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Wave Energy Systems: Methods for Assessing Risk to Personnel Including Task Analysis

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16. Abstract

This report (1) highlights several key documents for identifying the processes to assess the risks to personnel constructing, deploying, operating, and maintaining wave energy systems and (2) describes how task analysis can be applied for that purpose.

To learn about safety assessment processes for this application, start with the ABS Job Safety Analysis Guidance Notes. Other useful documents include: (1) the ABS Guide for Marine Health and Safety, (2) the ABS *Guidance Notes on the Investigation of Marine Incidents*, (3) The ABS *Guidance Notes on the Application of Ergonomics to Marine Systems*, and (4) the *ABS Guide for Marine Health, Safety, Quality, Environmental and Energy Management*.

For those interested in a conducting a task analysis, start with (1) the previously mentioned ABS Job Safety Analysis document, (2) ISO 31000 (Risk Management Guidelines), or (3) ISO 31010 (Risk Management Assessment Techniques). As an alternative to the methods in these documents, the author suggests using the goal-task analysis method popular in studies of human-computer interaction. In a traditional task analysis, the focus is on the actions. (Step 1: Turn off the power to the circuit at the main panel. Step 2: Check the power is off with a noncontact voltage tester.) That approach ignores much of the thinking the user needs to do to accomplish a task and misses instances where risk can occur. (Goal: Turn off the power to the circuit in question. Goal: Find the circuit number. Is there a label on the panel? If not, does the worker guess? Is the label correct/current?)

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CONTEXT OF THIS REPORT

This is the final report in a series of reports created to contribute to the ABS technical report titled *Establishing System and Personnel Safety Recommendations / Guidance for Marine Energy Technology (MET) (McSweeney, Wang, Mantooth, Lou, and Green, 2025)*. The other reports of this series include *Wave Energy Systems: Context and Types to Identify Safety* (Green, Wasi, Miller, and Capderou, 2025) and *Wave Energy Systems: Standards for Personal Safety and Safety Management* (Green, Wasi, Miller, and Capderou, 2025).

The goals of this third report are to:

(1) highlight several key documents for identifying the processes to assess the risks to personnel constructing, deploying, operating, and maintaining wave energy systems and
(2) describe how task analysis can be used for that purpose.

The research produced in these 3 reports by the University of Michigan Transportation Research Institute (UMTRI) were supported by a subcontract from the American Bureau of Shipping (ABS). The ABS contract was funded by the Ocean Energy Safety Institute (OESI). The OESI is a consortium of industry, national labs, non-governmental organizations, and academia developing the technology and workforce needed for energy production that is safer, more sustainable, and more cost-effective. OESI is supported by an agreement between the Texas A&M Engineering Experiment Station, the U.S. Department of the Interior's Bureau of Safety and Environmental Enforcement, and the U.S. Department of Energy.

KEY DOCUMENTS CONCERNING IMPLEMENTING SAFETY PROCESSES RELEVANT TO MARINE ENERGY SYSTEMS

These documents were identified based on discussions with ABS and the author's search of the literature. There are many publications on the topic of safety management systems, so to avoid scope creep the focus was on publications relevant to the offshore oil and gas industry and other related energy production industries.

The ABS Job Safety Analysis Guidance Notes provide an excellent description of this process (American Bureau of Shipping, 2014).

For novices, the author strongly suggests those interested in reading about this topic start with *ABS Job Safety Notes*. These Notes describe a 6-step process with a detailed example. These Notes are easy to follow and name other documents related to safety practices that are important to the oil and gas industry. Particularly useful are the hazard checklists and other tables described in the Notes. In fact, for some applications, that document could be more useful than this section. What the Job Safety Guidance Notes do not do (and were not intended to do) is cover some of the ways in which human error can occur or link to ISO and other standards that are relevant to this topic. Had that information been included, the Job Analysis Guidance Notes would have been unwieldy for their intended purpose.

