Assessment of Human and Organizational Factors in Operations of Marine Terminals and Offshore Platforms

Marine Technology & Management Group Report

by:

Brant D. Pickrell, M.E.
and
Professor Robert G. Bea

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Department of Civil and Environmental Engineering

University of California, Berkeley

Abstract

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Brant D. Pickrell
Master of Engineering in Civil and Environmental Engineering
University of California, Berkeley
and
Professor Robert G. Bea
Department of Civil and Environmental Engineering
University of California, Berkeley

Technological advances (i.e. computers, automation, robotics, etc.) and information flow have brought about an increased awareness of major accidents, especially those involving loss of life or damage to the environment. Major offshore catastrophes like the Piper Alpha explosion and the Exxon Valdez grounding have brought about significant changes to marine safety practices and guidelines. It is estimated 80% of all marine related accidents can be attributed to Human and Organizational Error (HOE), and since it is neither possible nor preferable in most cases to "design out" the human, methods must be developed to account for HOE. The Nuclear Power, Aviation, and Chemical industries have been quite proactive in recognizing the need to account for HOE. However, HOE has only recently become an area of concern in the marine industry with research primarily starting within the last seven years.

This project focuses on Human and Organizational Factors (HOF) and their influence on the occurrence of Loss of Containment (LOC) during marine terminal and offshore

platform operations. A Safety Management Assessment System (SMAS) is introduced. The SMAS project is two-fold: (1) - The development and introduction of an evaluation process, (which pays particular attention to Human and Organizational Performance Factors), designed to aid platform and terminal owners, operators, and regulatory agencies assess the likelihood of major losses of containment; (2) - The development and introduction of a computer Data Management Tool (program) which encompasses and compliments the SMAS process.

This report details item (2) of the SMAS project, development and introduction of the SMAS Data Management Tool. Item (1) will be reported on by Mr. Derek Hee, the other SMAS project team member at a future date.

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1. Introduction:

“To err is human....” This profound quote, first written down in 1711 by the poet Alexander Pope and since used by philosophers, educators, physicians, and even computer naysayers, has catastrophic meaning in today’s high-speed, technological based society.

Approximately eighty percent of accidents occurring in the marine industry can be attributed to humans and / or the organizations that influence humans. In offshore platforms, the largest source of failures which lead to loss of hydrocarbon containment and the associated fires and explosions is that of humans and organizations (Bea, 1994; Moore and Bea, 1993a; Moore and Bea, 1993b). A review of loss of containment mishaps on marine loading and discharge facilities also found the primary contributing source of failure was humans and organizations (California State Lands Commission, 1996). Fortunately, technological advances have greatly aided in reducing human associated mishaps. Unfortunately, these same technological advances have also made the margins for error smaller and mishap reaction times exponentially faster resulting in much larger consequences associated with the smaller mishaps.

The study of Human and Organizational Factors (HOF) seeks to improve safety by identifying areas in systems where the human and organizational influence can lead to accidents. Recent catastrophes like the Piper Alpha explosion, the Exxon Valdez grounding, the Slipner A destruction, etc. have spurred regulatory agencies to recognize the impact of HOF in the marine industry resulting in attempts to account for HOF through changes in their guidelines. The underlying goal of such guidelines is that through recognition, the human and organizational error risk potential will be evaluated for various activities and mitigation measures effected prior to the occurrence of a major accident.

The objective of this project is two-fold. One, develop an evaluation process, which pays particular attention to Human and Organizational Performance Factors, and is designed to aid platform and terminal owners, operators, and regulatory agencies assess the likelihood of major losses of containment. Two, develop a computer Data Management Tool (program) which encompasses and compliments the above process. The resultant, Safety Management Assessment System (SMAS), product is an evaluation protocol for evaluating the safety of marine terminal and offshore platform.

In order to cover research goals of the SMAS project team, the project is reported in two parts: One details the development of HOF for the marine environment and the SMAS process; The other, this report, details the design and development of the computer model designed to facilitate the SMAS process.

Since the focus of SMAS is HOF, this report provides a brief overview of human and organizational factors and their assessment methodologies. Following this background discussion, the Safety Management Assessment System development is discussed. Various portions of the SMAS development detail have been summarized as they will be reported by Hee in the near future. However, detail is given for the development of the SMAS Data Management Tool and particular attention is drawn to the Tool's User's Guide which is included as an appendix to this report.

2. Background

Safety of marine operations is clearly a function of human performance. In order to gain an understanding of HOF, a brief review of the history of human and organizational factors, their application to the marine industry, and current assessment methods follows.

2.1 HOF History

The study of HOF can be traced to the late 1800's when Frederick Taylor studied factory worker motion by motion movements to increase efficiency (Taylor, 1947). Studies similar to Taylor's progressed through the early 1900's. The primary focus of these studies was on human time-motion analysis and interaction with machines. These theories were subsequently tested / and applied to the mass equipment and weapons production lines developed in support of the World War II effort.

Subsequent to WWII, a new field of study, Human Reliability Analysis, was developed which combined human behavior, and engineering and operations, research areas (Dougherty and Fragola, 1988). By the 1960's, the disparate lack of data on human error gave rise to the development of various databases to track human performance, situational influences on performance, and the human behavior elements associated with various actions (Meister, 1969). To date, this acquired data has been most successfully applied to the design, construction, operation, maintenance and retirement of engineered systems in the form of ergonomics, the optimization of human-machine interfaces. While the area of ergonomics has been successful in minimizing error and accidents resulting from the man-machine interface, it and increasing technology have served to accentuate human error and related accidents.

Probably one of the most influential (and undesirable) factors on the development of HOF application in engineered systems has been catastrophic accidents. For example, Three Mile Island showed how blind faith in technology and operator misunderstanding of system alarms can be catastrophic, the Space Shuttle Challenger incident emphasized how organizational pressures can be lethal, the Piper Alpha destruction emphasized maintenance and operations errors, and the Slipner A demise demonstrated human error during design through improper use of technological models. Outfalls of these and other accidents have lead to the development of guidelines, selection and training procedures, and continued ergonomics refinement.

2.2 HOF Application in the Marine Environment

In 1996, the first “Human Factors in Offshore Operations” workshop was held to review and develop the current state-of-the-art of Human and Organizational influences in the offshore environment (Primatech and UCB, 1996). This workshop focused on six different areas: Design, Fabrication and Installation, Operations, Management Systems, Standards and Regulations, Science and Application. While the final compendium from this workshop will be published in the near future (August 1997), all the workgroups acknowledged the need for a greater emphasis on development and application of HOF in each workshop area and the implementation of current HOF guidelines and lessons learned.

Additionally, various regulatory agencies have begun recognizing the impact of HOF in offshore operations. This has manifested itself in various forms, from $1M Safety Cases in the UK (Cullen, 1990) to voluntary guidelines (SEMP; MMS, 1990) and Recommended Practice (RP 75; API, 1993)).

2.3 Assessment Methods

If the desire is to address the HOF issue in the marine industry, the problem is to determine just what HOF is (for the marine industry) and how to assess it. Therefore, the subject of defining HOF as it applies to the marine industry must be addressed. In order to do this, the place to begin is to look at current human error assessment methodology.

