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Controlling Risk during Major Capital Projects

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Abstract

This paper describes the best practices for scheduling and performing PHAs/HAZOPs, etc., during various key phases of major projects. The paper outlines the scope and content of each project phase hazard review and what the outcomes should be. The concepts are not new, but many contractors and vendors around the world do not seem to understand the concepts well. The paper presents the basics, and then shows best practices and examples from various companies. The paper also outlines how information related to process safety should be developed during and then delivered from a major project.

Background

The construction of a new plant/facility or a large capital expansion to an existing production facility represents significant risk. That risk increases when construction takes place in an operating environment and when critical tie-ins are made to "live" equipment. There have been many excellent papers over the past two decades on how to manage major capital projects to achieve a process design and the supporting operating procedures and process safety information that will control process safety. These papers include:

- The paper presented by Olin Chemicals in 1989, which provided a basic outline of risk control steps implemented during 5-6 stages of project (many companies followed and continue to follow such a process for controlling risk)[1]
- The paper presented by BP Oil in 1992, which provided a basic outline of risk control steps implemented during 5-6 stages of project[2]
- The comprehensive paper provided by Syncrude in 2001[3]

CCPS has provided excellent guidance in their original PSM resources[4] and in many subsequent textbooks and other publications.

All of these resources refer to the industry standard practice of conducting multiple risk reviews (also called hazard reviews, preliminary hazard analyses, process hazard analyses [PHAs], project risk reviews, design safety reviews, and many other names). Typically there are one to two risk reviews within a project related to a small project and up to 6 risk reviews building upon each other to yield the "initial PHA" for a large project (such as building a new plant or new unit/facility). Conventional risk analysis tools must be applied at strategic project milestones, but these alone will not ensure a safe and seamless startup and a positive return for investors. A holistic approach to managing risks on a large project requires some innovative measures that must be supported by the entire project team. Fortunately, there is a wealth of experience to draw on. The paper discusses lessons learned in the past two decades on the keys for controlling risk during projects.

Types of Projects

There are various sizes and structures of projects, depending on the scope of the endeavor, the urgency, the nature of the business, the company culture, the company sophistication, and many other factors. The two most important project types (factors) for purposes of this paper are (1) project size (expressed usually in expenditure expected or size and number of pieces of equipment to be installed) and (2) type of financial control for the project.

Typical Project Sizes:

This paper focuses on major projects, though most of the best practices translate into moderate and small projects as well. **Table 1** below provides a basic definition of projects sizes and the typical number of risk reviews conducted during the project:

Table 1: Project Size, Example Scopes, Relative Project Length, and Risk Review Effort

Project Size	Example Project Scope	Example Project Length/Duration (concept→ commissioning)	Number of Risk Reviews
Major	Major projects handled **external** to an affiliate/plant, such as expansions and new facilities	12-36 months	4-7
Moderate	Works **engineered by an affiliate/ plant** (installing a new design of knockout pot for a feed to a unit)	6-9 months	2-3
Small	**Minor** affiliate/plant works (installing piping to bypass a control valve)	1-2 months	1

<u>Financial Control of Projects:</u>

Financial control of a project can also influence the way risk is managed. There are various styles of financial control, but the most common are **(1) Sequentially Loaded,** where the estimate of the project and the next phase is adjusted after each successive phase is complete and **(2) Front-end Loaded,** where the project is essentially run as a "fixed cost, turn-key" contract where any change to the scope affects the contract cost and schedule, so each change requires a scope change approval. Many financial managers believe the "Front-end Loaded" approach is best, but typically the inertia against making scope changes is so strong, that the unit delivered typically has smaller long-term benefit to the owners. Below is a brief summary of the two types of projects:

- **Sequentially loaded** (time and material)
    - Requires more calendar time
    - Allows for risk approvals (gates) at major project steps
    - Allows more flexibility of design during project phases
    - Often more cost effective in the short-term
    - Usually more cost effective and safer in the long-term, reaping much more benefits over the life of the process

