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Minimizing risk. Maximizing potential.™

Conduct Effective Quantitative Risk Assessment (QRA) Studies

An ioMosaic Corporation White Paper

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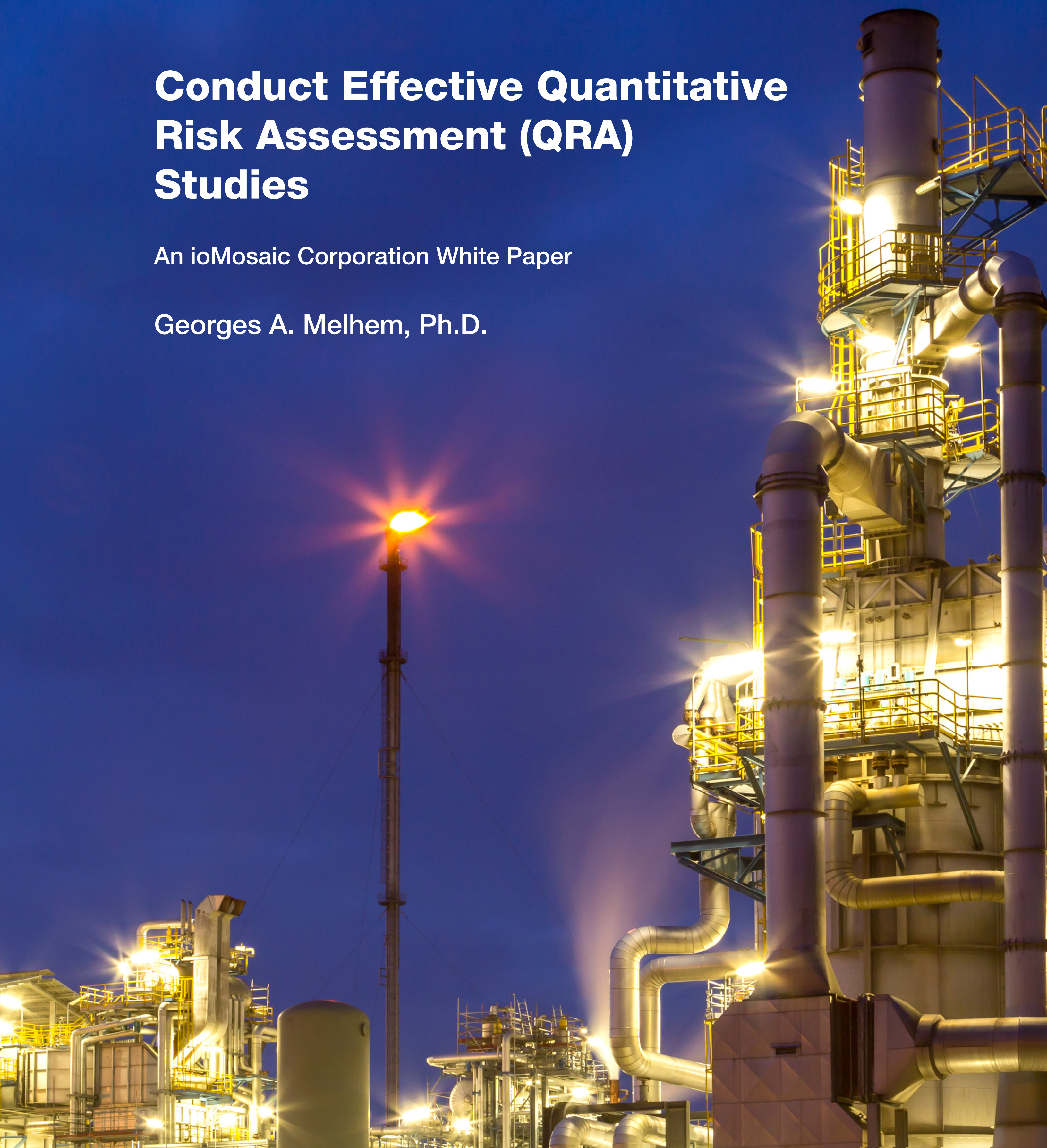

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Conduct Effective Quantitative Risk Assessment (QRA) Studies

Use of QRA for Risk Management

Quantified Risk Assessment (QRA) can be used for a number of different purposes. However, it is most valuable as part of a Risk Management program. Risk Management is the identification and control of hazards, through both technological and management solutions. Occasionally QRA is conducted solely to meet a regulatory requirement, but this rarely precludes using the results as part of a corporate risk management program.