There are numerous human error assessment models which have been developed, tested, and are either still in use or being replaced with better systems. Since the use of failure rate data has been successful in equipment reliability analysis, the same general methods have been adapted to human reliability analysis. Generally, the existing assessment models can be grouped in one of four groups: Probabilistic, Narratives, Checklists / Questionnaires, and Rankings. Hee (1997) developed a summary table, (Appendix A), of these four categories which defines the category and lists its deficiencies when applied to HOF assessments in the marine industry.

2.3.1 Human Assessment Methods

Probably the most widely accepted and used human assessment method is the Human Reliability Analysis method. This method uses a human factors analyst to identify human tasks which can lead to system failure. These tasks are then broken into steps which are assigned Human Error Probabilities (HEP). The HEP for each step is then rolled back up into a total HEP for the task. Lastly, each task HEP is multiplied by a Performance Shaping Factor (PSF) to obtain a probability of failure for the system due to failure of a given task (Dougherty and Fragola, 1988).

Various weaknesses have been observed with the above HRA methodology. Probably the most important weakness is the analyst (expert) who adds uncertainty into the process by subjective selection of tasks, HEP and PSF's. As demonstrated by Pouchet (1989) and

Humphreys (1990), the use of analysts leads to inconsistent evaluations of the same system by different teams. Another weakness, of equal importance, is the lack of ability to capture the uncertainty of the analyst or expert. Finally, HRA fails to recognize consequences associated with failure when determining HEP, therefore, low-probability, high-consequence (potentially catastrophic) tasks are eliminated from the probability study.

2.3.2 Organization Assessment Methods

Most organization assessment methods are based on questionnaires and surveys. Such methods are dependent on human analysts and experts to evaluate a system by answering "pre-weighted" questions. Weaknesses to these methods include lack of system operators on assessment teams and inconsistencies in scoring due to weightings and judgment biases in grading. Additionally, "weighting" adds uncertainty which is not reflected in the final outcome of the assessment.

2.3.3 Other Assessment Methods

A review of other industry assessment methods verifies use of HRA as the principal assessment method. However, there are three industries which use different methods that have elements which overcome some of the above weaknesses. First, the Nuclear Medicine industry uses a Relative Risk Assessment to determine high risk activities which need to be the focus of training, operations, etc. to lower the overall risk level. The relative risk method uses an assessor team to list and rank various operational activities according to likelihood of occurrence and consequence of error. The likelihood and consequence are then multiplied together to determine the relative risk (Jones et. Al., 1995).

In the Medical Health field, the Health Risk Appraisal Method is used. This method first identifies health risk factors (High blood pressure, Smoking, Drug abuse, etc.) and then develops screening questions relative to each risk factor. These questions are then used by trained nurses to identify risk factors and determine if more in-depth tests are required. This method is good in that it involves the patient and is relatively quick, but can be skewed if a perceived lack of trust exists between the nurse and patient (MDPH, 1985).

Lastly, the Fire Inspection field developed a risk ranking system to get away from tedious, complex, and expensive probabilistic risk assessments. This system (characterized by the Gretnener Method), defines fire risk as the product of the probability a fire will start and the degree of danger (severity) associated with that fire. This product (likelihood X consequence) produces a relative risk measurement which can be then broken down into its components to determine which areas have the highest risk and need mitigation efforts (Watts, 1995).

2.4 Assessment Method Summary

Given the problem of developing a way of assessing HOF in marine terminals and offshore platforms and the various weaknesses and strengths of existing HOF assessment systems, the following summary of desirable assessment method elements provide guidance for development of a new method:

1. Should clearly address both Human AND Organizational elements as separate and integrated elements.
2. Should be based on Relative Risk (Likelihood X Consequence)
3. Since, Human Assessors are unavoidable, the method must capture uncertainty and devise a method to show that uncertainty
4. Should ultimately be adaptable to existing and future HOF regulations

5. Must include the operators in the process (as they know the system better than anyone)

6. Should be qualitative (easier, quicker, and cheaper) in nature and yet produce some quantitative (tedious, time consuming and expensive) results

3. Safety Management Assessment System (SMAS)

3.1 Approach

The lifecycle phases of an engineered system (Concept, Design, Construction, Operations and Maintenance, and Termination) can be applied to the development of an assessment model or tool. Table 1 reviews these life cycle phases and lists the parallel actions taken during the SMAS development. The first three phases of this approach form the outline for the remainder of this section of the report. The Operations and Maintenance and Termination phases will be covered in the Testing and Analysis and Conclusions to this report.

Table 1: Life Cycle Phases for Engineered Systems

Phase	General Description	SMAS Application
Concept	Identify a need, Establish goals, strategy, team, resources, Develop scope and alternatives	Establish need for Marine System HOF Assessment Tool, Develop Objective and focus
Design	Select best alternative and develop methods, Develop formwork (plan) for construction	Develop Marine Human and Organization Factors and Evaluation Attributes, Develop assessment hierarchy and process,
Construction	Build the Model or project	Select computer program for model development, Develop initial computer model framework Develop menu driven database tool to support process
Operations and Maintenance	Use the model for intended purpose. Maintain the model, Document lessons learned	Conduct Table Top and Field Tests to verify usability of tool, Correct errors, Refine menus and add necessary utilities to support objective
Termination	Retire the model when obsolete or need no longer exists or a better system is developed	Develop Written User’s Guide and Release initial version of Program for use

It should be noted, Table 1 primarily details the development of the computer data management tool with summaries and references to the process and factor development areas only.

3.2 SMAS Concept

The need for a marine industry assessment method was identified in section 2.4 of this paper. Given the need, the objective and scope for SMAS were developed with Hee and Bea.

3.2.1 SMAS Objective:

Develop a Qualitative, Risk-Based, Safety Management Assessment System (focused on Human and Organizational Factors), which, when used to evaluate marine terminals and offshore structures, produces comparable Quantitative results for purposes of identifying and correcting potential safety problems before they lead to an accident.

3.2.1.1 Objective Definitions:

Qualitative assessment: Review of system components for those items which influence system performance and consequently system failure. Qualitative analysis techniques start with the big picture (Modules) and progress to smaller system (detailed) elements which influence the modules (Influence Factors) and could impact system performance. Qualitative results, by nature, are generally descriptive and not numeric (Bea, 1996).

Quantitative assessment: Detailed probabilistic review of system components to identify high likelihood of failure items. The results produced are numeric in nature and therefore easily comparable to other items within and between system components (Bea, 1996).

Risk: Risk can be defined as "The chance of certain occurrences adversely affecting" system performance ("project objectives"). In this definition, risk is characterized by risk events (what might happen to the detriment of the system), risk probability (how likely the event is to occur), and amount at stake (extent of loss which could result). Therefore, for purposes of engineered systems evaluation, risk is defined as the product of the Likelihood of Failure (of a system component) and the Consequences associated with that failure. This definition can be further developed into a Relative Risk approach where the risk associated with each system component is comparable to that of other system components (Bea, 1996; Bea, 1997a).

3.2.2 SMAS Project Goals

The following goals were developed for the SMAS project.