If this topic is one of risk assessment, then a key document is ABS Guide for Marine Health and Safety (American Bureau of Shipping, 2020).

The *Guide for Marine Health and Safety* is a higher-level document that identifies the issues in planning, implementing, evaluating, and improving a program for not only safety and health, but also for quality and energy management. It provides a model for implementation of an Integrated Management System covering these key issues and links to relevant ISO standards. In contrast to the *Job Safety Guidance*, it does not provide examples. However, the audience for this report is encouraged to read that document as it contains useful guidance.

For additional information relating to topic, there are 3 highly relevant ABS documents.

They are:

1. The ABS *Guidance Notes on the Investigation of Marine Incidents* (American Bureau of Shipping, 2014)
2. The ABS *Guidance Notes on the Application of Ergonomics to Marine Systems* (American Bureau of Shipping, 2018),
3. The *ABS Guide for Marine Health, Safety, Quality, Environmental and Energy Management* (American Bureau of Shipping, 2020).

HOW COULD A TASK ANALYSIS BE CONDUCTED?

There are multiple ways to conduct risk/safety analyses.

Although this report identifies many existing standards and guidelines that are applicable to the design of safe wave energy converters, there are important differences with offshore oil and gas applications on which those existing standards and guidelines are based. Therefore, this section describes a general method by which human factors and ergonomics considerations for safety and health can be identified. There is nothing unique or new about what is presented here. However, this audience is unlikely to have formal education or training in human factors engineering/ergonomics and safety engineering, so presenting it is important.

There are many documents that concern the steps in create an analysis to what is relevant here, which in various places has been called task analysis, risk analysis, hazard analysis, or other names. The underlying goal is the same – to identify what a person does (or did) and determine how the risks can be reduced to a level at which the risk to safety and health is minimal (or acceptable/some other criteria). The application of primary interest is the construction and maintenance of wave energy systems.

Of the many documents that describe the process of interest, 3 are highlighted (Table 1): the ABS 5-step process, the ISO 31000 3-step process, and the ISO 31010 6-step process, which is a reformatting of the process in ISO 31000 from which it was derived.

Table 1. Examples of Risk/Safety Analysis Methods

ABS Job Safety Analysis for the Marine and Offshore Industries		**ISO 31000 (Risk Management – Guidelines)**		**ISO 31010 (Risk Management – Risk Assessment Techniques)**
American Bureau of Shipping 2013		International Standards Organization, 2018		International Standards Organization, 2019
1. Define the job 2. List the job steps 3. Identify the hazards associated with each step 4. Identify the control measures for each hazard 5. Rank the hazards (identify additional risk controls, re-rank with them) 6. Validate the controls		1. Establish scope / context / criteria, and define: * scope, * external & internal context (e.g., org. factors) * risk criteria 2. Assess risk * identify causes, threats, impact, time factors, etc., * analyze likelihood, control effectiveness, etc. * evaluate options		1. Plan the assessment (scope, context, review criteria) 2. Manage info & develop models (collect and analyze info, develop models) 3. Apply risk assessment methods (identify risk sources and causes, examine controls) 4. Review the analysis (sensitivity analysis)

		3. Execute treatment option * select options * prepare, implement plan * monitor & review plan * record & report		5. Apply results to support decisions 6. Record and report outcomes

This section builds upon the ABS framework, incorporating ideas from the ISO standards, and recognizing the issue could be an entire context (such as working in a confined space) rather than just a specific task (removing a cooling fan). The steps are:

1. Gather information about the task and context
2. List the task/job steps
3. Using a specified analysis method, identify the risks
4. Rank the risks/hazards
5. Identify solutions
6. Report and validate solutions.

Step 1: Gather information about the task and context

One can have confidence in the background material if it is collected in an organized manner, such as a use case. There are 2 key references for that purpose, IEC 62559 (Use Case Methodology) and ISO/IEC 25063 (Context of Use Description). IEC 62559 has 4 parts:

1. Part 1 (Concepts and Processes) (International Standards Organization, 2019) gives example of a use case and XML expression.
2. Part 2 (Use Case Templates) provides information on use cases, the actors list and the requirements list (International Standards Organization, 2015).
3. Part 3 (XML) provides further detail about representing the use case in XML.
4. Part 4 (Best Practices) provides some useful examples on the application of 62559.