- **Front-end loaded** (fixed; turn-key)
    - Supported by financial officers
    - Shorter calendar time
    - Firm budgets; easier to sell to stake-holders
    - Scope changes are difficult, even for safety
    - Not always cost effective due to after-project changes and losses resulting from compromises in process safety and process reliability
    - Performance standards/measures are critical to success
    - Requires full-time process-safety expert from start

Project managers or team members likely do not have any say in the style of financial control used by the company. For a front-end loaded project, the best alternative is to make sure a full time process safety expert (preferably one from the owner/ultimate plant location) is available to help ensure that, by the final project phase, the needs of the facility are met. The project manager or process safety expert should have the authority or have ready access to the proper authority, to approve scope changes related to minimizing the inherent and residual risk of the process.

<u>General Concept of PSM Development during Major Capital Projects</u>

All of the PSM elements apply to, or are affected by, capital projects to varying degrees, especially:

- Process Safety Information – developed throughout the project phases
- Operating Procedures – developed in the last phases of a project

- Management of Change – heart of project risk control
- Process Hazards Analysis – heart of MOC
- Pre-Startup Safety Review – before highly hazardous chemicals enter and before production starts
- Emergency planning and response – cannot happen properly if the process layout, design, and operation do not consider it ahead of time

Most companies learned many years ago that the PSM elements are the same management practices required for operational and reliability excellence – so building for these during each project phase makes excellent business sense. Also, by addressing PSM early in the project development, it is easier to expand the goal of risk management to "sustainable control of human error," the key to controlling risks. This not only provides excellent process safety control, but excellent reliability, quality, and efficiency control.

Scope of Risk Reviews and PSM Development For Each Project Phase

As mentioned earlier, major projects can have 4 to 7 or more phases and these can be spread over 12 months to 36 months or more depending on the project size. However, decisions for controlling risk made during the project phases echo through the next 20 to 50 years of operation, because design features, automated control features, and human interactions must be controlled continuously to control the inherent hazards of chemical processes.

Figure 1 presents an example of a major capital project's phases for a large new chemical process unit or plant, with six "in-project" phases and one "post-project" phase. Though not universal, this approach appears to be a widely accepted view of major project phases. For smaller projects, condense this approach to 5, 4, or a minimum of two phases. **Table 2** on the following pages provides much more detail on the risk review for each project phase.

Figure 1: Example Project Phases and Related Scope of Risk Reviews (RR)

	Project Responsibility						Plant/Unit Responsibility
	Phase 1 Conceptual Design	**Phase 2** Feasibility & Detailed Specification	**Phase 3** Preliminary Design	**Phase 4** Detailed Design	**Phase 5** Construction	**Phase 6** Pre-Commissioning	**Phase 7** Post-Commissioning
Project Concerns and Deliverables	Fit to business strategic plan Fit to existing operations Review of available technology Inherent safety options Site planning Raw material resourcing options	Detailed feasibility study (availability of technical staff; marketing plan) Detailed technology review and specification development Preliminary plot plan and tie-in plan +/- 40% cost estimate Preliminary schedule & milestones	Preliminary construction & operation plans Initial process flow diagrams (PFDs) Initial material and energy balances Raw material planning Utility planning Candidate vendors for major components Fire protection plan	Process design and generation of Rev 0 P&IDs; continuing to Rev 5 (nominal) in this phase. Revise material & energy balance Technical specs for all components Basics design of process controller Fabrication started and major components ordered	Execute fabrication and installation plan Develop detail plans for tie-ins to OSBL Continue to develop specs for OEM manuals and operating procedures Set up CMMS/ database for ITPM Draft PSM management systems/procedures	Complete fabrication/ installation Complete development and closure of PSSR and other punchlists Commission/ validate equipment (dry, wet, with HHC) Populate CMMS and other PSM/ reliability databases Complete operating and MI procedures (by SMEs); validate	Assist commissioning team Ensure training by vendors/OEMs are completed in the field and proficiency of plant staff is validated Complete performance measure of initial operation (to ensure contract commitments are met) Manage changes Closeout project
Risk Reviews ⇨	**Conceptual RR** Strategic plans Inherent safety Plot plan review for Facility Siting; consequence modeling for major releases Begin Human Factor consideration		**Preliminary Design RR** What-if analysis of each major unit operation HAZOP/FMEA of selected scenarios LOPA of selected scenarios & review options for inherent safety	**Detailed Design RR** HAZOP/FMEA of most nodes (focusing on continuous mode of operation) LOPA of 1-5% of scenarios Final SIL (if needed) determination	**Final Detailed Design RR** HAZOP/FMEA of changes since previous RR, including rec. resolutions; place special attention to changes in field Begin human factor and facility siting (HF&FS) checklists	**Commissioning RR (“Initial PHA for new unit”)** HAZOP/FMEA of changes HAZOP and/or What-if of non-routine operating modes (startup, emergency shutdown, etc.) Complete HF&FS checklists	**Post-Startup RR (3 to 6 months after startup)** Close any recommendations that were rated as post-startup issues Review each MOC for its impact on the “Initial Unit PHA” Perform critique of risk review efforts during project.