QRA can be used to estimate the absolute level of risk of an activity or the comparative risks of alternatives. The results of absolute risk assessments can be compared with predetermined risk tolerability standards. Comparative risk studies are used to help select, or eliminate particular options. Risk takes many forms; injury to employees and third parties, environmental damage, capital losses, business interruption costs, compliance, and fines. QRA can address any and all of these, so it is important to decide which risks are to be included in each study.

Generally, companies define a level of risk that is considered intolerable. In a few countries, such as in the United Kingdom, regulations include definitions of intolerable levels of risk. More commonly, internal standards of tolerability are set based on the incident related costs an organization can bear each year, as well as levels of risk that society, and investors in particular, will tolerate.

Even when the tolerability standard is met, additional risk reduction measures may be justified if the benefits outweigh the costs. QRA often includes cost/benefit analysis of all or selected risk reduction alternatives. In these cases internal investment criteria may be applied to select measures for implementation.

Usually a wide range of options to reduce risk is available. But it takes skill to select the most cost-effective alternative. Is it better to go after a multitude of easily implemented modifications, or a few more expensive options?

You must also consider what to include in the overall risk. Manufacturing sites generally pose risks only to the work force and the surrounding community. If risks are to be considered for single units, it must be recognized that the unit may represent only part of the overall risk. Whole divisions or product lines may put a more diverse and ill-defined group at risk. Since a company may have facilities throughout the world, the overall risk from all of these facilities and all product lines may influence risk tolerability standards.

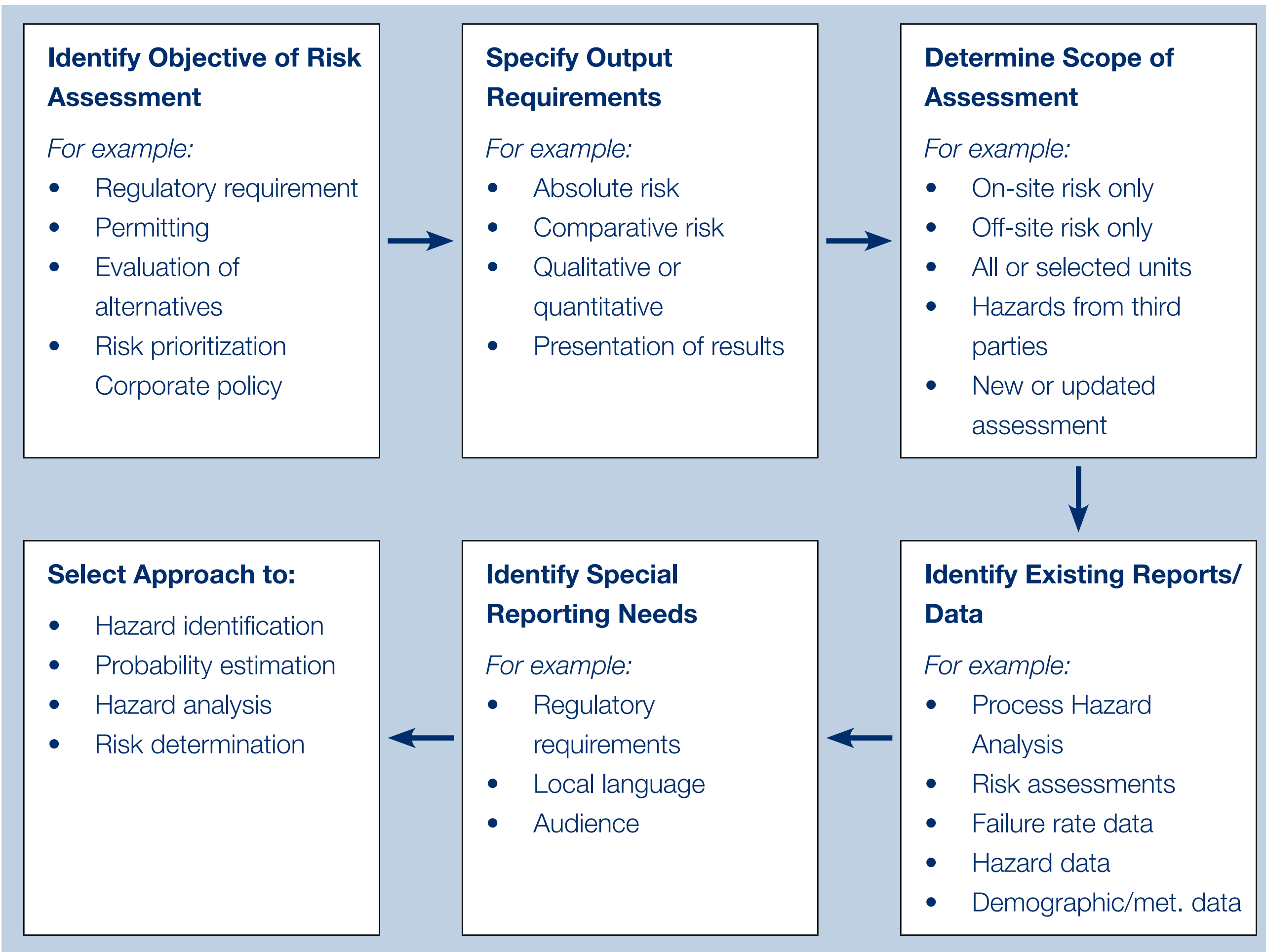
Before a QRA is conducted, the purpose of the study must be determined so that the appropriate results are generated. The facilities and risks to be included must also be determined. Any special reporting needs, such as regulatory requirements or local language, should be identified. Finally, QRA methodologies that will provide the required results must be chosen. All of these decisions require management processes and policies to guide the individuals responsible for overseeing and conducting the QRA.