Although extremely complete and the XML provides a useful structure, completing the IEC 62559 documentation is burdensome and, and sometimes, beyond what is needed.

An alternative to 62559 is ISO 25063 (Context of Use Description, International Standards Organization, 2014). The context of a use description is a more limited term than a use case. ISO 25063 defines context of use as “users, tasks, equipment (hardware, software and materials), and the physical and social environments in which a system, product or service is used” (definition 3.2). Thus, the key categories are (1) the subject of the description (its purpose and preconditions), (2) who the users are and associated constraints, (3) the tasks including the likelihood of accomplishment, (4) the goals to be accomplished, (5) the method by which each goal is achieved, and (6) the environment in which the task is to be accomplished. That document has considerable detail about each category. Table 2 provides insights as to how these topics are covered in ISO 25063, which organizes them in a slightly different manner.

Table 2. Context of Use

Category	Example Topics
Preconditions and constraints	Legal, budget, access to users, confidentiality
User population	Directly and indirectly involved, psychological and social characteristics (cognitive, language, literacy, cultural conventions), task related (knowledge and skills, motivation), social and organizational (resistance to change, organizational structure) , physical and sensory characteristics (body dimensions, biomechanical capabilities, haptic capabilities, visual and auditory capabilities, handedness, demographics
Goals of the user group and the organization	Task times, efficiency, design guidelines, organizational policy, security issues
Tasks of users	Attributes (goal, outcome, frequency, and importance of tasks), input variability, task duration, task complexity, task dependence, task load, human-technology allocation
Task representation	Workflow, task sequences, procedures, scenarios
Environment - technical	Tools, equipment, materials, hardware configuration, input devices, connectivity, assistive technology, personal protective equipment, documentation
Environment – social / organizational	Group dynamics, leadership, time pressure and constraints, interruptions, supervisory practice, monitoring, legal constraints, other responsibilities
Environment - physical	Space, workplace characteristics, lighting, temperature, noise, crowding, vibration

This scheme makes sense for this application, although readers could find following the ABS Jobs Safety Analysis Guidance Notes easier to apply because the Guidance Notes contain a worked-out example for each step. For other information on this process see De Merich et al. (2022) and Badri et al. (2012).

Step 2: List the task/job steps

There are 2 ways to do this step. The first, which is often easiest for those inexperienced in task analysis, is to list the actions (primarily the physical parts). To help the reader understand what is intended, the task of replacing light switch at home is given as an example. This task is simple and should be familiar to many readers.

(1) Turn off the power to the circuit at the main panel
(2) Check the power is off with a noncontact voltage tester
(3) Remove the cover plate
(4) Disconnect the faulty switch
(5) Connect the new switch
(6) Reinstall the cover plate
(7) Turn the power back on
(8) Verify the light switch now works

The drawback of this actions-only approach is that steps that involve thinking and planning are often omitted or ignored, many of which are associated with safety. An approach that includes those steps, popular in human-computer interaction, is a goal-task analysis. The essence of this approach is that one first identifies what is to be achieved at each step (the goal or goals) followed by the method with which each goal is achieved. Following is the same light switch example in the form of pseudocode, now including the goals and the methods. Note that in goal-task analysis, goals can have subgoals and even sub-sub-goals. Indenting is used as in programming to reveal the hierarchy of goals and methods.