Table 2: Details of Process Safety Development Phases of a Major Capital Project

Project Phase #	RISK REVIEW Phase Name	Goals of RISK REVIEW	RISK REVIEW Methodology	RISK REVIEW Team Membership (in addition to leader & scribe)	Key PSM Element Development for each Phase (using US OSHA PSM as template/example, OSHA PSM regulation in parentheses (_))
1&2	Conceptual	Choose inherently safer option, ensure overall feasibility, estimate impact on neighbors	• Consequence modeling (to help on next project phase) • What-If (no guidewords) • Selected checklist for judging inherent safety	• Senior operator for unit or from similar unit • Senior process engineer for unit or from similar unit • Process/design engineer from project • Process Safety specialist (if not already listed above)	• Process safety information, including chemical hazards, chemical reactivity, hazards of inadvertent mixing, inventories, applicable codes and standards (d) • Baseline info for future PHA (e) • Baseline info for future MI (j) • Begin inherently safer concept • Begins leadership • Begins employee participation (c)
3	Preliminary Design	Identify and resolve most expensive design alternatives, including layout of plant, facility siting concerns, environmental protection issues, and major tie-ins	• What-If (no guidewords) • HAZOP/FMEA of selected scenarios • LOPA of selected scenarios	• Senior operator for unit or from similar unit • Senior process engineer for unit or from similar unit • Process/design engineer from project • Process Safety specialist (if not already listed above)	• Process safety information, including applicable codes and standards, process flow diagram, thermal/kinetic chemistry information, material and energy balances, and materials of construction (d) • Facility siting basis set • Beginning emergency response plans and procedures (n) • Baseline info for future PHA (e) • Baseline info for future MI (j) • Continue employee participation (c)
4	Detailed Design	Begin detailed identification of potential accident scenarios, primarily focused on normal (usually continuous) mode of operation. Begin risk assessment for scenarios with large residual risk	• HAZOP/FMEA of equipment nodes, focusing on normal (usually continuous) mode of operation • What-If of lower consequence & lower complexity systems • LOPA of 1-5% of the scenarios; determine SIL, as necessary	• Senior operator for unit or from similar unit • Senior process engineer for unit or from similar unit • Process/design engineer from project • Process Safety specialist (if not already listed above)	• Process safety information, including applicable codes and standards, P&IDs, revised materials of construction, safety interlocks and controls, equipment design basis and some final equipment details (d) • Multiple layers of protection • Detailed info for future PHA (e) • Detailed info for future MI (j) • Begin detailed emergency planning and response (n) • Continue employee participation (c)
5	Final Design	Update results of previous RISK REVIEW for new details,	• Complete HAZOP, FMEA, or What-If for nodes started in previous RISK REVIEW	• Senior operator for unit or from similar unit	• Process safety information (revisions) (d)