ioMosaic considers that QRA consists of two principal steps; preparation – where the objectives, scope, standards and methodologies are selected; and implementation. Without adequate preparation, it is unlikely that the QRA will meet the needs of the end customer.

Preparation

As illustrated in Figure 1, preparation consists of six steps, each of which is briefly discussed below:

Figure 1: Important QRA Preparation Guidance



Identify Objective of Risk Assessment

Before work begins on a QRA, it is essential to understand how the results will be used. The end use will influence the format of the results, the scope of work, the methodologies to be used, and the format of the report. Some examples of particular requirements are:

- ***Regulatory requirement*** where many aspects of the QRA may be clearly defined. For example, in the European community, most regulators provide strong guidelines on report format and methodologies.

- ***Permitting*** where the legal process will set particular requirements and the possibility of legal discovery may be an important consideration. The report is likely to be submitted to the permitting authority and those responsible for preparation of the report may be asked to make depositions and appear at any hearing to give evidence in person. The level of detail provided in the assessment will be decided by the requirements of the legal process.

Identify Objective of Risk Assessment

For example:
- Regulatory requirement
- Permitting
- Evaluation of alternatives
- Risk prioritization
- Corporate policy

- ***Evaluation of alternatives*** on its own requires a much less detailed assessment than is needed for a fully quantified assessment. Only differences between alternatives need to be explored, an approach which is likely to be limited to comparative risks. For example, two different manufacturing routes may be under consideration, where much of the equipment is identical, with the only difference being the reactor itself. Consequently, the study can be limited to the reactor, but this will not provide the overall level of risk.

- ***Risk prioritization*** is used to rank potential hazards or system deficiencies for possible mitigation. The only requirement is to order the different risks correctly. In many instances in which only a limited number of hazards are involved, prioritization requires only the identification of potential hazards, and a qualitative assessment is sufficient. A risk ranking matrix is a common approach.

- ***Corporate policy*** may require all operations meeting particular criteria to be subject to QRA. This requirement is most often driven by a need to understand the risks facing the company and to manage the full set of risks to a tolerable level. The detail required in the assessment will vary according to the severity of the potential hazards and the size and importance of particular operations. Quite often the need for QRA is driven by results from less rigorous risk studies, such as risk prioritization or process hazard analyses.

- ***Cost/benefit analysis*** is most commonly used to select risk mitigation measures for potential implementation. This requires as assessment of the reduction in risk if a particular measure is implemented. Most measures reduce either the likelihood of occurrence or the severity of the hazard. The assessment typically only addresses the relevant mitigation, recognizing that to qualify the absolute risk reduction would require a baseline risk assessment. In some cases a QRA may be justified when a recommendation from a more qualitative study will be expensive to implement and a more precise level of risk needs to be developed.