Goal: Plan the task
    Goal: Identify the tools and materials needed for this repair
     ** Say how the worker would realize they need certain tools or a kit, a switch,
     insulated gloves, work light, etc. **
    Goal: Obtain the tools and materials needed
     ** Say how that would be done **
    Goal: Plan other steps including now to do this safely
     ** Example: find out where the electrical panel is **
Goal: Turn off the power to the circuit in question
    Goal: Find the circuit number or ID
     ** This could involve a label on the breaker box, an electrical plan to be obtained,
      a label on the switch plate or via another method. **
    Goal: Verify shutting off that circuit does not have unintended consequences
      ** E.g., shutting off someone's heart pump in an adjacent room **
    Goal: Shut off the power and verify there are not unintended consequences
     ** Listen for someone to complain, check for other signs that something is not
      working, or label / tape over the breaker so that someone else does not turn it on. **
Goal: Get to the failed switch
    ** Say how **
Goal: Prepare to remove the switch
    ** This can include placing a toolkit somewhere and opening it, turning on some
     work lights, etc. **
Goal: Verify the desired circuit is off
    Check the power is off with a noncontact circuit tester
    ** If the power to the desired circuit is not off, then find the desired circuit **
Goal: Remove the cover plate

** This includes finding the desired tool which could be a power screwdriver or a small slotted head screwdriver **

** Put the parts somewhere where they will not get lost or damaged. *Note: If one decides to put them in a sink, make sure the drain is closed so the small screws do not go down the drain* **

Goal: Remove the switch and verify it is faulty

Using a screwdriver for Phillips/slotted combination screws, remove the top and bottom screws holding the switch in place

Pull out the switch

Unscrew the black, white, and finally the ground connections using a screwdriver

Using an ohm meter, check that the switch is indeed faulty

(If this is not the case, then there many other steps)

This should be enough to give the reader a sense of how including goals make the analysis much more complex, but the process of including goals makes it more likely that all steps are included, and safety checks are not omitted.

Step 3: Using a specified analysis method, identify the risks.

Sources of risk data (deaths, injuries, property damage)

The risks can be determined from historical data, analysis, or using both sources. For jobs, the primary historical indicators risk are the death and injury data. *Where is relevant data?* For wave energy converters, death and injury data collection and dissemination is the responsibility of the Department of the Interior, specifically the Bureau of Offshore Energy Management (BOEM) and the Bureau of Safe and Environmental Enforcement (BSEE). Operating in parallel with these 2 organizations is the Office of Natural Resources Revenue. Details follow about the first 2 organizations collect risk-related information and how.

The *Bureau of Ocean Energy Management* investigates serious incidents as defined in Series: 27-Safety Management (Part 485 Safety and Occupational Health Program, Chapter 7: Incident/Accident Reporting/Serious Accident Investigation) as a work-related accident which results in:

"(1) One or more job-related fatalities or imminently fatal injuries or illnesses to employees, volunteers, contractors, or the public,
(2) The in-patient hospitalization of three or more employees, volunteers, or members of the public due to departmental operations, or
(3) Amputation(s) or loss of an eye(s), or
(4) Property damage (including site mitigation or cleanup) or operating loss of $500,000 or more, or
(6) Accident, illness, or incident that a Bureau Designated Agency Safety and Health Official judges to warrant further investigation using the serious accident investigation procedures."

BOEM produces 2 types of reports for these incidents, (1) Panel Reports (for deaths, https://www.bsee.gov/what-we-do/incident-investigations/offshore-incident-investigations/panel-investigation-reports) and (2) District Reports (for serious injuries, https://www.bsee.gov/what-we-do/incident-investigations/offshore-incident-investigations/district-investigation-reports). The status of their investigations can be found at https://www.data.boem.gov/Other/DataTables/IncidentInvestigations.aspx. Each entry lists the date and time of the incident, the lease number and area/block, the incident type and status information. The incident description is quite brief (e.g., "Shutdown from Gas Release - Required Muster;" "Fire - Incident >$25K"). In 2024, there were about 30 incidents reported. Once an investigation is completed, a downloadable report is posted on the website, depending on what type of incident it was. Reports contain 350-600 words describing the investigation finding, plus added text for the probable cause(s) and the contributing cause(s).
These reports are clearly useful in general. However, their value for wave energy devices is unknown because they don't cover manufacturing and because of operation and maintenance of wave energy converters appears to involve hazards that are different from offshore oil and gas (e.g., no fires or explosions). Should such data prove to be useful, data from multiple years must be aggregated to provide sufficient statistical power.