Project Phase #	RISK REVIEW Phase Name	Goals of RISK REVIEW	RISK REVIEW Methodology	RISK REVIEW Team Membership (in addition to leader & scribe)	Key PSM Element Development for each Phase (using US OSHA PSM as template/example, OSHA PSM regulation in parentheses (_))
		identify potential accident scenarios for nodes not previously reviewed, primarily focused on normal (usually continuous) mode of operation. Resolve most previous recommendations Complete risk assessment for scenarios with large residual risk	• Perform HAZOP, FMEA, What-If for nodes not covered in previous RISK REVIEW (due to previously missing information) • Begin Human Factors and Facility Siting checklist • Perform general Utility Failure checklist • LOPA of 1-5% of the scenarios; determine SIL, as necessary	• Senior process engineer for unit or from similar unit • Process/design engineer from project • Process Safety specialist (if not already listed above)	• Multiple layers of protection (revisions) • Revised details building toward initial PHA (e) • Revised data for MI, including development of inspection, test, PM plans and populating databases (j) • Begin detailed consideration of human factors • Data and recommendations for developing operating and maintenance procedures (f) & (j) • Continue employee participation (c)
6	Commis-sioning	Conduct full hazard/risk review of operating procedures to control risk of errors during startup, shutdown, emergency shutdown, and other non-routine modes of operation Close out previous RISK REVIEW issues (from earlier phases of project) and complete the human factors & facility siting checklist This RISK REVIEW creates the "Initial PHA" of the process	• HAZOP (2 guideword or 8 guideword) or What-If (no guideword) of operating procedures (choose method based on hazard and complexity of each task) • Complete HAZOP, FMEA, or What-If for nodes started in previous risk reviews • Perform HAZOP, FMEA, What-If for nodes not covered in previous risk reviews (due to previously missing information) • LOPA of 1-5% of the scenarios; determine SIL, as necessary • Complete Human Factors and Facility Siting checklist	• Senior operator for unit or from similar unit • New/junior operator for unit • Senior process engineer for unit or from similar unit • Process/design engineer from project • Process Safety specialist (if not already listed above)	• Process safety information (revisions) (d) • Multiple layers of protection (revisions) • Complete the initial PHA (e) • Revise MI plans, procedures, and database (j) • Complete detailed consideration of human factors • Continue employee participation (c) • Complete development of emergency planning and response procedures (n) • Complete operating procedures (f) • Complete initial training (g) & (j) & (h) • Develop remaining elements of PSM, including MOC procedures and incident reporting and investigation system (l) & (m) • Conduct initial PSSR (i)
7	Post-Startup	Conducted 3-6 months after startup similar to the future Revalidations, but with the goal of compensating for weaknesses in MOC process at the initial startup of the new unit/process	• Audit of MOCs (and P&IDs and SOPs) since "Initial PHA" (since commissioning RISK REVIEW) to ensure nothing has been missed by MOC • HAZOP or What-If of missed or poorly reviewed changes • Update PHA for the entire set of	• Senior operator for unit or from similar unit • New/junior operator for unit • Senior process engineer for unit or from similar unit • Possibly project/design engineer (for QA of project)	• Initial PHA Revalidation (completed much earlier than the required 5 years cycle) (e) • MOC (l) • Incident investigation (for lessons learned in first 3-6 months) (m)

Project Phase #	**RISK REVIEW Phase Name**	**Goals of RISK REVIEW**	**RISK REVIEW Methodology**	**RISK REVIEW Team Membership** (in addition to leader & scribe)	**Key PSM Element Development for each Phase** (using US OSHA PSM as template/example, OSHA PSM regulation in parentheses (_))
			changes (looking at whole picture for effect of all changes) • Close any pending recommendations (if possible)		