1. Develop an assessment method which focused on Human and Organization factors.
    - 1a. Develop Human and Organization factors.
    - 1b. Develop a methodology to assess these factors.
2. Develop a protocol which combines the methodology and factors and is qualitative in nature. The protocol must:
    - 2a. Utilize Relative Risk based approach
    - 2b. Capture and Display Uncertainty
    - 2c. Incorporate system operators (i.e. those most knowledgeable about the system)
    - 2d. Use qualitative assessment techniques to produce quantitative results
3. Develop an assessment tool (computer program) which drives and is driven by the process. The program must be:
    - 3a. Menu (process) driven
    - 3b. User friendly
    - 3c. Highly flexible for varying conditions and requirements

3.2.3 SMAS Project Scope

Loss of Containment (LOC) at Marine Terminals and Offshore Platforms was identified as the focus of the project. However, after testing and demonstration, it is felt the final product of this project could be easily adapted to other terminal and platform foci and more importantly to other industries (this will be discussed in the Conclusions)

3.3 SMAS Design

Design of the SMAS project focused on the above scope and objectives. The design phase of SMAS was the longest step in the overall project, and it is continually being refined. The design phase can be divided into three main areas: Development of the likelihood hierarchy for the assessment areas, Development of the consequence measurements protocol, and Development of the SMAS assessment process.

3.3.1 Likelihood Hierarchy

The first step in the design of SMAS was to develop the assessment hierarchy (i.e. a systematic way of approaching and capturing the different aspects of safety management and ensuring HOF aspects were included) for determining likelihood. Attempting to capitalize on the strengths of various existing methods like FLAIM and Tripod Delta, a three tiered hierarchy was developed for SMAS (Gale et.al., 1994)(Hudson et.al., 1994)(Bea, 1997b). The tiers (depicted in Figure 1) are defined below:

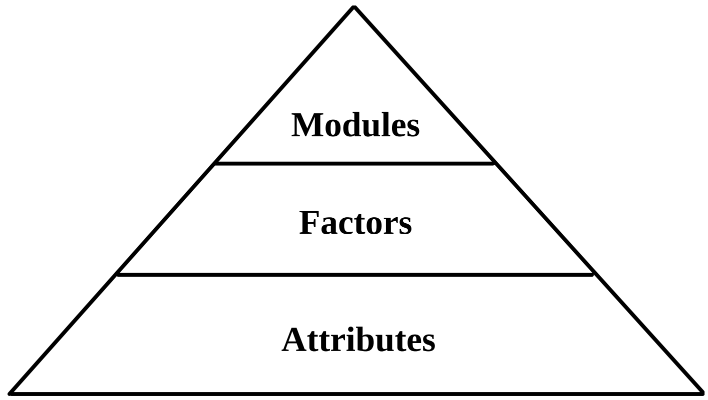

Figure 1: Likelihood Hierarchy

Modules: (Total of 7 in SMAS) Broad categories used to encompass safety aspects in the marine industry.

Factors: (Total of 53 in SMAS) Detailed areas falling under various modules. The average number of factors within a module is 8. In general, this is the level at which evaluating is conducted (i.e. "raw" data (third tier) scores are combined at this level for evaluation of likelihood and consequence to develop relative risk. More on this later).

Attributes: (Total of 140 in SMAS) Descriptive attributes which make-up the factor. Attributes vary from one to ten per factor. This is the level where actual scoring is accomplished (i.e. the raw data is collected).

3.3.1.1 SMAS Modules

With this as a basic framework, seven modules were defined as follows: (Figure 2 demonstrates the relationships between the seven modules.)

Structure: The marine terminal / offshore platform deck and supporting members

Equipment / Hardware: The mechanical items through which hydrocarbons flow (i.e. piping, pumps, loading arms)

Procedures: The operating and maintenance procedures

Environment: The external (weather) and internal (both climate control and social) conditions at the terminal

Operating Team: The group of personnel that operate the terminal (the human in HOF)

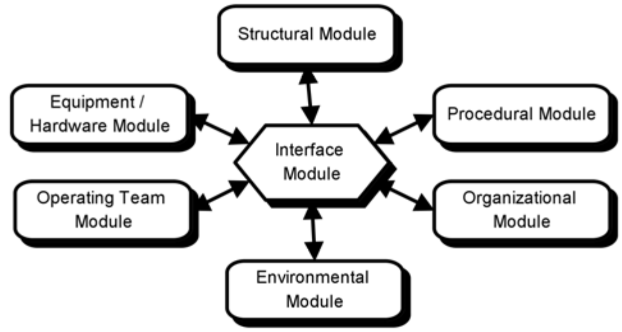

Figure 2: Seven Modules of SMAS

Organization: The company that owns the marine terminal and defines policy (the organization in HOF)

Interfaces: The interactions between the above six modules

3.3.1.2 SMAS Factors

After review of existing safety guidelines, assessment methods and a few brainstorming sessions, the following list of factors was developed for the first four modules and interfaces (Table 2).

Table 2: SMAS Modules and Factors List

Module	**Factor**
Structural	Berthing Capacity
	Live Weight Capacity
	Dead Weight Capacity
	Environmental Capacity
	Fire Load capacity
Equipment / Hardware	Pipe Capacity
	Pump Capacity
	Hose Capacity
	Loading Arm Capacity

	Fire Load Capacity (active and passive measures)
	Electrical
Procedures	Operating
	Maintenance
	Safe Work Practices
	Contractor Selection
	Pre-startup Review
	Emergency Response and Control
	Management of Change
Environmental	External (Weather, etc.)
	Internal (HVAC, Climate Control Systems)
	Social - External from: Society, Regulatory
	Social - Internal to: Organization, Operating Team
Interfaces	Structure - Equipment/Hardware
	Structure - Procedures
	Structure - Environment
	Structure - OpTeam
	Structure - Organization
	Equipment/Hardware - Procedures
	Equipment/Hardware - Environment
	Equipment/Hardware - OpTeam
	Equipment/Hardware - Organization
	Procedures - Environment
	Procedures - OpTeam
	Procedures - Organization
	Environment - OpTeam
	Environment - Organization
	OpTeam - Organization

3.3.1.3 Human and Organization Factors

In order to develop Human (Operating Team) and Organization factors a study of human and organization elements was conducted. Sources of human and organization factors were found in text books, study of high reliability organizations and various guidelines and regulations. Table 3 and Table 4 provide summaries of human and organization factors found in the literature. (Hee, 1997)

Table 3: Human (Operating Team) Factors

Factor	Definition
Communications	The ability of the individual to clearly transmit information to others and to clearly understand received information.
Selection and Training	The selection process by which the personality and individual characteristics are taken into account. The training of those individuals.
Education	The ability of the person to learn and understand information. The ability to counter ignorance.
Limitations and Impairment	Actual physical limitations and impairments due to a person's physical and emotional make-up.
Organizational (Planning & Preparation, Changes)	The ability of the individual to plan, to prepare, to be organized and to adjust to changes.
Experience (Mistakes, Slips, Violations)	The work experience of a person, and how the person uses this experience to avoid mistakes, slips, and violations.
External Environment	The harshness of the environment (external, internal, and social) in which the person is working.

