Explosives Safety Risk Assessments at Ports

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Keywords: Quantitative Risk Assessment, Ports, Explosion Effects and Consequences, Risk-based siting, TP-14, IMESAFR

Abstract

Ports in the U.S. and around the world are integral components of the global explosives supply chain. Ports are utilized for the shipment of both commercial and military explosives. Ships used in explosives transport could carry large amounts (millions of pounds) of explosives into ports. Often, the large amounts of explosives these ships carry make it impossible to meet the quantity/distance (QD) rules in place in ports around the world. The shipment of explosives through ports cannot simply come to a halt because of national and global dependence on the explosives products. One possible solution to this problem is to use a quantitative risk assessment (QRA) to determine the level of safety at a port instead of QD rules. Once a QRA is completed, there must be a level of acceptable risk (risk criterion) that a governing body will accept to allow port operations to continue.

Guidelines for conducting a QRA at a port, and various risk criteria and their applicability to ports are discussed in this paper.

Introduction

Explosive QRAs are designed to quantify the risk of harm to people and assets from explosive operations. QRAs are becoming increasingly more common in the explosives industry and are a method, in addition to historic QD methodology, for determining the safety of explosive operations. Examining the risk for unloading and loading of explosives at ports using a QRA is more complex than a traditional QRA but provides a valuable tool for determining if the risk at these operations is acceptable.

In recent years, several ports have used QD rules to eliminate or reduce explosives shipments through the ports because of the presence of people in close proximity to where explosives operations would occur. This trend of reducing the amounts of explosives allowed through a port, or closing ports to explosives entirely, is counterproductive to the growing need for more/larger shipments of explosives. When ports are closed to explosives, or significant reductions of explosives materials are mandated, system wide safety and security risk exposure is greatly increased by causing more ships to travel to some ports, with more frequent loading and unloading operations. In many cases, a reduction in net explosive weight (NEW) may render a port no longer economically feasible for commercial explosives shipments. If companies switch to another viable port, the risk shifts to surface transportation with trucks travelling greater distances and for longer time periods.

Guidelines for a QRA at a Port

The purpose of these guidelines is to describe a method to assess risk using a QRA. In order to conduct a QRA, a tool that implements QRA methodology is essential. This document discusses both Safety Assessment for Explosives Risk (SAFER) and Institute of Makers of Explosives Safety Analysis for Risk (IMESAFR) when referencing tools used for a QRA. SAFER is the current U.S. Department of Defense (DoD) QRA tool that implements the QRA methodology presented in the Department of Defense Explosives Safety Board (DDESB) Technical Paper (TP) 14[1] (Ref 1). IMESAFR[2] is a QRA tool sponsored by the Institute of Makers of Explosives (IME) that has been developed closely alongside the SAFER tool. This section of the document references IMESAFR when referring to a QRA tool.

IME has drafted a document titled "Guidelines for IMESAFR-Based QRAs for Ports" (Ref 2). This document lays out basic guidelines for performing an IMESAFR analysis on port operations. These guidelines are also applicable to other QRA tools, such as SAFER.

These guidelines include a caveat that a QRA should only be conducted on port operations that handle closed shipping containers and is not intended to examine operations involving bare explosives. This stipulation is meant to limit the analysis to scenarios categorized as "with-warning." Research has been conducted shipping containers with explosives being dropped from a maximum possible height. A dropped shipping container containing explosives was simulated and the results of this research led to a conclusion that a dropped container of explosives did not pose an initiation risk. A dropped container will act elastically upon contact with the ground, causing less energy to be transmitted at a slower rate to the explosives inside, thus eliminating any initiation.

For standard loading and unloading operations at a port, the QRA is not that different from a standard QRA of a fixed facility. As with a standard QRA for a fixed facility, the details of the potential explosion site (PES) (the ship in a port operation) and the exposed sites (ESs) must be identified for input into the QRA. Examples of PES inputs (Figure 1) and ES inputs (Figure 2) for IMESAFR are shown in the following figures.