Risk Control – Initial Phases of a Major Capital Project

As described in **Figure 1** and **Table 2**, the first two project phases are critical for establishing the inherent safety of the process, and therefore an opportunity for company leadership to show their true colors. These first two project phase design reviews are typically called "Conceptual Design Reviews" and "Preliminary Risk Reviews," and are frequently referred to as "Preliminary HAZOPs" outside of the USA. The figure and tables list some of the activities during Conceptual Design and follows into the Preliminary Design phase. A partial list of these and other activities include:

- Select process (inherently safe or at least inherently safest design):
  - Identify lower waste chemistries
  - Low inventory
  - Select non-hazardous solvents and reagents
  - Low energy reactor configurations[5]
- Decide on the maximum level of inherent risk (not residual risk) that will be accepted
- Establish siting and layout (with control of inherent risk to neighbors considered)
- Establish grading and drainage
- Establish process design (preliminary)
- Establish circuit isolation requirements
- Establish process control philosophy
- Establish strategy for control of ignition sources (electrical area classification)
- Establish relief and blowdown requirements
- Establish fire protection strategy

In 1996, Trevor Kletz noted that little literature exists for describing these front-end studies.[6] Perhaps this is true for the "public domain literature," such as textbooks and papers/articles. However, most companies have internal documents that explain how to grow a PHA throughout the project from concept to startup. These internal procedures have been summarized in various papers and textbooks listed earlier[1,2,3,4] and in many other forums over the years. The point Trevor Kletz was making appears to be that despite the past 35 plus years of adoption of HAZOP (and a longer period for adoption of What-If and FMEA), the implementation of risk review methods during the early stages of a project has been lacking in a great many companies. This is especially true for the owners who allow the "prime contractor" to have main oversight of the risk review process, a conflict of interest. No one will care about controlling the risk of the delivered process/unit **more that the owner/operator**.

Project level risk reviews have been performed to increasing levels of care for the past 40+ years. Over that time, methods have been improved or customized for theses early- phase Risk Reviews. In the past 15 years, considerable focus has been placed on controlling inherent safety at the initial concept phase of a new unit/process. Now there is a major focus not only on inherent safety, but also inherent reliability, and inherent environmental protection during the **Conceptual Design phase and Preliminary Design phase.**

Table 3 below (adapted from Syncrude, 2001)[3] presents a more detailed list of considerations during the Risk Reviews for the earliest phases of a project.

Table 3: Conceptual and Continuing into Preliminary Design Risk Reviews – Key Concerns and General Methods to Guide these Reviews and Development

Key Concern	**Ways to Address/Evaluate Key Concern during Risk Review**
Inherently safe/reliability process selection	▪ Evaluate lower waste chemistries ▪ Evaluate low inventory ▪ Evaluate use of non-hazardous solvents and reagents ▪ Evaluate low energy reactor configurations[5]
Plot Location Relative to Other Units	▪ Process opportunities – reduced pipe runs ▪ Operating logistics – number of operators ▪ Distance from control room and tie-in to control room ▪ Backup contingency considerations – begin Utility Failure risk review ▪ Knock-on effects from major incidents in nearby units; including consequence modeling is necessary ▪ Begin Facility Siting risk review (checklist-based) here, if possible
Size of Plot Areas – based on preliminary process designs	▪ Access to utilities and other support systems, sewers, etc. ▪ Cost of real estate, site preparation ▪ Elevation considerations
Precise Spacing Between Unit Boundaries – standoff distances between battery limits or between major equipment in nearby units	▪ Insurance and Industry spacing guidelines ▪ Knock-on effect to nearby units ▪ Business interruption considerations
Inner Unit Layout	▪ Ease of Access (begin Human Factors considerations) ▪ Operability and maintainability ▪ Constructability and Repair considerations (considering future lifting activities for construction and repairs) ▪ Equipment decking and layering (don't expect operators to climb through caged ladders to take routine process reading)
Fire Protection Review	▪ Emergency access/escape routes ▪ Fire fighting or toxic rescue capability ▪ Placement of detectors ▪ Strategy to protect neighbors from your releases ▪ Construction of control rooms to protect "stay-behinds" (See consequence modeling mentioned in "Plot Location")

However, weaknesses still persist among these improved early-phase Risk Review practices. Below is a listing of keys to optimize the Phase 1 and 2 Risk Reviews for a project.