Table 4: Organizational Factors

Factor	Definition
Process Auditing	The action of monitoring processes and when necessary, taking actions to correct deviations which lie outside of the established norms.
Culture	The cognitive framework consisting of attitudes, values, behavioral norms, and expectations shared by organization members. In High Reliability Organizations, this includes a high state of quality and an appropriate reward system **Mission/Vision:** The goal of the organization is accepted and wholeheartedly believed by all personnel.
Appropriate Risk Perception	The organization's acknowledgment of risks that are both known and unknown.
Emergency	The organization's plans to minimize risks, and plans to minimize

Preparedness	the severity of an incident by preparing plans to mitigate an incident. This also includes the drills and exercising of emergency plans.
Command and Control Functions	The organization's structure for making decisions. This includes migrating decision making, redundancy, rules, seeing the "big picture", requisite variety, and alert systems.
Training	The organization places emphasis on training which is indicated by the amount of money and time invested in training and how the people of the organization feel about the relevance of the training.
Communications	The ability of the organization to clearly and accurately transmit and receive information throughout the organization.
Resources	The ability of personnel on the front-line to receive resources quickly and in adequate quantities.
Equipment and System Maintenance	The organization places significant emphasis on the procurement, installation, construction and maintenance of equipment and systems. Quality equipment is installed and properly maintained. "Gerry rigging" is not allowed, and repair parts are quickly delivered.
Procedures	This topic covers all documentation required by regulatory agencies and any internal audits the organization has. Procedures are in place for safe work practices and regulation compliance. Procedures are involved in the documentation of work completed, certification of personnel and the reporting of accidents

The above tables were combined to develop the following eight operating team and organization factors: (Hee, 1997) (Note the first 7 are common to both Operating Team and Organization)

1. **Process Auditing:** A system of ongoing checks to spot expected as well as unexpected safety problems during a process (Libuser & Roberts).
2. **Safety Culture:** Attitudes, values, behavioral norms, and expectations toward safety shared by members (Weinfield & Tiggerman, 1990; Schein, 1985)
3. **Risk Perception:** Is risk perceived? Are appropriate strategies in place to mitigate risk? (Libuser & Roberts)
4. **Emergency Preparedness:** The written pre-planned actions and practiced rehearsal drills for possible oil spills.
5. **Command and Control:** How the organization is set up to make decisions.

6. Training: The program by which initial and continuing training is conducted to increase skill levels.

7. Communications: The formal and informal avenues for passing information.

8Org. Resources (Organization): The time and money invested in effectively implementing and conducting the above programs.

8OpT. Requisite Variety (Operating Team): Having a group of resource people with individual knowledge and experience to assist in making decisions and/or effecting action.

3.3.1.4 The Complete Hierarchy

The last step in developing the likelihood hierarchy involved identifying observable, measurable, or otherwise quantifiable attributes and the seven-point scoring scale (anchors) for these attributes. Once again research and brainstorming were used to develop the attribute list and anchor scales. Hee (1997) developed the final comprehensive list of the completed likelihood hierarchy. This list can be found in Appendix B.

3.3.2 Consequence Measurements

In order to determine risk, a consequence measurement methodology was developed. Consequences are linked to the definition of system failure, for SMAS this means a loss of product containment. Consequences of past "failures" involving loss of containment, can be loosely grouped into four consequence areas, (Spills, Injuries, Loss of Production, and Monetary Costs), which can be used to develop a method for measuring consequence. Table 5 defines each of these consequence areas and discusses the method of measurement used in SMAS.

Table 5: Consequence Areas

Consequence Area	Definition	Measurement Method
Spills	Any quantifiable release of product to the ground of water.	Barrels released
Injuries	Any reportable injuries occurring as a result of the failure.	Extent of Injury (subjective), Man-days lost
Production Downtime	Loss of production capability.	Time - (days, months, ...)
Monetary Costs	Clean-up, Regulatory and Environmental Penalties, Revenue Loss (due to negative politics, etc.)	Dollars

The SMAS Data Management Tool is designed to allow users of the system to define the measurement scales associated with each consequence area (See Section 3.4.3.4).

3.3.3 The SMAS Process

As envisioned and designed, the Safety Management Assessment System is based on a three phase process (Figure 3) (Bea, 1997b).

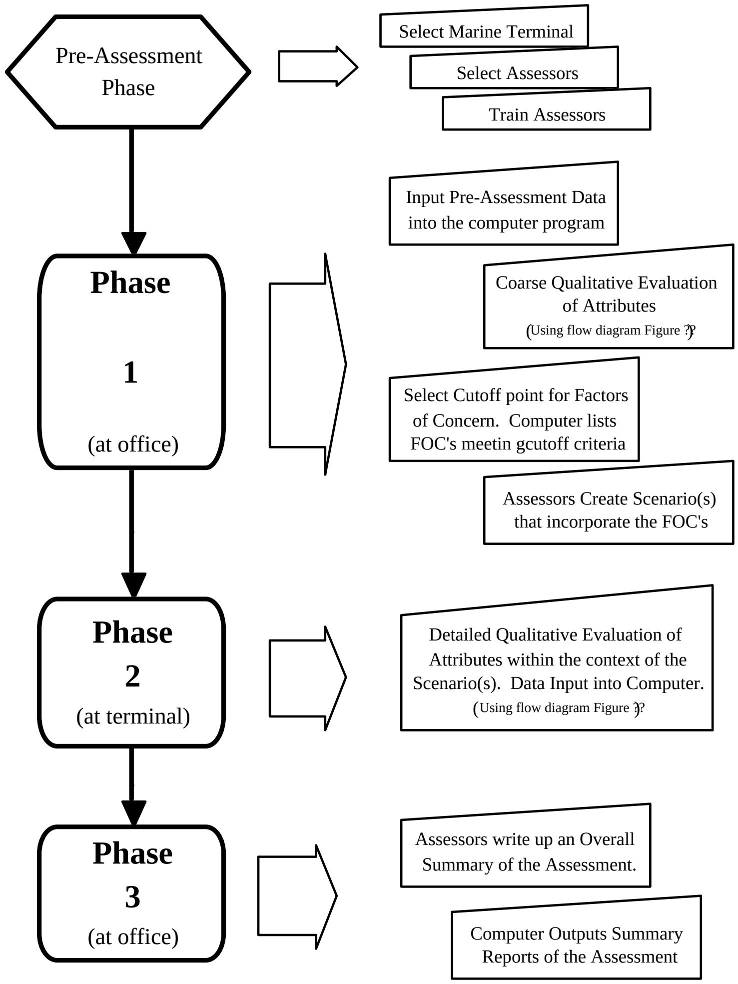

Figure 3: SMAS Process Flow Diagram

Specifically, SMAS has a pre-assessment phase and three distinct assessment phases. Briefly, the Pre-assessment phase involves the selection of an activity (marine terminal or platform) to assess, selection of the assessment team members, and training of the assessment team members.

3.3.3.1 Phase 1

Phase 1 of the assessment is the Coarse Qualitative assessment phase. The intent is to evaluate the activity on all attributes given activity documents, manuals, interviews, etc.. It is envisioned, this review / evaluation would be accomplished apart from the activity (i.e. in an office NOT at the terminal or platform). Coarse qualitative assessments are “big picture” assessments without the details associated with specific scenarios. After all attributes have been “scored” based on coarse qualitative data, the attribute datum are combined to produce factor “scores”. These scores are then used to determine “high” likelihood Factors of Concern (FOC’s). Note, by using this methodology, the term “high” is really defined as high relative to other factors. In this manner, no matter how good the activity is, the weakest areas are highlighted by the process. The last step in phase 1 is to create plausible accident scenario(s) given the FOC’s. The purpose of the scenario is to provide a framework (mindset) for the assessor to work from during phase 2.