- ***Business interruption*** is caused not only by hazardous events, but also by mechanical and operational break-downs that pose no safety or environmental hazard. This requires a more comprehensive study of initiating events than a “standard” QRA. However, the output may be limited to the duration of any outage and the lost production associated with this outage. It is also important to recognize that the impact on the company may be reduced if: your manufacturing capacity is not fully committed, you may have adequate inventory to cover the outage, or if alternative supply is available.

Specify Output Requirements

The format of the results must meet the requirements objective of the assessment. Examples of different requirements are:

> **Specify Output Requirements**
>
> *For example:*
> - Absolute risk
> - Comparative risk
> - Qualitative or quantitative
> - Presentation of results

- ***Absolute or comparative risk.*** Absolute risk estimates are generally needed where there is concern over the tolerability of the risk, when the risks from different studies are to be added, or if the systems to be compared are very different. Comparative risk estimates are used to choose between different options when there is no question about the tolerability of the risk.

- ***Qualitative or quantitative risk.*** Developing fully quantified risk assessments can be very expensive and time consuming. In many instances a qualitative study will provide sufficient data on which to base a decision. Qualitative assessments are generally used for internal purposes. Qualitative (semi-quantitative) assessments rely on the experience and judgment of the assessment team who will draw on their experience in conducting rigorous quantified assessments. The results of qualitative assessments may determine the need for more rigorous QRA of certain operations.

- ***Results format.*** Risk may be presented in many different formats. The most common for fixed facilities are:
  (a) Risk contours, which show individual risk on a geographic plot, and
  (b) F/N curves which plot the number of fatalities or injuries against frequency of occurrence.

Selection of the results format or formats is driven by the objective of the study and the target audience. There are many different possible formats. Factors that influence the selection include:

- Focus on individual or societal risk
- Interest in maximum versus average risk
- Focus on level of hazard or probability of injury
- Proximity and nature of surrounding population
- Fixed facility or transportation

The output requirements have a significant impact on the level of effort and cost required to complete the QRA. It is important to carefully select results formats that meet your needs.

Determine Scope of Assessment

The scope of the assessment must meet the objectives of the QRA. The following are examples of what might be included in the scope:

- ***On-site risk only*** is used where the hazards are known to be primarily limited to the immediate vicinity of the equipment or there is a “buffer” zone surrounding the facility.

- ***Off-site risk only*** is used when the focus of the study is impact on the surrounding community. For example: the US EPA is responsible for off-site hazards and its regulations focus on off-site risk.

- ***All or selected units*** at a particular facility may be covered by the QRA. Particularly where the focus is off-site risk, many units, such as utility units, pose no off-site threat and these may be excluded from the study. However, because an accident at one unit may impact an adjacent unit causing an offsite hazard, it may be necessary to consider risks at all units to make sure the study includes these initiating events. Individual units may also be considered if a screening of the units has indicated that some pose higher risks than others and should be considered sooner.

- ***Hazards from third parties*** operating facilities close to yours may cause damage at your facilities. Although it is unlikely that a QRA can be conducted of third-party facilities, there is usually sufficient general information available to make a qualitative estimate of potential hazards. In many industrial areas, land use planning has resulted in many different companies building facilities in close proximity to one another. In some instances the regulators have coordinated QRA work so that this issue can be adequately addressed. An example of this is Rijmond in the Netherlands. Third parties are also a significant factor in pipeline transportation risk.

- ***New or updated assessments*** generally require quite different levels of effort. An updated assessment may be limited to a confirmation that nothing has changed in the design and operation. It may include new knowledge of hazard modeling or the likelihood of a failure which will allow a more accurate estimation of risk. Most commonly, an updated assessment is required when existing equipment or operations have been modified or new equipment has been added. In these cases the objective is to estimate the incremental impact of these changes.

Determine Scope of Assessment

For example:
- On-site risk only
- Off-site risk only
- All or selected units
- Hazards from third parties
- New or updated assessment

Clearly the scope of the assessment has a direct impact on level of effort and cost, thus it is important to accurately scope the study so that there is no wasted effort.