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[1] The current published version is TP-14 Revision 4a

[2] "IMESAFR Overview" International Explosives Safety Symposium & Exposition 2018, Paper 20720; J. Tatom, B. Evans, J. Hoffman, C. Fritz, M. Duncan, M. Robinson

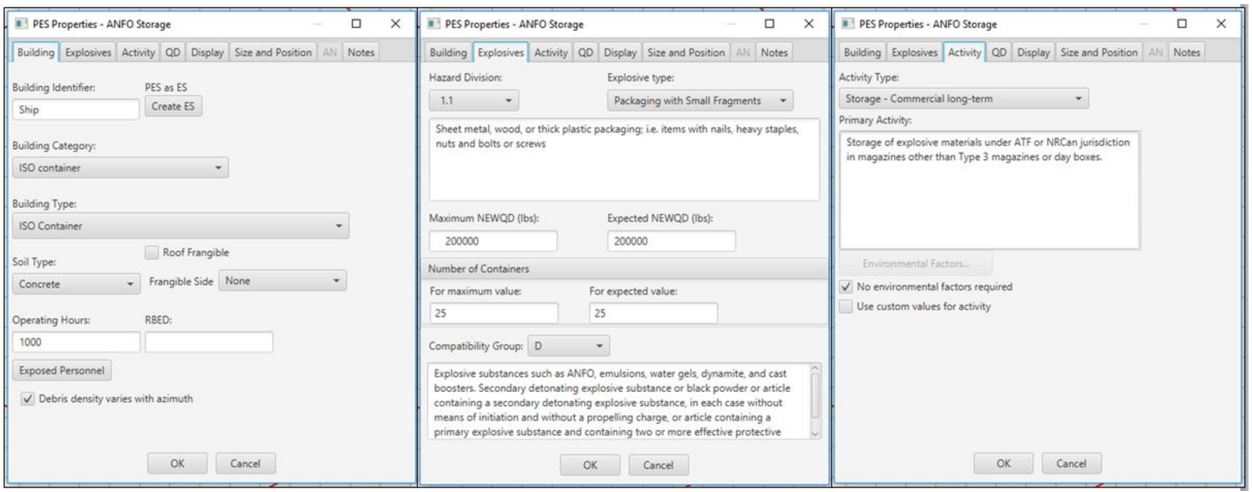

Figure 1: PES Inputs

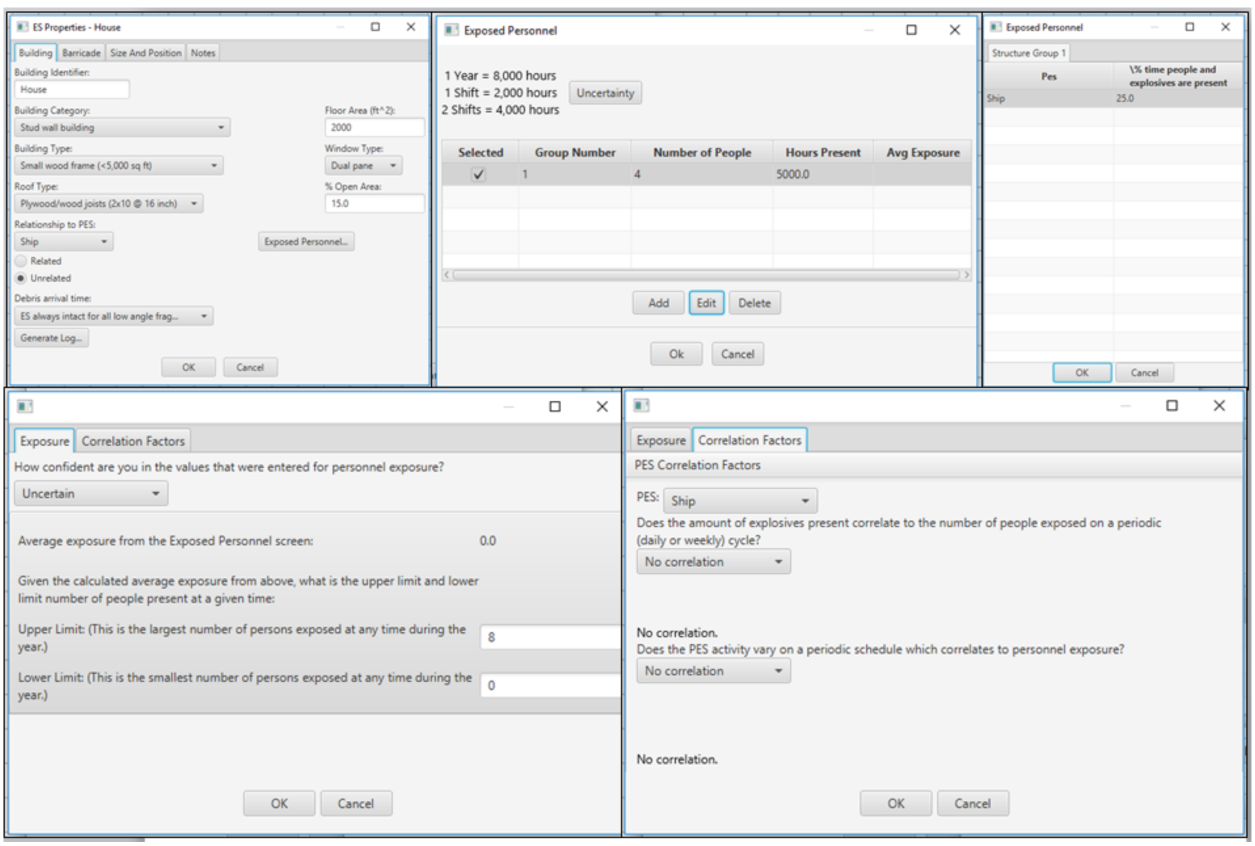

Figure 2: ES Inputs

In IMESAFR, there are two PES models that can generally be applied to port operations. The first is the *Ship* model, and the second is the *ISO Container* model. The *Ship* model should generally be used when large amounts of explosives are stored below deck. In the *Ship* model, it is possible for the entire ship to turn into debris following an explosion. The *ISO Container* model should generally be used when explosives are stored above deck. In the *ISO Container* model, the ISO containers would become debris following an explosion. The debris that originates from the deck of the ship is modeled by setting the soil type to *Concrete*. If the *ISO Container* model is chosen, the number of ISO containers used in each operation needs to be identified. Generally, it is mandated that all explosives be located above deck, so the *ISO Container* model will usually be the appropriate choice. However, ammonium nitrate (AN) will almost always be shipped below deck, so the *Ship* model would be applicable.

Once a PES model has been determined, the amount of explosives for the operation needs to be defined. To establish this, the maximum possible size of a shipment should be determined and that weight should be used for all operations in the year.

Determining the amount of activity hours for use in a port analysis is fairly straightforward. The maximum number of shipments that will occur in the year should be estimated. Next, it should be determined how long each loading or unloading operation takes. To calculate the yearly activity hours, the maximum number of shipments should be multiplied by the number of hours each operation takes.

The time that port operations occur should be carefully considered. For example, operations that occur at night will greatly alter the exposure to explosives at ESs when compared to operations during the day. Operations at night are more likely to expose individuals in their residences because people are more likely to be home. Operations during the day are more likely to expose individuals in businesses or roads because people are usually active at that time.

The first analysis that should be completed for port scenarios is a standard annual risk analysis. This analysis should be completed just as it would for a fixed facility analysis, with the caveats described previously.