Another potential source is the *Bureau of Safe and Environmental Enforcement* offshore incident statistics (https://www.bsee.gov/stats-facts/offshore-incident-statistics). As an example, their database lists 943 incidents for 2023, the most recent information available. That database has information for about 40 items for each incident, many of which are not relevant to wave energy converters (e.g., loss of well control diverter, drilling, pipeline). Interestingly, there is a column labeled "human error." Given the difference in the source of hazards and given the absence of a narrative, it is uncertain how useful this data will be for the application of interest, even if wave energy devices become more numerous.

As alternative source to BSEE and BOEM data is *historical data for the industry of interest*. As the wave energy converter industry is young, there will be little direct historical data. However, one could examine overall data from companies that have the same Standard Industrial Classification (SIC) code, such as 3490 (miscellaneous fabricated metal products), or 3559 (special industry machinery, NEC). See https://www.sec.gov/search-filings/standard-industrial-classification-sic-code-list. Another alternative is to use a relevant NAICS (North American Industry Classification System) code (https://www.census.gov/naics/). The data for NAICS code for Oil and gas field machinery and equipment manufacturing (333132) could be examined, but it pertains to much larger equipment. The accountants for wave energy converter manufacturers should be able to provide the relevant code from tax forms. This approach assumes that there is consensus within the industry as to what the appropriate code is, and that the industry category is sufficiently homogenous that the injury patterns are consistent across companies.

If there is consistency across companies within an industry, then the industry-specific injury data from the Bureau of Labor (BLS) statistics injury tables (https://www.bls.gov/iif/nonfatal-injuries-and-illnesses-tables.htm) could be used to

preemptively identify areas of concern. Most useful will be the BLS injury data by event or exposure (e.g., intentional injury by other person, fire from ignition of vapors/gases/liquids, fall on same level while climbing stairs/steps/curb, exposure to direct electricity <200v, overexertion in lifting-multiple episodes). Also useful will be the BLS data by injury type (11 categories, e.g., fractures, cuts/lacerations, heat burns, amputations, carpal tunnel syndrome) by the body part injured. The injury type data can be converted into a severity level using either the AIS score for each injury category or the KABCO scale, both of which are explained next.

Scales for injury severity (including death)

The AIS or Abbreviated Injury Scale was developed for automotive applications but is used for other applications. AIS is an anatomically based 7-digit coding scheme, written as "12(34)(56).7". Each digit identifies part of the injury. In order, the digits identify the body region injured (using 1 digit, e.g., 1=head, 2=face), the type of anatomical structure damaged (using 1 digit, e.g., 3=nerves), the specific anatomical structure (using 2 digits, 10=amputation), specific injuries (2 digits), and the severity score (using 1 digit mapped onto a scale from 1=minor injury to 6=fatal) (For further details on AIS, see Greenspan, 1985 and/or Loftis et al., 2018.) Thus, AIS provides both a specific description of the type of injury and a severity score.

KABCO also has automotive origins. KABCO stands for K = killed, A = incapacitating, B = not incapacitating, C = possible, O = no injury, property damage only. When people are injured, specifically if they either are seen by EMS personnel or are taken to a hospital, each of their injuries is identified using the International Classification of Diseases, Tenth edition (ICD-10) (U.S. Center for Disease Control, 2024). ICD-10 codes are also used for medical billing. For a comparison of AIS and KABCO, see Burch et al. (2014).

Methods to identify causes from risk data

The go-to document for identifying techniques (methods) to evaluate risk data is IEC 31010 (Risk Assessment Techniques, International Standards Organization, 2019). That document includes a useful figure (Figure 1), that groups methods into 10 categories. IEC 31010 also provides summaries containing which phase of the risk assessment process each analysis method would be helpful for and a summary of each method, identifying the strengths and weaknesses, and providing references to the source of information on each method.