3.3.3.2 Phase 2

Phase 2 is the Detailed Qualitative assessment phase. This phase is conducted in the field (at the terminal or on the platform). During Phase 2, the scenarios are used as a working base, to validate and expand on phase 1 research. This is accomplished via extensive formal and informal interviews of operating team personnel, visual inspection of the facility, physical observation of operations and maintenance actions and informal fact gathering sessions. The end result is that the assessors have a different perspective and broader working knowledge base from which to better evaluate the activity. Finally, the assessors again “score” the attributes capturing central tendencies and uncertainty and providing detailed comments where applicable.

3.3.3.3 Phase 3

The final phase is phase 3. Here a new list of Factors of Concern is developed based on the phase 2 data and suggested mitigation measures are provided by the assessment team. Finally, the assessors provide a final overall assessment summary and produce hardcopy reports of the assessment findings.

Section 3.4.2.1 provides a more detailed process flow diagram of the SMAS process as it relates and is linked to the computer data management tool.

3.4 Computer Platform

In order to develop a computer based assessment system, an appropriate software platform to be used had to be chosen. Based on previous experience and review of past models developed at U.C. Berkeley in this field, the initial software platform was going to be Microsoft's Excel® spreadsheet software using the Visual Basic® programming tools. However, as the elements of SMAS took form, it was decided to expand the platform search. The below minimum criteria was defined to aid in platform selection.

1. Universality - the platform, if not standalone, needed to be supported (driven) by widespread and commonly accepted software. (Off-the-shelf software was highly desired to facilitate future project enhancements.)
2. Programming difficulty - due to time limitations, extensive learning curve requirements were deemed prohibitive.
3. Analytical capabilities - there was no requirement to accomplish higher order mathematics.
4. Text features - needed ability to acquire and save large text fields (comments).
5. Cost - the cheaper the better

Given the above, several different systems were looked at including: MS Excel® w/ Visual Basic Macro Language, MS Visual Basic® (stand alone), Delphi® (similar to Visual Basic in nature), C++®, and MS Access®. Upon review of available data on the various platforms, it appeared MS Access®, with its built-in macro capability and relational database technology, best met the criteria. This was confirmed by a presentation of a MS Access® management system developed to track construction projects.

3.4.1 Program Framework

Once the initial Modules, Factors and Attributes were developed and the computer platform chosen, computer program development began. Using past experience and guidance found in the MS Access® manuals, the beginning framework for the computer program was developed. The program's basic framework is best summarized by this comment from early project notes:

> SMAS Database Structure: General Information: There will be two types of tables in the database, Information tables and Data tables. Information tables will contain general information and descriptions of components (modules), factors and attributes. Data tables will be built for each assessment and will be tailored to coarse and detailed qualitative data.

3.4.2 SMAS Data Management Tool Development

The major thrust of this work is wrapped up in the program code of the SMAS Data Management Tool. It would be impossible and a waste of the readers time to attempt to chronicle the programming effort put into SMAS. However, certain aspects bear mentioning and the few calculations performed by the program need to be described.

3.4.2.1 Data Management Tool Overview

The SMAS Data Management Tool is a completely menu driven system which works in the MS Access® operating environment. The underlying objectives of the program are listed in section 3.2.2. It is designed to facilitate the SMAS process described by section 3.3.3 and Figure 3. Appendix C provides a brief overview of how data input flows in the program (as compared to Figure 3). Figure C-1 covers Pre-assessment activities and Phase 1 work. Figure C-2 covers Phase 2 and 3 work and Figure C-3 details the attribute by attribute evaluation process (this process is transparent to the program user due to the menuing system).

The program User's Guide provides the most detailed description of how SMAS works and is therefore incorporated into this report, by appendix, in its entirety (Appendix D).

3.4.3 Key Aspects of the SMAS Data Management Tool

There are certain aspects of the data management tool which are not covered in detail in the user's guide, are unique programming challenges, or are specific analytical techniques which need to be explained. They include: Capturing Uncertainty, Mathematical Concepts, Triangular and Normal graphs, Consequence Measurement Scales,

3.4.3.1 Capturing Uncertainty

As discussed in section 2.4, a major weakness of current assessment methods is their inability to address uncertainty associated with evaluating attributes. In order to overcome this weakness, a “range” scoring method is used in SMAS. This method requires assessors to input three scores for each attribute. These scores represent the Best, Most Probable, and Worst likelihood or consequence for the attribute being evaluated. In general the scoring works as follows:

1 - The Most Probable score is the score which most closely indicates the true state of the attribute.

2 - The Best and Worst scores injdicate the best and worst possible scores associated with the attribute could be).

Using this methodology, the Most Probable score captures the central tendency of the attribute while the Best and Worst scores capture the uncertainty associated with the Most Probable score. See Section 5.4 of Appendix D for a more detailed description of how scores are entered into the SMAS Data Management Tool.

3.4.3.2 Mathematical Concepts

Mathematically, the challenge is to develop a mechanism to translate assessor assigned qualitative scores into a quantitative probabilistic distribution which can be used to determine the relative risk of failure.

The foremost basic assumption made during this project is that scores (best, most probable, worst) can be represented as a unit triangular distribution (Area = 1) where the values of the scores form the apex’s of the triangle. In order to best understand this concept, the following example is provided:

An assessor's evaluation of 2 - 4 - 5 (Best - Most Probable - Worst) can be represented as a triangle with apex's at A(2,0) - B(4,0.67) - C(5,0) and an Area = 1 (Figure 4).

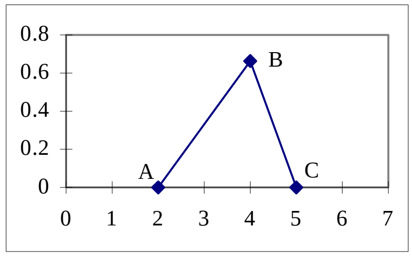

Figure 4: Sample Triangular Distribution

Using the above representation, the mean and standard deviation for the distribution can be determined using the Algebra of Normal Functions:

Mean (Z) is defined by:

$$\textit{(Equation 1)} \quad \overline{Z} = [A + B + C]/3$$

Standard Deviation (σ) is defined by:

$$\textit{(Equation 2)} \quad \sigma = \sqrt{\{A^2 + B^2 + C^2 - AB - AC - BC\}/18}$$

(Where A, B, and C are the X values of the triangle's apex's for a Unit Triangle)

Therefore, for the above triangle, Z = 3.67 and $\sigma = 0.62$

Continuing the use of the Algebra of Normal Functions, two triangular distributions can be multiplied together to determine their product as follows:

Given Triangle A with Za and σa and Triangle B with Zb and σb, their product would be:

Mean (*Zp*) is defined by:

$$\text{(Equation 3)}\quad Zp = \{Za * Zb\}$$

Standard Deviation (σp) is defined by:

$$\text{(Equation 4)}\quad \sigma p = \sqrt{\{Za^2 * \sigma b^2 + Zb^2 * \sigma a^2 + \sigma a^2 * \sigma b^2\}}$$

Therefore, given the sample triangle in Figure 4 with Za = 3.67 and σa = 0.62 and another triangle with Zb = 5.25 and σb = 0.48, the product of these two triangles would be: *Zp = 19.27; and* σp *= 3.71*.

Equations (1-4) form the basis for all mathematical computing in the SMAS project. In order to accomplish this, Equations (1-4) were developed into Access® functions within the data management tool code and used extensively in conjunction with arithmetic averaging to develop the likelihood, consequence, and relative risk calculations and data displays which are at the heart of the data management tool.