Identify Existing Reports/Data

Existing data or reports can significantly reduce the level of effort required to conduct the work. Some reports will provide data for input to a new QRA; others will be the starting point for updating existing work. Existing reports/data may include:

- Process Hazards Analyses reports (HAZOP reports, FMEA studies, event/fault tree studies, etc.)
- QRA reports
- Company failure rate data and accident data bases

Identify Existing Reports/Data

For example:
- Process Hazard Analysis
- Risk assessments
- Failure rate data
- Hazard data
- Demographic/met. data

- Hazard data (Material Safety Data Sheets, hazardous consequence calculations, historical accident data, etc.)
- Demographic data
- Meteorological data

Identify Special Reporting Needs

The most obvious special reporting needs are regulatory requirements where the report format and content may be specified. Internationally the report may be required in the local language. In many instances the QRA has multiple audiences with different needs: QRA specialists, local management, corporate management, regulators, community interest groups, and lawyers all have different interests and levels of expertise. It is common to require two or more different report formats to meet different needs.

Identify Special Reporting Needs

For example:

- Regulatory requirements
- Local language
- Audience

Select Approaches

Once all the requirements outlined above have been defined and existing data reviewed the specific approaches to be used for the QRA can be selected. Some of the choices available are described below:

Select Approach to:

- Hazard identification
- Probability estimation
- Hazard analysis
- Risk determination

Risk Analysis Step	Approach	Commentary
Hazard Identification	HAZOP	Good for complex systems or new technology
	FMEA	Used where a very detailed assessment is required
	Checklist	Good for simple common facilities with similar designs, for example; pipeline pump stations
	Historical Data	Good for simple systems, such as pipelines where one is confident that all possible scenarios will be revealed by historical data

Risk Analysis Step	Approach	Commentary
Frequency Analysis	Fault/Event Trees	Good for complex systems where multiple accident causes exist
	Historical Data	Good for transportation studies and simple common systems
	LOPA	Provides a consistent basis for judging whether there are sufficient independent protection layers (IPLs) to control risk
Hazard Analysis	Simple Models	Used where the overall risk is not sensitive to the hazard zones or where a quick study is required
	Public Models	Required by some regulators (e.g. the Netherlands, California)
	Complex Models	Used where the overall risk is sensitive to the hazard zones or where conditions cannot be modeled using simpler approaches (for examples, mixtures)

Risk Determination

Generally, risk determination is now done using risk assessment software. The number and detail of simplifying assumptions affects the level of effort.

