1, suggesting mitigating actions be put into place to raise the Outside Operators situation awareness. As the DCS has been optimized for the equipment and controls in question, no mitigation steps are considered for that aspect of the PSF.

The sum of the SLIs for this Category (External Factors) is 50 from a total potential SLI of 100. These results are summarized in Table 8.2, which forms part of a much larger SLI results table as previously illustrated in Table 6.4

Table 8.2 SLI Results for PSF Component - Assess Task Activities

Cooldown of Pump & Caisson	1.2	External Factors		
System Cooldown	1.2B	Weather	Ergonomics	SLI
Assess and Monitor	1.2B.1			
Assess Task Activities	1.2B.1.1	28.6	21.4	50

Table 8.3 provides a straightforward means of assessing the SLIs associated with each PSF and cue the assessor to consider mitigating steps to improve situation awareness.

Table 8.3 SLI Criteria for each Performance Shaping Factor

SLI %	SA Criteria
0-25	Not Applicable
26 -50	Needs Improvement
51 - 75	Adequate
76 - 100	Enhanced

Risk mitigation steps that can improve the situation awareness for the Outside Operator include:

- Car seal log survey and update.
- Construction of temporary scaffolding appropriate to assess valves in question.
- Replacement of valve tags where needed.

The SLI for the External Factor, PSF, can be reassessed based on these mitigating steps. The weight (importance) of the PSFs is independent of the state of the PSF, and hence the PSF rating need only be reassessed as shown below:

- Rating increased to 30 to 70
- New SLI is 70 * .714 = 50 or 70% of the maximum SLI of 71.4
- The total SLI for the PSF Category (External Factors) has increased to 78.6 out of potential 100

The summary table can now be updated as shown in Table 8.4.

Table 8.4 Revised SLI Results for PSF Component - Assess Task Activities

Cooldown of Pump & Caisson	1.2	External Factors		
System Cooldown	1.2B	Weather	Ergonomics	SLI
Assess and Monitor	1.2B.1			
Assess Task Activities	1.2B.1.1	28.6	50	78.6

Referencing Table 8.3, the SLI for this PSF has improved to the Enhanced category from Needs Improvement. It may be deemed by the assessment team that no further changes are required as the risk of human error from a lack of situation awareness, for this task, is as low practicable. This process is repeated for each task until a compilation table of results is finalized, encompassing all the tasks and their respective PSFs. This provides an overall map of team situation awareness and helps identify areas that may be strengthened by improving the quality of specific PSFs.

9.0 CONCLUSIONS

As situation awareness and performance are connected in a probabilistic manner, there is no defined limit to optimal situation awareness that can guarantee a given level of individual Operator or team based performance. Situation awareness should be thought of in relative terms, that is, how can PSFs be optimized to provide Operators the best chance of making good decisions and fewer errors. Since situation awareness is operationally defined as information an individual needs to know, having more constructive feedback, both passive and active, and an understanding of these elements would always seem to be preferred, as this goes to better decision making and Operator performance. Decisions to invest in designs and processes that raise the level of situation awareness in Operators can best be made through proactive assessment techniques, such as SAIT, with input from root cause failure analysis from prior incidents and the ongoing capture of lessons learned from the field. Capturing lessons learned actively promotes a feedback loop into the SAIT protocol, allowing for the refinement of PSF weight and rating calculations, as well as the effectiveness of mitigating actions to improve Operators' level of situation awareness.

SAIT provides a systematic means to break down procedures into tasks that can be readily analyzed through an evaluation of the relevant PSFs that influence situation awareness. Leveraging the weighting and rating components of the SLIM methodology this semi-quantitative approach provides a means of assessing the state of individual and team situation awareness through expert judgment. Areas that require improved situation awareness can be proactively addressed to help mitigate human error and the associated consequences. SAIT provides a framework for wide application within the work tasks associated with an LNG offloading, storage and regasification terminal and can also be applied across a wider spectrum of processing scenarios.

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