3.4.3.3 Triangular and Normal Graphs

Using Figure 4 as an example triangular distribution, the vertical component of point B can be determined by setting the area of the triangle to one (a unit triangle). This approach is easily accommodated by typical spreadsheet programs such as Microsoft Excel®. However, Access® does not have the capability of linking both X and Y data to a graph, therefore the ability to create and display triangular and normal graphs with variable X,Y combinations is not possible.

Upon review of the over-riding purpose of these graphs, it was determined the vertical component of the graphs was not a key issue. The two most important pieces of information the graphs convey is the central tendency (most probable) of the data (score) and the associated uncertainty (best and worst) of that score. Therefore, the triangular and normal graphs generated by the data management tool do not represent “unit” areas. Rather, the vertical components for each “apex” is fixed (at 0 for the extremes and 50 at the most probable) in the computer tool. In order to eliminate confusion, the vertical scales have been eliminated from the graphs produced in the data management tool. Since the goal is knowledge of central tendency (where the mean falls on the 1-7 scale) and uncertainty (how narrow or wide the triangle is), this “artificial normalizing” of vertical components is reasonable and does not introduce error into the process.

This works for the triangular distributions, however, when relative risk calculations are made the fixed three point triangle is lost and purely defined by a mean and standard deviation value for the risk. A similar “artificial normalizing” technique can be used to create a “normal” graph which indicates varying degrees of uncertainty in the calculated risk. The difference between the triangular and normal distributions is in selection of the X-coordinates. For the normal distributions, the X-coordinates on either side of the mean are functions of the calculated standard deviation.

While the above “fixes” work for the accomplishment of the project goals, the limitations of Access® in this area are considered a weakness in the program which will be discussed in the recommendations section of this report.

3.4.3.4 Consequence Measure Scales

Section 5.3.2 of Appendix D discusses the defining of Anchor scales for the consequence areas (Section 3.3.2). In order to maintain flexibility in the system (one of the goals for the computer program, Section 3.2.2), the system had to be able to accommodate different anchor scales for different activities (i.e. marine terminals, offshore platforms). In order to accomplish this, the data management tool has assessors document two key types of information. The first piece of information is the various influencing information which impacts the score levels for differing sites. The following example is provided to clarify influencing information:

Suppose Terminals A and B are both located in San Francisco Bay. Terminal A is located very near to two highly sensitive environmental areas which depending on tide, can be severely damaged in the event of a release of product. Terminal B, on the other hand, is located in an area where the nearest environmental sensitive area is over 5 miles away. For these terminals, environmental issues clearly influence how consequences are measured.

In the SMAS Data Management Tool, there are three defined types of information which can have significant impact on consequences and an "Other" catch all area: (Table 6)

Table 6: Consequence Influence Factors

Consequence Influence Factor	Information Description
Environmental Factors	Includes: weather patterns, currents, tides, wave action, wildlife habitats, fauna habitats, etc.
Political Factors	Includes: community relations, activist groups, past media attention, electoral climate (presidential election year ...), etc.
Regulatory Factors	Includes: relations with regulatory agencies, etc.
Other Factors	Includes: cost of doing business, cost of clean-up support services, general population interest, etc.

This consequence influence information is meant to provide background "justification" for the setting of anchor scales, the second key element of information assessors must document. In the data management tool, assessors are given opportunity to set the range of consequence anchors. Range refers to the best and worst possible outcomes of a system failure (loss of containment) and how the range is divided into a seven point scale. For example, a best score for injuries might be no injuries, a worst score multiple deaths, and a median score multiple minor injuries. If the assessors feel an anchor scale is not applicable to an activity, the related anchor scales can be left blank without impact to the program.

To see how this works, the reader should review Appendix D and experiment with the program.

3.4.4 Computer Program Summary

Section 8 of this report contains the program disks developed under this project. Appendix D, the User's Guide, provides detailed instructions on how to install and use the program.

4. Testing and Evaluation

As with any system development, a crucial element to the development is to validate the quality (Serviceability, Safety, Compatibility, and Durability) of the system. For purposes of system testing, the quality components are defined below:

* **Serviceability:** Can the system be used for its intended purpose?
* **Safety (Risk):** Does the system produce erroneous results?
* **Compatibility:** Does the system meet the original specified goals?
* **Durability:** Is the system designed in such a way that it can be continually improved to better support what it was designed for? Can the system be adapted to uses other than what was originally intended?

SMAS testing occurred in three phases. First, each component was tested by the developer during development to verify serviceability and safety (this is a continuous type of testing). Second, the system was used to conduct a Table-Top assessment by the SMAS project team. The primary purpose of the table-top assessment was to validate the system serviceability and safety prior to going to the field. The third test was field testing. Here the system was tested by people other than the SMAS project team to verify all quality aspects of the system. Each of these tests is discussed below.

4.1 Developer Testing

As mentioned above, developer testing was performed throughout system development up to the day this report and the initial release (ver. 1.0) were submitted. The objective of developer testing was to validate the system macros functioned properly. Developer testing was accomplished by attempting to exercise the system through all conditions which might occur when in use by a system user. This first level of testing is good for catching fatal errors and making sure connections appear to work. However, the knowledge of how the system was developed, and therefore how it "should" work, results in biases and filters during testing and consequently, system flaws go undetected.

4.2 Table-top Assessment

The table-top assessment was designed to test the total system prior to going to the field. This test was conducted by the SMAS project team with help from a local regulatory agency. The purpose was to systematically test the program as it was envisioned to work. During the table-top assessment, numerous system shortcomings were identified. A partial list of these shortcomings and their fixes is listed below:

Table 7: Table-Top Assessment Program Problems / Fixes

Identified Problem	**Fix**
No ability to transfer data from computer to computer without transferring the entire program.	Created data import / export functions to allow for transfer of data between systems.
Lack of a listing of required data types slowed data input.	Created data collection forms in the reports area of the system. (One weakness with this is the detailed attribute data collection forms total approximately 90 pages.)
If there were no changes to a particular attribute between phase 1 and 2, the ability to import phase 1 comments to phase 2 would save time.	Created comment import option on the phase 2 data collection form.

4.3 Field Testing

Field testing was conducted with the aid of a local marine terminal. This phase of testing had a two-fold purpose: One, to test the SMAS process and Human and Organization Factors; Two, to test the Data Management Tool. The validation of selected Human and Organization factors was conducted and will be reported by Hee.

The field test was extremely helpful in validating the quality of the data management tool and provided useful information to improve the system. Table 8 is a summary of system problems, fixes, and improvements which were identified through, and subsequent to, the field test.

Table 8: Field Test Recommendations and Improvements

Recommendation / Improvement	Fix / Action
The assessors felt the phase 1 scores should be automatically loaded into phase 2 and then they could simply modify them	In order to prevent simple acceptance of phase 1 scores after detailed data gathering, it did not seem reasonable to import the phase 1 scores automatically into phase 2. However, the phase 1 scores were added as information fields to the phase 2 data input form for reference. The assessors agreed this was probably best.
If the Pre-assessment Initialization process is not completed, there was no provision to create the required blank data records to allow phase 1 and 2 data input without initializing a new assessment. This resulted in numerous erroneous assessments.	A Data Initialization option was added to the menu options to correct this situation.
A phase 2 note taking form was suggested to help assessors maintain focus on developed scenarios.	Developed a phase 2 note taking form which lists the scenarios and provides space for notes in each module / factor area.
An error in the import / export utilities was discovered.	This was corrected.
The need for various utilities was surfaced.	The following utilities have been added to the system since the field test: Company and Assessor Delete Utilities Module, Factor, Attribute, Anchor Utilities for adding and editing these elements
Module Summary reports with uncertainty ranges were identified as skewed based on extremes.	Added additional uncertainty bars to these reports to show plus and minus one standard deviation from the central tendency.