Keys to Performing Excellent Risk Reviews in the Conceptual and Preliminary Phases of a Major Capital Project:

- **On the risk review team, include a senior operator, not just supervisory personnel from an existing or very similar unit, even if the person must be contracted or must travel a great distance to attend the Risk Review.** There have been many projects where this did NOT occur at the Conceptual or Preliminary Design stages and the missed considerations led to either a flawed project (i.e., the scope of the project is limited to 3 year vision instead of 5-8 year future vision) or an inherently unsafe and/or unstable process due to range of typical operating parameters for pressure, temperature, or level; or a poorly planned pathway for foot traffic due to plot plan errors of omission, etc.). This should be a company requirement for all risk reviews (all project phases, all PHA revalidations, all MOC risk reviews). As an example, this was the SINGLE best rule for project risk management developed within Amoco Oil and Phillips following accidents in their facilities in the late 1980s.

- **On the risk review team, include senior process engineer from an existing or very similar unit, even if the person must be contracted or must travel a great distance to attend the Risk Review.** This is for the same reasons listed for the senior operator. However, these two senior staff members will see the process quite differently, due to their typically very different experiences in the same process units. This should also be a rule at your company for all risk reviews.

- **Allow contingency in budget and schedule for possible changes.** If the project managers are put in an "overly" uncomfortable position with respect to changing scope, adding or changing features, etc., then the resulting project could be an "on-time/on-schedule" new unit, but may be unsafe or run poorly long-term. Recall the comparison of front-end loaded versus sequentially loaded projects described earlier.

- **NEVER let the contractor/vendor manage the risk review or provide the risk review leader.** Typically, the contractor does not have the owner's/operator's interests in mind since their chief concern is to deliver a project on schedule, for a stated price, and meet an initial performance warranty. The owner/operator should always chose the Risk Review leader and should ensure the leader is:
    - Independent of the project management team
    - Independent of contractors/vendors
    - Independent of the Unit/Process/Plant that the major project is related to
    - Fully capable PHA team leaders/facilitators (well trained and practiced in the HAZOP, FMEA, and What-If methods) – a dedicated scribe is also necessary to help the leader, if the risk review meeting is expected to last more than 8 hours total.
- **Force the consideration of inherently safer/more reliability alternative.** For all of the reasons mentioned earlier.

There are many other factors that lead to successful risk reviews in the early project phases, but the considerations listed above are key.

Risk Control – Detailed Design Phases of a Major Capital Project

The risk reviews are a major risk control feature of the design phases of a project as well. These risk reviews can be one to three progressive efforts over one to three project phases, depending on the size of the "major capital project," with the Risk Review report building toward the "initial" official hazard review report for the process unit (discussed in the next section). The Risk Reviews during the detailed design phases can typically include:

- Using HAZOP, FMEA, and/or What-if (brainstorming methods) in progressively more detail
- Initiating and then progressively improving (from phase to phase) the risk review record (HAZOP tables, What-If tables, checklist tables)
- As mentioned in **Figure 1** and **Table 2**, the risk reviews during detailed engineering will evaluate the risk of any design modifications and/or newly identified hazardous scenarios, which have been added since the previous reviews. This includes making sure the final detailed design resolves the occupational safety, process safety, reliability, and operational risk issues identified in previous reviews
- Maximize inherently safer design in the selected process:
    - Design tanks, and piping to make overflow hydraulically impossible
    - Lower feed pump pressures to make hydraulic overpressure impossible
    - Optimize reactor conditions and recycle loops to minimize waste
    - Design manual charge stations at ergonomic work height
    - Site hazardous operations away from zone impacted by possible explosion
    - Design tanks to withstand maximum possible pressure[5]
- Performing a final review of equipment, ventilation, containment, and environmental safeguards, including instrumentation, interlocks, fail-safe decisions, detailed layouts, and fire protection provisions
- Begin the Human Factors risk review (checklist-based)
- Continue the Facility Siting risk review initiated earlier (checklist-based and modeling-based risk reviews)
- Apply Layers of Protection Analysis (LOPA) to complex risk scenarios and use this to define Safety Instrumented Systems' needs

As before the Risk Reviews during the detailed engineering phase require intensive participation by operations' senior staff, including operators, supervisors, and process engineers.

Keys to Performing Excellent Risk Reviews in the Detailed Engineering Phases of a Major Capital Project:

- **As for Risk Reviews in the earlier project phases, continue to have your most senior operator and process engineers from the unit or similar unit on the Risk**

Review team. Maintain the rules mentioned earlier for the Risk Review leader/facilitator.

- **Catch design problems before they create operational traps.** This is the goal through all of the Risk Reviews for a new process unit, but given that the inherently safest and more reliable option has most likely been chosen, the detailed design phase becomes the time when to most effectively detect and eliminate such traps. **To accomplish this in the detailed design/engineering phases, equal focus must be given to hazards and operability/quality issues.** Look for ways to keep the final process easy to operate, easy to maintain "online" and ways to avoid process upsets." Two-thirds of accidents occur during non-routine modes of operation, so by avoiding deviations from the norm, the plant's exposures to these higher risk modes of operation are reduced.

Write Operating Procedures Designed to Control Risks.

After the Risk Reviews are complete, the next important step in controlling risk before start up is developing the written procedures for controlling operations, controlling troubleshooting, controlling emergencies, and maintaining equipment. The data needed for writing procedures is mostly developed by the end of the **Final Design Phase** and the finalization continues into the **Commissioning Phase** (other papers address best practices for drafting, formatting, and validating procedures using subject matter experts (SMEs)[7]). In summary, operations must write procedures containing the right content (right instruction for each step, in the right sequence) and format the instructions (steps and pages) properly to lower the chances of someone making errors when following the procedures. There are about 25 rules for formatting procedures and these are readily available in the published literature. If done right, these written procedures will become the basis for performing the initial training of the new unit's operators and serve as a refresher guide for these experienced staff over the long-term. This in turn will minimize (but never eliminate) human errors of skipping steps and doing steps wrong, and is important in controlling the human error portion of process safety risk.

Risk Control – Pre-Commissioning / Commissioning (Initial Startup) Phase of a Major Capital Project

The pre-commissioning Risk Review builds upon the previous Risk Reviews in the project. As the equipment design is completed the fabrication and construction begins. During this same period, initial training of the new or transferred staff occurs, using the procedures mentioned in the previous section. The pre-commissioning Risk Review can begin just prior (4-6 weeks prior) to start-up of a new facility, or a little earlier if possible.

The key consideration for this project phase is to complete the risk review of non-routine modes of operations. The project Risk Reviews to this point will not have covered these modes of operation very well. (Note that in perfect world, the risk review of the non-routine modes of operations, which uses the operating procedures as a basis, would be completed before training begins. However, in most cases, the training begins as the procedures are being completed and as the risk review is done.) The risk review of non-routine operating modes can be performed using a full 8 guideword HAZOP, a streamline 2 Guideword approach (which is what was used before HAZOP was invented in the 1960s), or a No Guideword What-if. All of these approaches are described elsewhere and will be explained in some detail in the 3rd Edition of the Guidelines for Hazard Evaluation Procedures, CCPS, due late 2008. References are available to explain these methods (Bridges[8]). This procedural analysis is to ensure that hazards due to human error in association with the process design have been identified and analyzed.