If an annual risk analysis fails to meet criteria (discussed in a later section) for port operations, then it is probably fruitless to continue the QRA process. If a standard annual risk analysis is very close to criteria and includes a very low number of activity hours in a year, then it might indicate a very high probability of fatality given an event, and/or too many people close to the location of the operations. In the case of a close pass on a standard annual risk analysis, a regulator or governing body could possibly request an hourly risk assessment for the scenario. Hourly risk assessments are described in the next section.

Hourly Risk Assessment

Often times an hourly risk assessment can be justified and will often be required by a regulator reviewing a QRA for a port. Hourly risk assessments are beneficial for scenarios that include few loading and unloading operations in a year, which leads to few hours of activity per year. For example, a port could only have 100 hours of activity in a year, which would mean 8,660 hours with no activity. In such scenarios, the annual risk is offset by a very large number of hours where the risk is zero. The benefit of an hourly risk assessment is that it only considers the time when an activity occurs.

To calculate the hourly risk, most inputs remain the same from a standard annual risk analysis. First, the level of exposure to people in the surrounding area during operations should be determined. If operations are carried out at a fixed time, which is normal for most port scenarios, then the occupancy/traffic data should be used for the surrounding ESs at that time. If operations occur at random times, then the average occupancy/traffic data should be used. Once the amount of people is determined, these people are assumed to be exposed to the explosives for the entire hour of an hourly analysis. In IMESAFR, it should be entered that explosive activity occurs for one hour per year. The personnel determined using the methodology above should be entered as present at each ES for one hour and the percent time that people and explosives are present should be entered as 100% of the time.

IMESAFR presents the probability of event (P_e) for all activities as the probability of event in a year. To complete an hourly analysis, the P_e for an hour must be determined. IMESAFR presents a baseline annual P_e value for each activity. The activity that matches the operations should be chosen. The hourly P_e value is determined by adjusting this baseline annual P_e. A typical number of operating hours per year is presented for each activity type the P_e is based on. The annual P_e value is divided by the typical number of hours for the activity to determine an hourly P_e. It is also possible for the user to define a P_e value if the user has a solid basis for the value. An example hourly P_e calculation for commercial loading and unloading is:

$$Annual\ P_e = 1.90E-05, based\ on\ 1{,}560\ hours$$

$$Hourly\ P_e = \frac{1.90E-05}{1{,}560\ hours} = 1.22E-08$$

This hourly P_e value can be entered in IMESAFR as a custom P_e value.