5. Conclusions and Recommendations

5.1 Conclusions

The intent of the SMAS project is to aid in the safety assessment of marine systems. The process focuses on Human and Organizational Factors that are critical to the safety of marine terminal and offshore platform facilities. The focus of this portion of the SMAS project is the development of a computer application which drives and is driven by the SMAS process. This application, the SMAS Data Management Tool, was developed and tested and is ready for initial release for follow-on testing by different organizations. It is felt the objectives and goals identified for the data management tool have been accomplished and the resulting program offers a unique, user friendly, medium for assessing safety management systems of marine facilities.

5.2 Recommendations

As with any development, the final report marks the beginning of improvements and future work. The SMAS Data Management Tool is only as good as it is useful to those who can see and derive benefit from its intended use. Therefore, it is envisioned the SMAS process and subsequently the data management tool will continue to evolve with advances in technology and our understanding of the Human and Organizational aspects of engineered systems. The following list of recommendations is provided as suggestions for follow-on development of the SMAS Data Management Tool:

1. The current system is almost constructed entirely of MS Access® macros. An investigation into the possible benefits of converting the macros into Access Basic® might prove beneficial and result in more efficient operation of the system.

2. Not withstanding the above, another investigation into developing this system as a standalone program (developed with C++®, Delphi, or another programming tool) could also result in a more efficient system. However, this also defeats one of this projects goals of having a system which can be easily modified with off-the-shelf software.

3. The following program changes should be developed and tested to increase system flexibility: Add capability to delete Modules, Factors, Attributes, and Anchor Scales (this was omitted to preserve the integrity of supporting the SMAS project process), Password protect access to the database window to prevent accidental modification to program code, Develop a better relational link between the assessors and assessment tables.

4. Investigate better methods of developing the triangular and normal graphs for display of data. The current method meets the project objectives, however, there is probably a more efficient method of achieving this goal by developing another work-around for the Access® and Microsoft Graph® limitations.

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7. Appendices

The following appendices are provided to enhance this report.

7.1 Appendix A - Background Summary of Assessment Methods

The following pages present a comprehensive summary of different HOF assessment methods currently in use.

7.2 *Appendix B - SMAS Likelihood Hierarchy of Definitions*

The following pages present a comprehensive summary of the Modules, Factors, Attributes and Anchors developed for the SMAS project.

7.3 *Appendix C - SMAS Computer data Input Flow Diagrams*

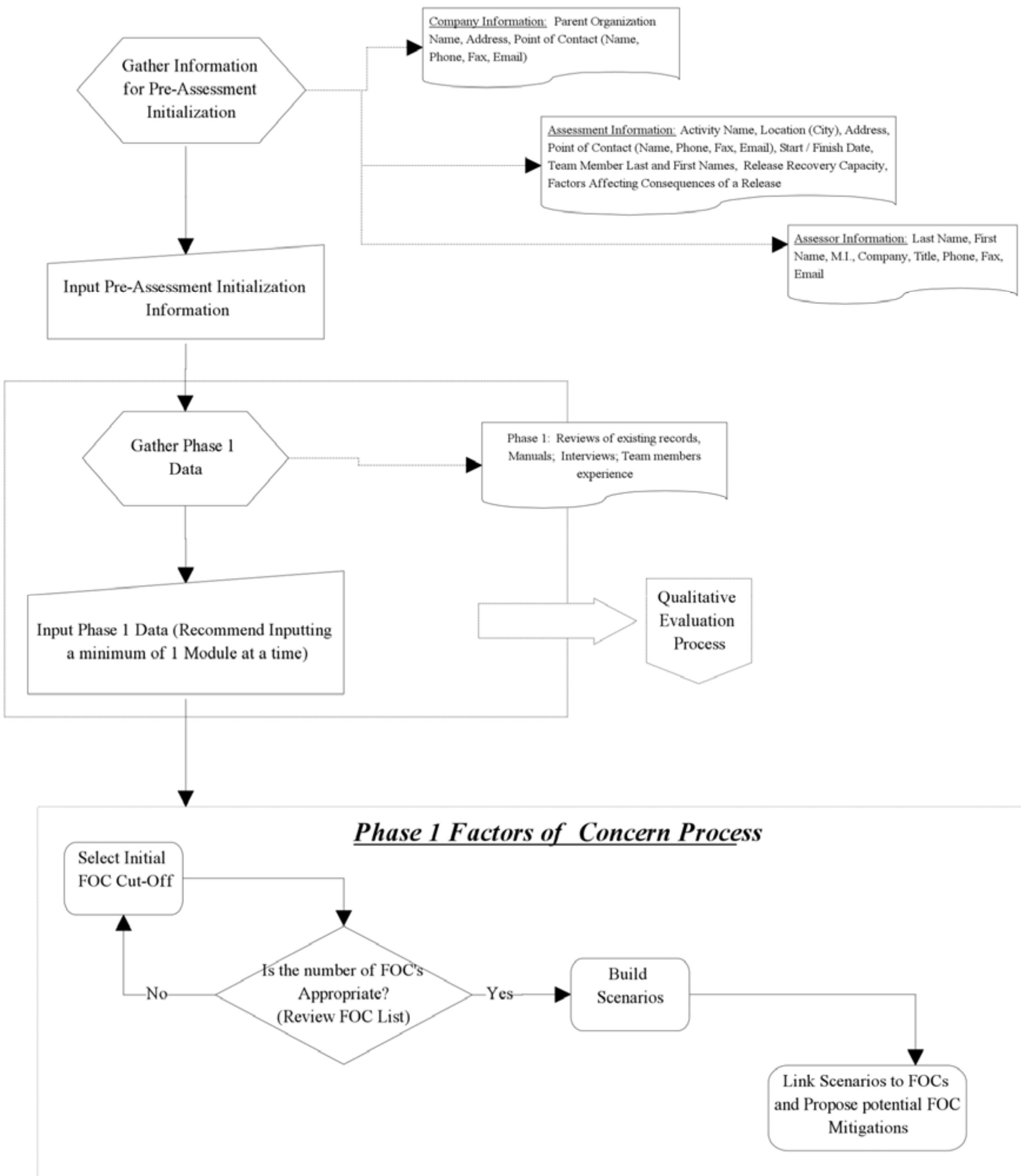

Figure C-1 - SMAS Data Management Tool Process Diagram (Pre-Assessment & Phase 1)