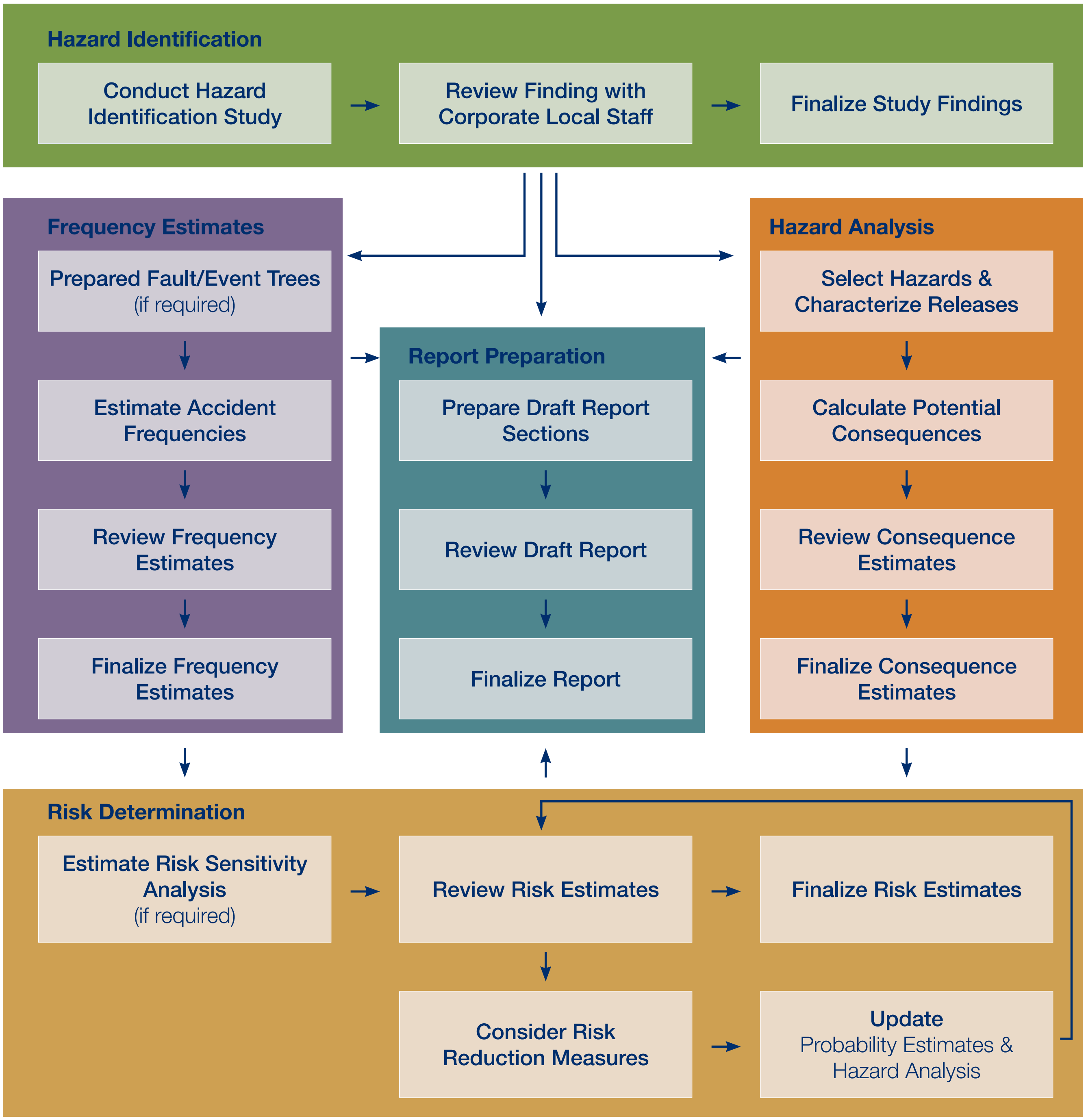
Conducting the QRA

In conducting QRA work ioMosaic divides the work into four primary tasks and a reporting activity. Each of the primary tasks is sub-divided into several sub-tasks. These are illustrated in Figure 2. The primary tasks are:

- Hazard Identification
- Frequency Analysis
- Hazards Analysis
- Risk Determination

For each of these tasks both the ioMosaic specialists and client staff with whom we will work may vary. These tasks also provide logical breakpoints in the work where it is important for the client to review and accept the findings/results before moving to the next step. In this way we minimize the need for rework.

Figure 2: Conducting the QRA



Hazard Identification

The Hazard Identification activity is routinely led by a senior ioMosaic engineer familiar with the methodology to be used. Wherever possible, the lead engineer will also have prior experience with operations similar to those being studied. Generally, the hazard identification step is a team activity, such as HAZOP, where we work with a team of client staff and engineers to identify potential hazards. The client team should include staff familiar with the design, operation and control of the facility. If the work is an update of an existing study, the client team should also include someone familiar with the previous hazard identification work.

An ioMosaic engineer will record the findings of the team, using Process Safety Office® PHAGlobal® software component. PHAGlobal® PHA templates are designed to document the findings of all types of hazard identification approaches including HAZOP, What-IF, and FMEA. Copies of the findings are distributed to every member of the team for review and comment daily during the hazard identification study. Once the study is complete, the findings are collated for review and comments incorporated.

Once the findings are finalized, draft report sections are prepared describing the methodology and findings. These sections form part of the final QRA report and are submitted to the end customer for review and comment before finalization.

Frequency Analysis

For most QRA work, fault or event trees are prepared to describe the logical sequence of events that can lead to a hazard. In some cases, for example pipeline studies, accident probabilities are estimated by analyzing historical data and no fault or event trees are necessarily prepared. Where fault or event trees are required, these will be prepared by the ioMosaic engineers who conducted the hazard identification work.

When using layer of protection analysis (LOPA), each cause – consequence pair will be quantified based on the frequency of the initiating event and the probability of any enabling or conditional events and the probability of failure on demand of any IPLs.

Fault trees are drawn and the unquantified trees are submitted to the client for review and any comments incorporated.