Once the hourly exposure and hourly P_e has been determined, IMESAFR will calculate an hourly risk of the operations.

Hourly criteria are discussed in the criteria section later in this paper.

<u>Sequential Operations Protocol</u>

In some port scenarios, explosives may be transported several times from ships, to trucks, trains, and storage facilities. In these scenarios, explosives are increasing and decreasing at each location over a certain period of time. This creates a unique scenario that requires the risk at each location to be evaluated over time, then aggregated to determine the overall risk from operations. A simple example of this type of operation is shown in Figure 3.

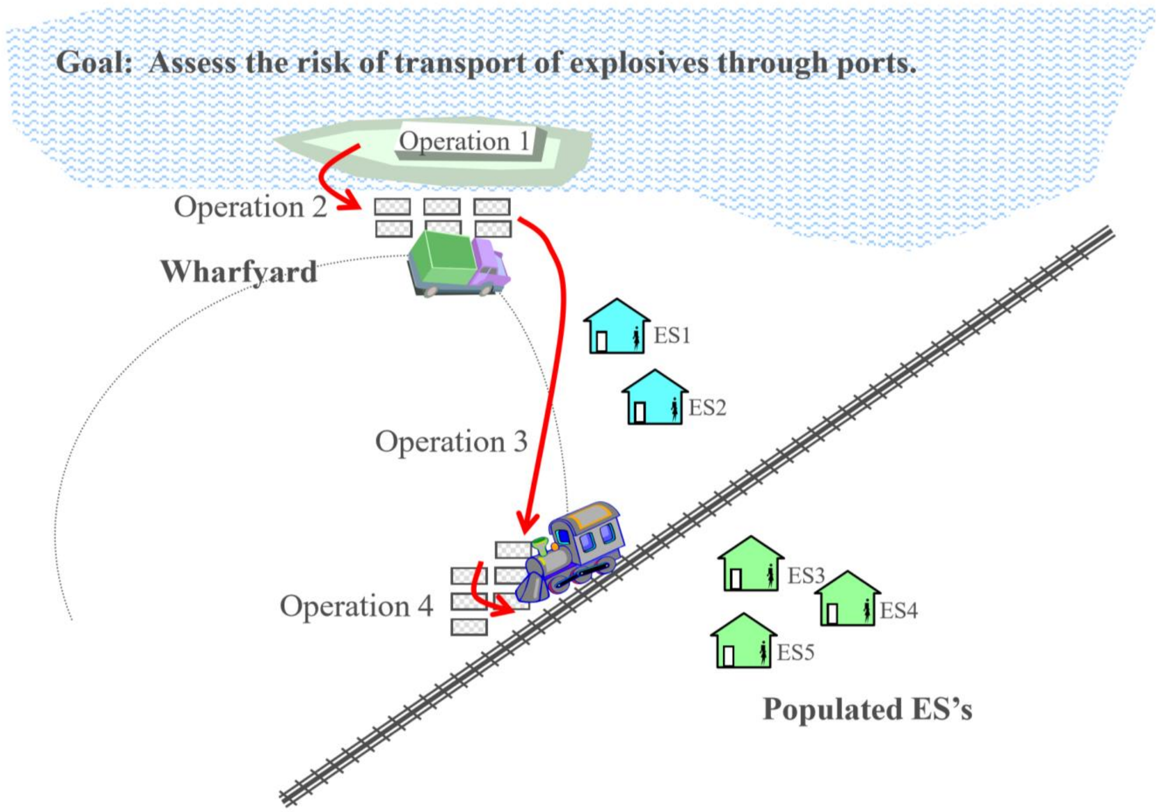

Figure 3: Example Port Operation

A Sequential Operations Protocol (SOP) is designed to handle these complex operations with hourly changes to explosives at multiple locations. In this approach, an SOP and QRA tool, such as IMESAFR or SAFER, are used together to evaluate the risk from the operations. A sequential operation involves chains of activities, broken down into operation and steps, that must be analyzed hour by hour. Figure 4 provides an example of the operations and steps definition.

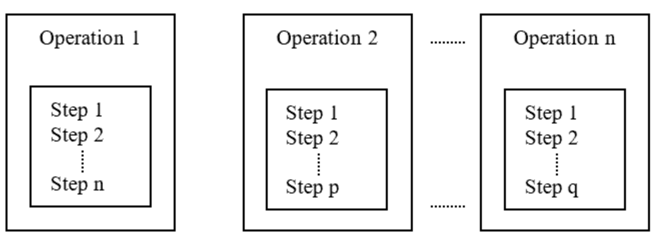

Figure 4: Sequential Operations Activity

For an analysis following an SOP, a "step" is a single activity, occurring over one or more hours, involving explosives at one PES. An "operation" is defined as a series of steps. For example, every step involved with loading a ship is included in the "Loading Operation".