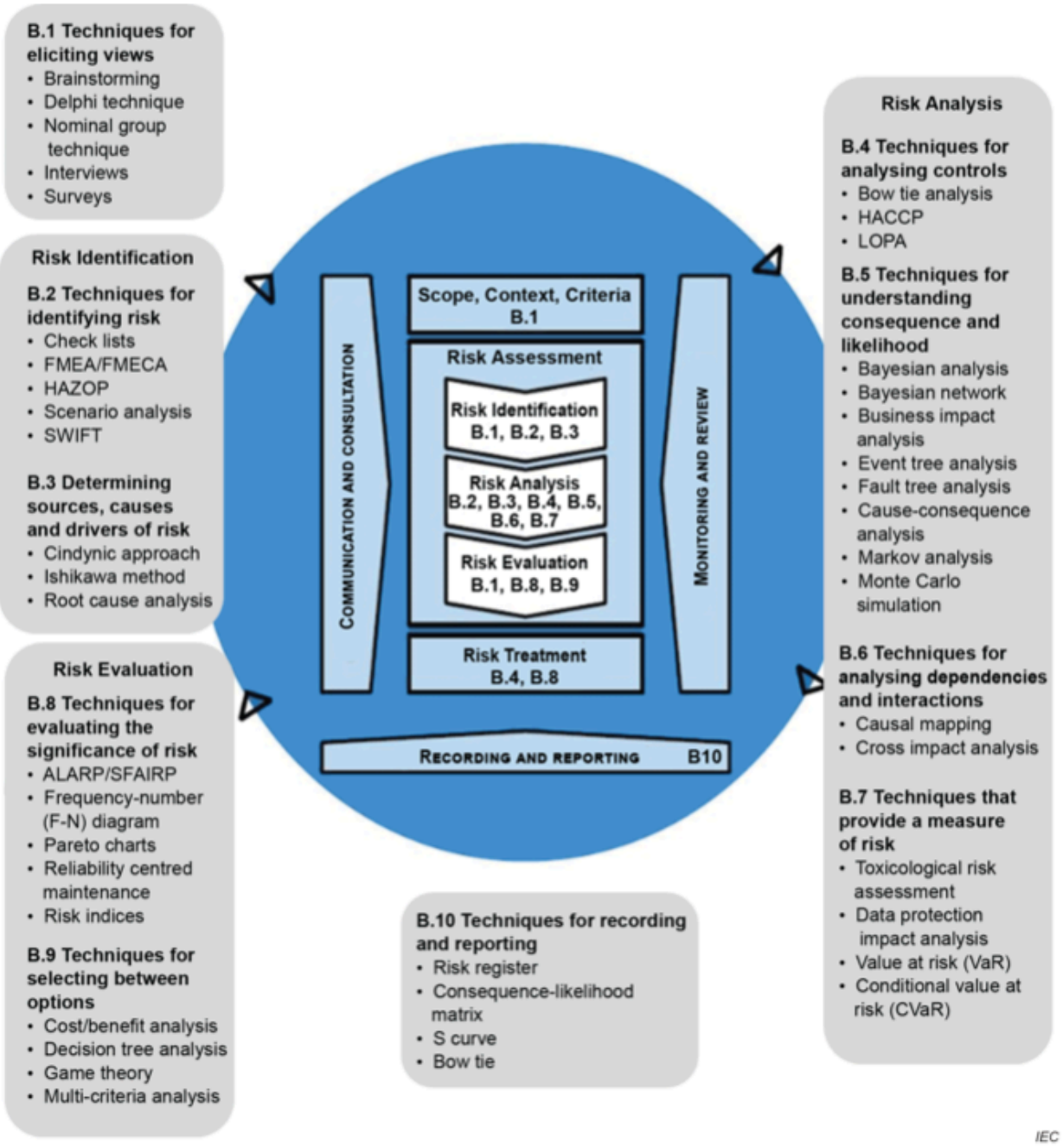


Figure 1. Overview of Risk Assessment Methods
Source: IEC, 2019, p. 37

A similar list of methods (Table 3) appears in the ABS Guidance Notes on Risk Assessment Applications for the Marine and Offshore Industries (ABS, 2020).