Once the unquantified trees have been finalized, they are quantified by an ioMosaic risk analyst working with the engineers responsible for the hazard identification. Often there will be an initial task to identify failure rate data sets for use in all work for a particular client. A senior ioMosaic risk analyst will work with the client to identify the data sets to be used for all work for that client. However, equipment and human reliability varies with operating conditions, age and maintenance programs. Failure rates appropriate for the conditions must be selected. Achieving consistency between studies is vitally important. To aid in this we prepare a justification for the selection of each failure rate. This is included as an appendix to each report. We also include the derivation of other statistical data in this appendix, for example, equipment counts, number of operations per year, etc.

In some studies, for example, pipeline and transportation assessments, we use historical databases to select failure or accident rates. The selection of the databases to be used and the approach to deriving failure rates for your studies will be reviewed with the client on a case-by-case basis. The quantified trees or LOPA tables, and numerical database are submitted to the client for review.

Once client comments have been incorporated we prepare report sections describing our approach, the fault trees, descriptions or each tree and the supporting appendices. These sections form part of each final QRA report and are submitted to the client for review and comment before finalization.

Hazard Analysis

The ioMosaic engineers responsible for the hazard identification work define the release scenarios to be considered. Each scenario is described in sufficient detail to allow our hazard modelers to estimate the release rates and quantities accurately. The data they will provide include:

- Hole size and shape (release geometry)
- Configuration of upstream equipment (to allow pressure loss calculation)
- Upstream operating conditions
- Composition of material being released (reactivity data, where appropriate)
- Flow rates into section of plant
- Inventory of plant section
- Protective system that will limit the duration of the spill or limit spill consequence (i.e. dikes)

Working with the hazard identification team our modelers select the hazards of interest for the study. Generally these include all potential hazards from the materials of interest, usually flammable and toxic hazards. The modelers must also select representative meteorological conditions for inclusion in the study. Generally two or three sets of wind speed, humidity and atmospheric stability data are selected. Usually at least two sets of conditions are chosen: one to represent daytime and the other night-time conditions. In many cases complete wind rose data spanning 8, 12, or 16 directions are used.

The modelers must also select hazard levels of concern. In some jurisdictions these are defined by the regulator. Hazard levels must be selected for:

- ***Radiant heat from fires.*** Generally levels for injury and fatality are required and are set by considering an exposure time based on how long it might take someone to escape or reach a safe haven. Typical values are 5kW/m2 for injury and 12.5 kW/m2 for death. Thermal radiation damage probits are also used routinely.

- ***Radiant heat dose from BLEVEs.*** Typical values are 80 kJ/m2 for injury and 160 kJ/m2 for fatality. Thermal damage radiation probits are also used routinely.

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- ***Overpressure.*** Overpressure must take into consideration how injuries could be sustained. Very low overpressures can shatter standard windows potentially causing injury to anyone inside the building. It requires a higher overpressure to cause structural damage that could result in building collapse and potentially fatal injury. Very high levels of overpressure are required to directly cause fatal injury, but lower levels can throw a person against equipment causing serious or fatal injury. Typical values are 0.1 bar for injury and 0.3 bar for fatality, these are based on failure of windows and conventional brick or concrete buildings. There are also several published overpressure probits that we routinely use to determine the potential for damage to objects and humans based on peak pressure and/or impulse.

- ***Toxic exposure.*** The toxic response of humans is extremely complex and difficult to model. For a limited number of materials probit equations have been developed that relate exposure time and concentration to a probability of injury. A number of simple concentration dependent data also exist, for example IDLH (Immediately Dangerous to Life and Health) and ERPG (Emergency Response Planning Guidelines) limits are published by a number of authorities, including several regulators. Other available data include Lethal Concentration (LC) and Lethal Dose (LD) data, usually expressed in terms of a particular percentage of fatality for a specified exposure duration. All of these data are based on some extrapolation of test or theoretical data and are further impaired by assumptions on the average response of the human body to the toxic material. In reality every individual reacts differently and different populations may be more or less sensitive. The most commonly used data are probit equations and ERPG values.

The hazard modelers prepare the input data for the selected hazard models (chosen during the QRA preparation phase) and then execute the models. The input and output data are submitted to the client for review.

Once client comments have been incorporated we prepare the various report sections describing our approach, the selection of meteorological data, the selection of hazard levels of concern, a description of the models used, a summary of the results and an appendix containing the input data and detailed results. These sections will form part of the final QRA report and are submitted to the client for review and comment before finalization.