The risk analysis approach used in QRA tools such as SAFER and IMESAFR has to be slightly modified to include steps and hours of each step within an operation. This can be seen in Figure 5 with the addition of the step and hour loops in the calculation process.

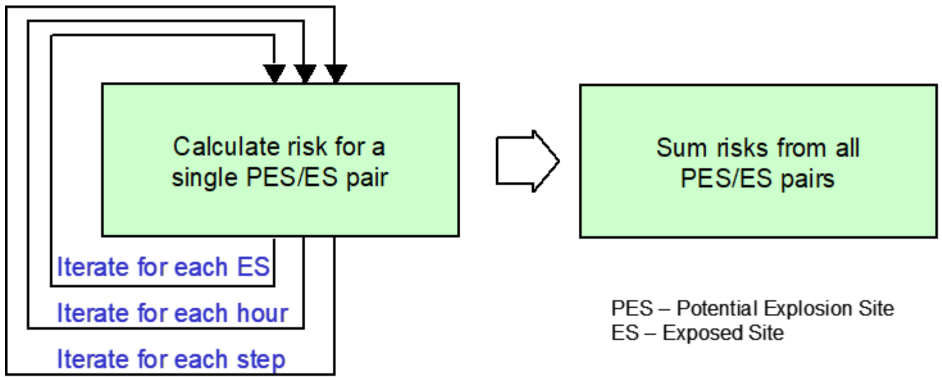

Figure 5: Risk Analysis for a Sequential Operation

The common risk equations can be expanded for sequential operations. Generally, group risk or expected fatalities, E_f, is defined as the summation of all individual risk.

$$E_f = \sum_{Person\ 1}^{Person\ n} P_f$$

This group risk equation can be expanded so that the expected number of fatalities are summed for all exposed sites, hours of the step, and steps of the operations.

$$E_{f\,(operation)} = \sum_{step\ 1}^{step\ p}\left(\sum_{hour\ 1}^{hour\ n}\left(\sum_{ES\ 1}^{ES\ m}\left(P_e \times P_{f|e} \times E_P\right)\right)\right)$$

The risk analysis process in an SOP is a 10-step process, as shown in Figure 6. Figure 6 references IMESAFR, but the same steps apply for a SAFER analysis.

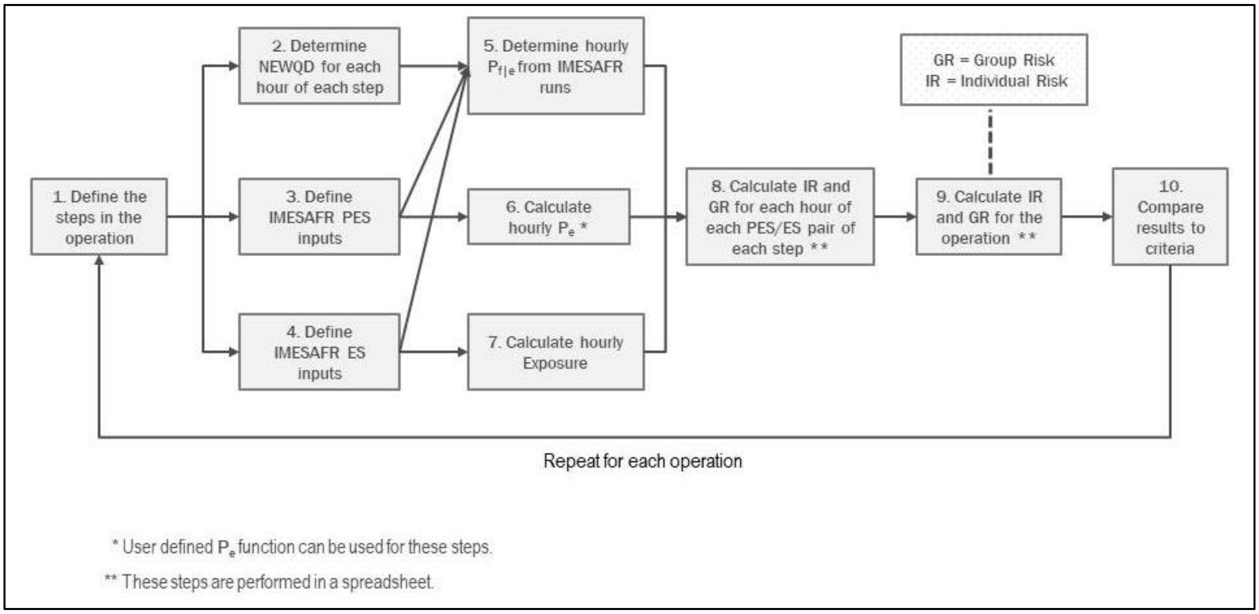

Figure 6: Sequential Operation Protocol

The 10 SOP steps are defined in greater detail, as follows:

Step 1: Define the steps of each operation. The number of steps will vary depending on each operation. The total numbers of hours in each step should be defined as well. This step should be carefully thought out and based on actual operations if possible. A simple example definition of steps can be seen in Table 1.