Table 3. Analysis Methods

Change Analysis,	Fault Tree Analysis

Checklists	Human Reliability Analysis
What If Analysis	Reliability Centered Maintenance (RCM)
Hazard Identification Technique (HAZOP)	As Low as Reasonably Practicable (ALARP) Overview
Bowtie Analysis	Gas Dispersion Analysis, Fire Hazard Analysis
Layers of Protection Analysis (LOPA)	Explosion Hazard Analysis
Safety Integrity Verification Level	Probabilistic Risk Assessment (PRA)
Failure Modes and Effects Analysis (FMEA)/Failure Modes and Effect and Criticality Analysis (FMECA)	Formal Safety Assessment (FSA).
Event Tree Analysis	

Source: American Bureau of Shipping (2020)

Notice that many of the same methods are listed in both sources. For more information on the use of these methods, see Mouras and Badri (2019) and Torres et al., (2022).

What would be helpful would be a flowchart helping the user to decide which method to use for specific questions.

Hazards of that risk analysis can identify as causal factors

Finally, the extent to which a task is hazardous depends upon the conditions under which it is performed. Table 4 lists some of the hazards that ABS has identified that could be helpful to those using the methods just described.

Table 4. ABS Hazards List.

1.Chemical Hazards	*4. Physical Hazards*
Toxicity	Moving, falling, or overhead material/equipment
Corrosivity	Slips and trips
Reactivity	Falls
Flammability/Combustibility	Pinch points, crushing, and cuts
	Excessive strain/posture
2. Biological Hazards	*5. Work Environment*
Blood-borne diseases	Noise
Food-borne diseases	Vibration
Water-borne diseases	Lighting
Airborne diseases	Extreme Heat
Carrier-borne diseases	Extreme Cold
Surface contamination	Dangerous Atmosphere/Asphyxiation
3. Energy	*6. External*
Pressure	Heavy Seas
Electrical	Heavy Winds
Static Electricity	Rain/Storm/Lightning
Inadvertent startup of equipment	Snow Storm/Ice
Fire/Explosion	
UV, IRA, visible light radiation	
Electromagnetic fields (non-ionizing radiation)	
Ionizing (gamma) radiation	

Source: American Bureau of Shipping (2013), p. 44

Step 4: Rank the risks/hazards

Hazard rankings should consider both frequency and severity data. Frequency can be determined by examining each instance in which a hazard occurs and either (1) weighting by the likelihood that instance occurs or (2) averaging across all instances to examine task frequency and the severity of a task failure. Severity can be determined from the scenario outcome, typically assessed in terms of deaths and injuries, as well as property damage, but public image and reputation can also matter.

Consider the following example, related to the work the author has done on commercial aircraft. A hazard analysis could be done for all final approach in general, or for landing a Boeing 737-800 at SeaTac on runway 34C on a Saturday night at 2200 hrs under specified wind and weather conditions. In this case, the hazards could an engine failure during final approach, wind shear, a loss of communication with the tower, or another aircraft on the ground inadvertently intruding onto the runway, for example. The likelihood of each hazardous event or condition could be determined from historic data of that type of airplane at similar airports

under similar weather conditions. That information could be supplemented by flight simulator data in which those conditions were recreated to further refine the estimates, which often are expert judgements, typically from experienced test pilots. The consequences and their severity could also be determined from historical data in which the scenario described occurred and/or from engineering analyses of that scenario. Potential outcomes could include (1) a crash in which some or everyone on board died, (2) some passenger and crew injuries of varying severity, (3) structural damage from an abrupt maneuver, or other outcomes, singly or in combinations In the case of Boeing, some of those other outcomes could include grounding of aircraft leading to repair costs and loss of revenue by the airlines, and a public more reluctant to fly on Boeing aircraft, leading to a loss of future sales.