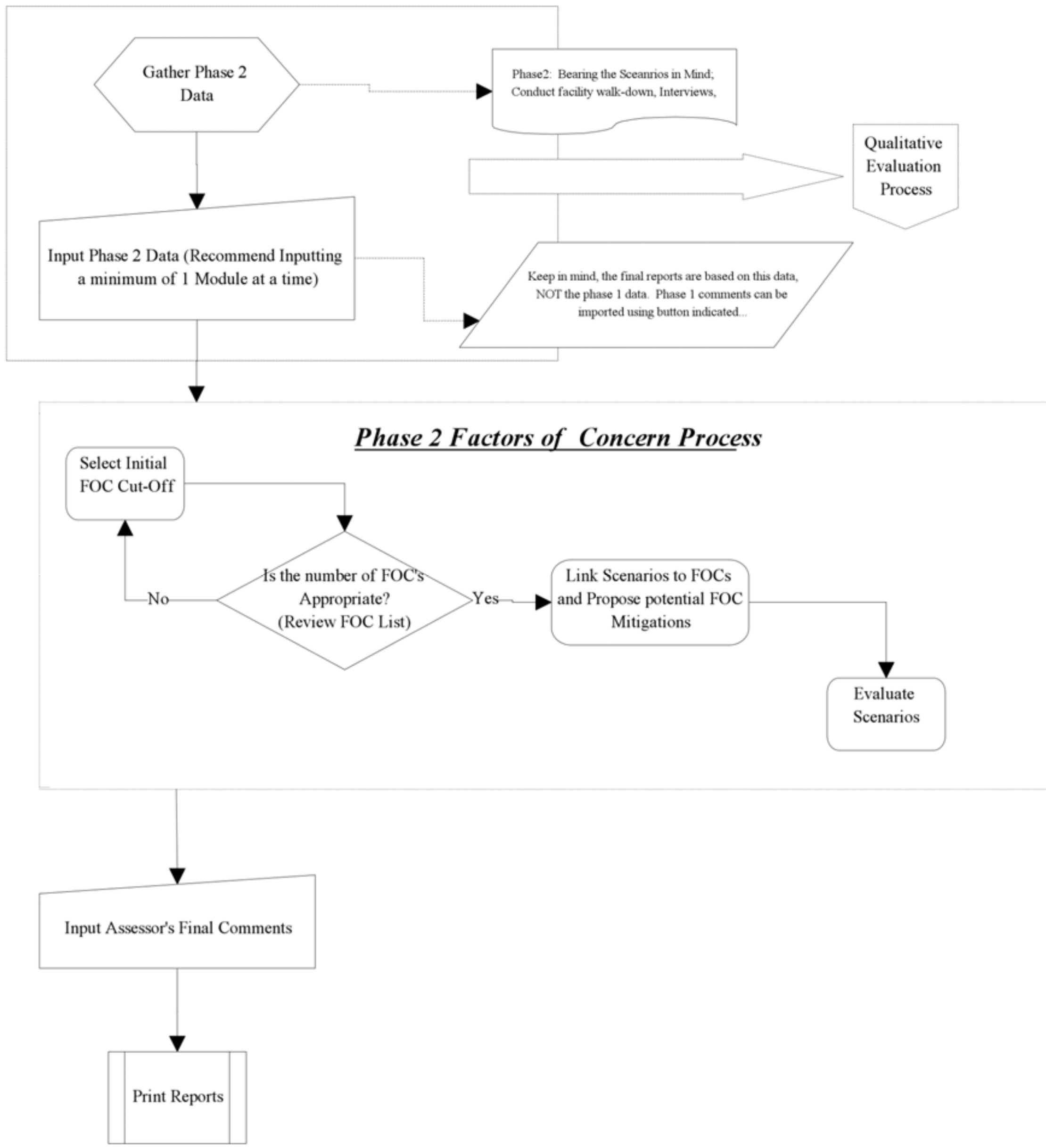

Figure C-2 - SMAS Data Management Tool Process Diagram (Phases 2 & 3)

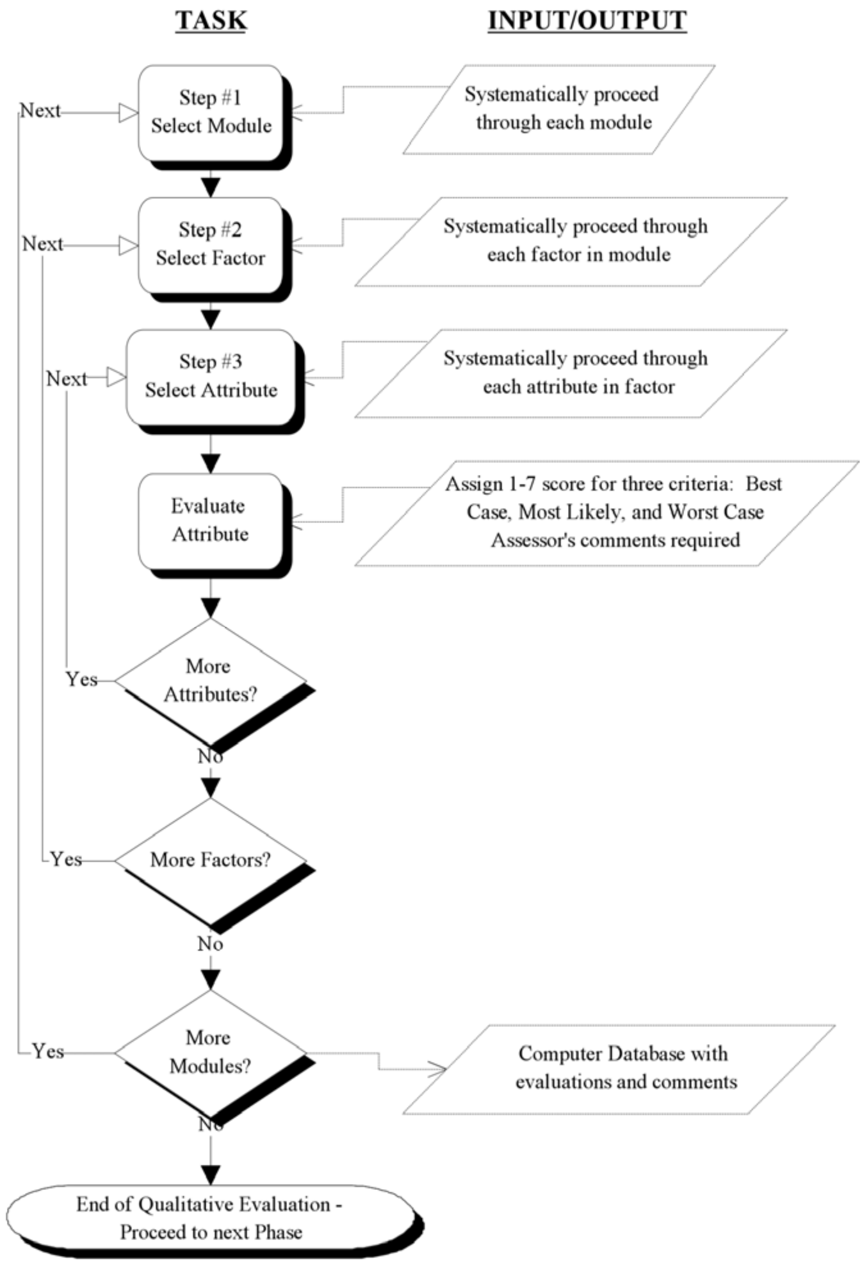

Figure C-3 - SMAS Data Management Tool Qualitative Evaluation Process

7.4 ***Appendix D - SMAS Data Management tool User's Guide***

The following appendix is the complete user's guide for the SMAS Data Management Tool.

8. SMAS Data Management Tool Program and Data Transfer Disks