Table 1: Example Step Definition

Step	Description	Total Time of Step	PES
Step 1	Loaded train arrives, waits to be unloaded.	4 Hours	Train
Step 2	Containers are removed from train.	8 Hours	Train
Step 3	Containers are placed on ship.	8 Hours	Ship
Step 4	Loaded ship awaits departure.	4 Hours	Ship

Step 2: Define the NEW at each hour of each step. It needs to be determined if the NEW is increasing, decreasing, or remaining constant within each step. Table 2 continues the example by defining the NEW by step and hour. The NEW for Step 1 and Step 4 are constant for all hours. The NEW for Step 2 is decreasing as the train is unloaded, and the NEW for Step 3 is increasing as the ship is loaded.

Table 2: NEW by Step and Hour

Step - Hour	NEW (lb)	Step - Hour	NEW (lb)
Step 1 – All Hours	100,000	Step 3 – Hour 1	12,500
Step 2 – Hour 1	100,000	Step 3 – Hour 2	25,000
Step 2 – Hour 2	87,500	Step 3 – Hour 3	37,500
Step 2 – Hour 3	75,000	Step 3 – Hour 4	50,000
Step 2 – Hour 4	62,500	Step 3 – Hour 5	62,500
Step 2 – Hour 5	50,000	Step 3 – Hour 6	75,000
Step 2 – Hour 6	37,500	Step 3 – Hour 7	87,500
Step 2 – Hour 7	25,000	Step 3 – Hour 8	100,000
Step 2 – Hour 8	12,500	Step 4 – All Hours	100,000

Step 3 and Step 4: Define the inputs required for each PES and ES for a QRA. These inputs are defined by the QRA methodology used for the analysis. The types of input include the building characteristics, personnel at the ESs, and activity at the PES.

Step 5: This step calculates the probability of fatality given an event, $P_{f|e}$, for every hour of every step based on the inputs provided in previous steps. The calculations are completed based on the QRA methodology used.

Step 6: Both SAFER and IMESAFR use a P_e matrix that presents the event likelihood per year. An analysis following sequential operation protocol requires the P_e to be on an hourly basis. An example method to determine an hourly P_e using IMESAFR values is presented earlier in the *Hourly Risk Assessment* section.

Step 7: This step calculates the hourly exposure in the risk calculation. This step is based on the exposure inputs from Step 4.

Step 8: This step calculates the individual risk and group risk for each hour of each step based on the hourly $P_{f|e}$, hourly P_e, and hourly exposure. As noted in Figure 6, this step needs to be completed in a spreadsheet format since available QRA tools are not able to complete these hourly assessments.

Step 9: Aggregate the hourly risk calculated in Step 8 to determine total risk for the operation. As noted in Figure 6, this step also needs to be completed in a spreadsheet format.

Step 10: Compare risks for the operation to criteria to determine if the level of risk is tolerable.

Each SOP step should be repeated for other operations at the port, if applicable.

An analysis using the SOP is a very complex process, and it's recommended that they are only completed by qualified individuals experienced with the SOP for QRA.

Criteria

Determining the risk of port operations using a QRA is a valuable effort, but it is imperative to have tolerable risk criteria against which to compare the risk.

In IME's "Guidelines for IMESAFR for Ports" (Ref 2), several suggested annual public risk targets are presented. These public risk targets are as follows:

Pass/Fail Criterion-

- Annual Individual Risk: 1E-06, i.e., for the person most at risk, the fatality rate is less than 1 per 1,000,000 years.
- Annual Group Risk: 1E-05, i.e., the total fatality rate will be less than 10 people per million years.

As Low as Reasonably Possible (ALARP)-

- Annual Group Risk: The fail line is defined as 1E-04, i.e., the total fatality rate will be less than 100 people per million years. The ALARP region is defined as an annual group risk between 1E-04 and 1E-05. This is acceptable for short durations or under special circumstances. However, measures should be in place to reduce this to 1E-05 in a timely fashion. Annual group risk under 1E-05 is considered passing.

Figure 7 presents these risk targets graphically.