Often, determining numeric values for task frequency and severity is difficult or not possible. The solution is to use expert judgment to determine categorical estimates for frequency and severity. Figure 2, from ISO 31010, is an example of such. However, sometimes the ordering of the scales is different, and the greatest risk appears in other corners. Often, each category is assigned a range of values. The values assigned vary with the context.

Likelihood						
	Almost certain (5)	Low	Medium	Medium	High	High
	Likely (4)	Low	Low	Medium	Medium	High
	Possible (3)	Low	Low	Low	Medium	Medium
	Unlikely (2)	Low	Low	Low	Low	Medium
	Rare (1)	Low	Low	Low	Low	Low
		Insignificant (a)	**Minor (b)**	**Moderate (c)**	**Major (d)**	**Extreme (e)**
		Negative consequence				

Figure 2. A 5 x 5 Risk Matrix
Source: International Standards Organization (2021), p. 20

Note that obtaining reliable estimates of frequency, and to a lesser extent severity, is a challenge. People do not provide reliable estimates of low frequency events. Hazard characteristics, such as its visibility, worker control over it, and other factors, affect those estimates (Kahneman and Tversky, 1982; Slovic, 2016).

After all the hazards are identified, a list is created ranking them from greatest to least. In that list are frequency and severity values, along with other information identifying each hazard.

Step 5: Identify solutions

Hazardous tasks are considered one at a time, from the most to the least consequential. For each hazardous task, the analyst considers each task one step at a time. For each step, the analyst determines if changing something about each step could have changed the outcome of the event sequence. Often that means adding a comment to the analysis with the proposed change, a subjective estimate as to how much the change could alter the outcome ("usually", "very likely", "somewhat likely", "possible"), and then repeating that consideration for every step of a task. Also added to the analysis is information about implementing the change, including who is responsible, the number of person hours required to make the change, the date by which the change is planned to be implement, and other information that needs to be considered.

The next step is to order this information with cost-benefit data to make decisions about which solutions to implement. Other considerations can include overload of individuals to implement the desired changes, activities that need to be scheduled together, funding limitations, and so forth.

Step 6: Report and validate solutions.

Generally, reporting is done using special software for this purpose which is intended to track safety problems and their resolution. Most of the software for this purpose is intended for large manufacturing operations with many plants and multiple units in their plants. For the likely application here, a small business, the reporting format is likely to be a custom spreadsheet.

Some commercial products for this purpose have additional features to *facilitate implementation* such as those just described (actions to be taken to resolve the problem, who is responsible, expected completion date, etc.). Other features include:

- *Notification support* - When an incident is entered into the database, emails pointing to it are automatically sent to affected parties. This can include those directly affected (e.g., the injured worker, their manager, the site manager, the site safety and health engineer) but also others at other sites with similar operations. There can also be emails to union representatives and government agencies.

- *Automatic status support*- Some systems automatically generate periodic status reports (weekly, monthly) across multiple sites (if they exist) of new incidents during the reporting period and unresolved responses to incidents.

As examples, some of the more popular health and safety software management platforms are HSI Donesafe, Velocity EHS, KPA Flex, and EHS Hero.

For additional information, see Capterra's EHS Management Software listing (https://www.capterra.com/sem-compare/ehs-management-software/?utm_source=ps-google

&utm_medium=ppc&utm_campaign=:1:CAP:2:COM:3:All:4:US:5:BAU:6:SOF:7:Desktop:8:BR:9:EHS_Management&network=g&gclid=Cj0KCQjw4cS-BhDGARIsABg4_J1ulnhqldw8POpYcHEL_CsBBpHDggmoghO)

Generally, validation involves determining if a task that led to an incident continues to occur after the remedy has been implemented. For an interesting implementation idea, see Marhavilas et al. (2022).

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