Risk Determination

We use Process Safety Office™ SuperChems™ software component to estimate the overall risk. SuperChems™ requires the following data:

- Location of releases
- Probability of releases
- Maximum extent of each potential hazard for each release
- Location of ignition sources and ignition probability and/or algorithm
- Population distribution data
- Wind rose, speed and stability distribution data

The data is input by one of our risk analysts. These data are combined by SuperChems™ to provide an estimate of the overall risk. The results are generated in the format selected during the preparation phase. At this stage a sensitivity analysis may be required to better understand the key contributors to the overall risk. Such an analysis allows us to make sure that any critical assumptions are reviewed carefully and to identify the most effective risk mitigation strategies. For example, if ignition probability assumptions were found to have a significant impact these would be carefully reviewed for accuracy. If one particular event frequency dominates the risk then this would be an obvious event to analyze further or to try to mitigate with design or operational changes.

When the overall risk estimate is complete it is compared with the client's risk tolerability criteria be they qualitative or quantitative. If the risks are found to exceed the criteria, we will work with the client to identify the most cost-effective risk reduction measures. Risk reduction analysis may require rework of parts of the frequency analysis and hazard analysis activities.

If the study includes cost-benefit analysis of possible risk reduction measures, regardless of the overall risk, we use a Monte Carlo approach to review these measures. Where a potential mitigation measure has been identified we develop an estimation of the range of costs that may be incurred both with and without risk mitigation. We also assign a frequency of occurrence (usually taken from the frequency estimation task) and a cost to implement the change. The Monte Carlo simulation estimates the "annual cash flow" with and without mitigation. The benefits of the mitigation measure can then be compared with the cost to implement and a cost/benefit decision made. We have had success applying this methodology on completion of the hazard identification task using qualitative data generated by the hazard identification team.

Once we have completed the risk assessment we submit our input and output to the client for review. Once the client comments have been incorporated we prepare report sections describing our approach for this task, a description of the models used, a summary of the results and an appendix containing the input data and detailed results. These sections form part of the final QRA report and are submitted to the client for review and comment before finalization. Such detailed reporting will facilitate future updating of these analyses.

Reporting

Our approach is to generate most of the report sections and appendices as we complete each task. However, some sections are prepared once all the risk analysis work is complete. These sections are prepared and submitted to the client for review as part of the overall draft report.

As far as possible where special reporting requirements have been identified, we will prepare these in parallel to the "base" report. However, in many instances it will be more efficient to prepare these reports after the "base" report is complete. Where a local language report is needed we try to assign staff fluent in the language to the work. Where this is not possible, we will prepare the report in English and then engage professional translators. We will submit both the English and local language versions to the client for review.

Computerized Tools / Process Safety Office™ - SuperChems™

With SuperChems™, the user first scans a map of the site of interest. The map is then viewed and the user identifies two points on the map and enters the actual scale. A map origin is then identified.
All the scenarios previously defined are then located on the map visually. Population and ignition sources are also located on the map visually as rectangular area, lines, or point sources.

Once that is completed, the individual risk and societal risk contours are calculated automatically by SuperChems™. A variety of outputs and graphs are available to illustrate and document the risk profiles. Wind rose data, presence factors, outcome probabilities, etc., are managed by SuperChems™ automatically. The use of automated computerized tools such as SuperChems™ drastically reduces the cost of conducting a QRA, especially if mitigation and sensitivity analyses are to be performed.

About ioMosaic Corporation

ioMosaic Corporation is the leading provider of safety and risk management consulting services, training, and software solutions. Whether you need pressure relief system design services, quantitative risk assessments, onsite training, or the latest in software technology, ioMosaic has the knowledge, experience, and resources to address your unique needs. At ioMosaic, we are delivering practical solutions for safety, risk, and business challenges facing our clients.

- Auditing
- Chemical reactivity management
- Combustible dust hazard analysis (DHA) and testing
- Due diligence support
- Effluent handling design
- Pressure relief and flare system design
- Facility siting
- Fire and explosion dynamics
- Incident investigation, litigation support, and expert witness
- Liquefied natural gas (LNG) safety
- Pipeline safety
- Process engineering design and support
- Process hazard analysis (PHA)
- Process safety management (PSM)
- Quantitative risk assessment (QRA)
- Risk management program development
- Structural dynamics
- Training
- Software solutions
  - Process Safety Office
  - Process Safety Enterprise