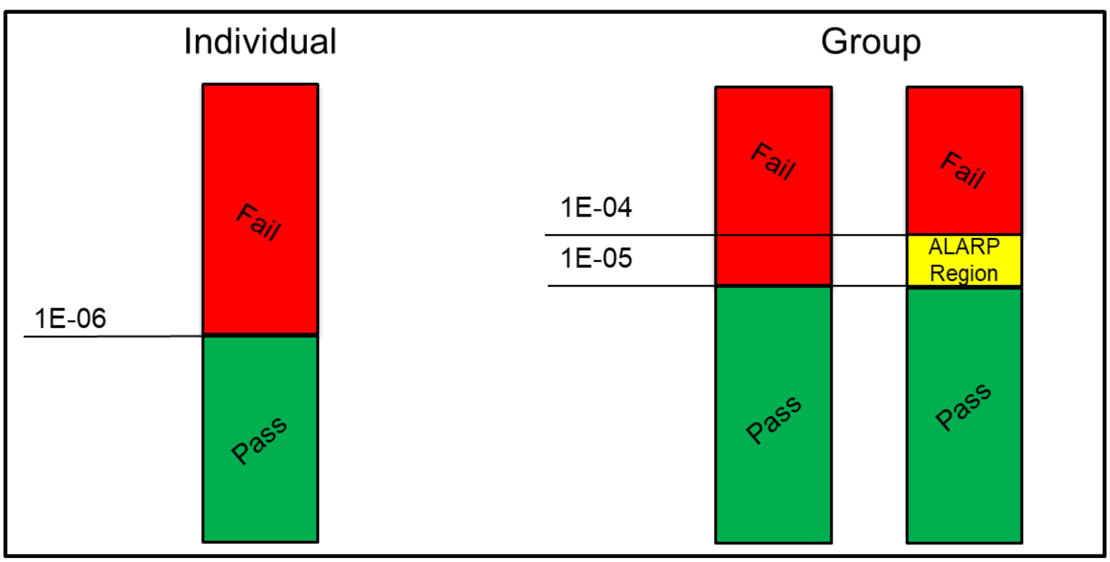

Figure 7: Suggested Risk Targets

Regulatory agencies might be interested in hourly risk targets for operations that only occur a few times a year. If regulatory agencies decide to require hourly risk assessments, then associated hourly criteria should be investigated and established. Since regulatory hourly risk targets have not yet been established for port operations, one (very) conservative option for examining hourly risk is by dividing the annual risk targets presented previously by 8,760 hours (hours in a standard year). Determining an hourly risk target using this method is essentially saying that any one hour a port operation cannot have a higher risk than the average risk for annual operations. This method of looking at hourly risk is not recommended as a long-term solution because of its overly conservative nature, but if the risk from a port assessment falls below the hourly risk targets defined using this method then there should be no question that the risk is tolerable.

While suggested risk targets are useful when examining port operations, regulatory risk targets are critical for approval of QRAs for ports. The stances of the U.S. Coast Guard and NRCanada Explosives Regulatory Division on risk assessments at ports are presented in the following sections.

NRCanada Explosives Regulatory Division

In December 2017, Natural Resources Canada (NRCan), Explosives Regulatory Division (ERD), published its first draft of proposed amendments to the *Explosives Regulations*, *2013* and the *Cargo Fumigation and Tackle Regulations* that allow for QRAs and establish criteria for approval methods and reporting. The criteria accepted by NRCan ERD follow the suggested annual risk criteria presented in “Guidelines for IMESAFR for Ports” (Ref 2). The criteria are:

- Annual Individual Risk: 1E-06, i.e., for the person most at risk, the fatality rate is less than 1 per 1,000,000 years.
- Annual Group Risk: 1E-05, i.e., the total fatality rate will be less than 10 people per million years.

Further, the agency has published guidelines to assist ports and industry with conducting a Quantified Risk Assessment and identified the allowable NEWs for loading and unloading operations at ports and wharves.

Based on those regulatory and policy changes, Canadian Port Authorities have begun issuing guidelines for movement of Class 1 Dangerous Goods through marine facilities. On at least one occasion, this has reversed a moratorium on all Class 1 cargoes.

USCG Policy

U.S. Coast Guard (USCG), Captains of the Ports (COTPs) have policy and precedence available to support decisions for allowable NEWs at ports based on QRA. In 1999, the USCG recognized that the agency’s regulations and policies intended to protect the safety of the public should align with technology and best practices of the industry. In July of that year, a memorandum from the Acting Commandant with the subject line “Commercial Explosives Handling; Application of Quantity/Distance Tables” directed the USCG to consider advances in containerization, performance-based packaging, and product sensitivity stabilization that exceed the USCG standards and had significantly reduced the potential for explosion. The memorandum specifically acknowledged the industry's "enviable safety record" and noted IME's detailed Safety Library Publications (SLP)[3] and the association's willingness to partner with the USCG.

USCG policy, which is described in part by a June 2003 memorandum by then-Commandant, Rear Admiral Pluta, encourages COTPs to consider certain factors prior to denying permits based solely on QD. Those factors include the degree of public exposure, acceptance of risk by the community, other hazardous materials present, critical infrastructure, development and use of sound industry practices, the overall system of risk alternatives, and cost. Admiral Pluta articulated his ultimate goal for the USCG "to move to an entirely risk-based decision-making process using software currently under development by DDESB." (For clarification, the DDESB's SAFER tool is the original tool on which IMESAFR was based.)

Additionally, given that the largest percentage of U.S. manufacturing states do *not* have ports, safe entry of explosives at any given port likely has a *nationwide* economic impact, which is a cost-benefit factor directed to be considered by USCG policy.

IME's Stance on QRAs for Ports

IME has been discussed previously, but not fully defined. The Institute of Makers of Explosives (IME) is a nonprofit association founded in 1913 with the mission "To promote safety and security and the protection of employees, users, the public and the environment and encourage the adoption of uniform rules and regulations in the manufacture, transportation, storage, handling use and disposal of explosive materials. IME represents their member companies that are U.S. manufacturers and distributors of commercial explosives and oxidizers, and companies that provide related services.

When applied to ports, a risk-based decision supported by a QRA is more scientifically modern and accurate than historic QD tables, such as DoD K factors applied in the U.S. IMESAFR provides regulatory and other enforcement authorities with a mechanism to properly evaluate risk in areas not supported by traditional QD measures.

To underscore the potential for shift in risk, in February 2003, an Intermodal Explosives Working Group[4] issued a report examining risk and cost implications of strict QD adherence by USCG COTP when considering permits for loading and unloading of commercial explosives at ports. The report summarizes, "In the examples explored it was found that system-wide risks from such a course could be orders of magnitude higher than from allowing unloading in a port closer to the intended destination of the cargo." In short, the group determined that convoluted solutions, such as multiple smaller shipments instead of one large shipment, to meet QD actually increase the risk from operations.

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3 IME SLP 24 addresses "Recommendations for Handling 50 Metric Tons or More of Commercial Division 1.1 or 1.2 Break-Bulk and Containerized Explosive Materials in Transportation at Commercial Waterfront Facilities in the United States."

4 U.S. agencies that participated in the Intermodal Explosives working group included the Department of Transportation (DOT), USCG, Federal Motor Carrier Safety Administration (FMCSA), and Federal Railroad Administration (FRA).

It is an important reminder that explosives underpin a modern nation's infrastructure, energy production, and quality of life. Public safety should be the number one priority when examining explosive risk, but economic consequences should also be examined. In one case study, a drastic reduction of shipments of Class 1 cargoes imported and exported from a North American port would have impacted the local community by an estimated loss of $2 million dollars annually. A proposed reduction of allowable NEW would have had direct bearing on five IME member companies that manufacture explosives[5] in nine states, with some level of consequence on approximately 1,000 manufacturing jobs. The impacted member companies varied from small businesses with two dozen employees to large, global businesses. This initial impact assessment did not include a sizable number of downstream customers receiving explosives as components for further manufacture or completed products for end use in diverse sectors such as mining, construction, oil and gas, aerospace, specialized safety devices, and defense.

Conclusions

For many ports, QD rules severely limit or prohibit loading/unloading activities of explosive material. QD limitations can lead to non-ideal solutions, such as multiple smaller shipments that lead to increased handling, to meet QD rules that actually lead to an increase in the risk from operations. A QRA is an alternative methodology to provide a state-of-the-art examination of the risks for explosive port operations. It is possible to perform a QRA on an annual basis that looks at the average risk of all operations over a year, or on an hourly basis that only looks at the risk during loading/unloading operations. Also, it is possible to assess the risk from very complex port operations using SOP to perform the QRA. Lastly, QRAs for ports are becoming more accepted in regulatory environments, led by NRCan ERD.

References

1. Hardwick, Meredith, Hall, John, Tatom, John, Baker, Robert, Ross, Tyler, and Swisdak, Michael, "Approved Methods and Algorithms for DoD Risk-Based Explosive Siting," DDESB Technical Paper 14 Revision 4a, 17 March 2017.
2. Institute of Makers of Explosives, "Guidelines for IMESAFR-Based QRAs for Ports," In final draft.

[5] IME member companies and their affiliates manufacture an estimated 98% of commercial explosives made in the United States.