During this final risk review before start up, the project team must also ensure that all the PSM requirements for initial PHAs have been met. If all preceding Risk Reviews have followed the guidelines discussed in this paper for controlling risk at each project phase, meeting the "initial" PHA requirements will not entail a tremendous amount of effort other than the risk review of non-routine modes of operation. PHAs must address the hazards of the process; therefore hazards during all modes of operation must be analyzed. The resulting report will be the "initial PHA" of the process unit, which is required to meet PSM standards.

This pre-commissioning risk review should not be confused with the pre-startup safety review (PSSR), which is also necessary but the purpose of the PSSR is to validate that the process design and specifications have been met.

This final Risk Review session before startup consists of:

- Reviewing and evaluating changes made during construction, ensuring that no new hazards have been added since the last hazard review. High priority is given to detecting details which may have been overlooked, and to concentrating on the adequacies of plans to cope with operating emergencies that might arise
- Maximizing inherently safer design in the selected process, such as planning for rework of initial product[5]
- Completing reviews for Facility Siting and access issues
- Completing the review for Human Factors issues
- **Reviewing (HAZOP/What-If) of start-up, shutdown, emergency shutdown, and on-line maintenance procedures.** Some believe this risk review to be another "validation" review of procedures, to ensure they are correct. But that is not the purpose of this risk review of procedures. Our aim in the HAZOP/What-If of the procedures is to ensure we have adequate safeguards (hardware, interlocks, SIL, and/or independent administrative safeguards) to offset the errors of skipping steps and performing steps wrong – such human errors WILL occur, it is just a matter of when.[8]

The lack of risk review of non-routine mode of operations, such as by HAZOP or What-if of procedural steps, is the most frequently observed weakness in the project risk review cycle.

After this risk review, the project team can proceed to close recommendations, decide which (if any) of the recommendations can be deferred until after initial startup, close the PSSR (not part of the risk review, but part of PSM in general), and finalize the initial PHA report for the new process unit. Typically, the plant MOC system begins to take over control of new risks after the pre-commissioning Risk Review meeting is closed.

There are of course many deliverables from the project team, including the finished equipment, ready to commission and then smoothly commissioned, operating and maintenance procedures, populated databases for mechanical integrity (MI), Process Safety Information - files of all necessary design bases for relief valves, completed drawings, complete equipment files of all types, etc.

Risk Control – Post-Commissioning Phase of a Major Capital Project

Many companies require a final risk review related to a new process unit about three to 6 months after startup. This was implemented when managers realized that the MOC system (which starts at the close of the pre-commissioning RISK REVIEW meeting) typically becomes overwhelmed by the magnitude of changes necessary in the final rush to startup a new unit. To avoid missing a key risk factor for very long, it is wise to schedule a post-startup Risk Review. This can also serve as the first PHA Revalidation for the new process unit. The Post-Commissioning PHA is conducted the same as a PHA Revalidation.[9]

Factors That Determine the Number of Risk Reviews for a Major Project

This paper has dealt with Major capital projects (12 months length or large). However, projects come in all scopes and sizes and there are varying scopes within the project categories. As mentioned earlier, the number of risk reviews for a major capital project varies by the combination of project size, process complexity, and process risk/hazard.

Example 1 shows that for a **large process** (more than $100 million USD of installed cost and two or more years of project time) that is **complex** (high pressure system, high temperatures, complex control) and that **handles hazardous chemicals**, about 5 Risk Reviews are needed of varying scope before the plan is fully commissioned. The table shows actual expenditures of Risk Review team labor expended for each review. This expenditure includes the time to document the Risk Reviews.

Example 1: New Ethylene Plant

- Size: 250 nodes of equipment (nodes are vessels, columns, fired heaters, lines/exchanger circuits, etc.) plus the typical number of operating and maintenance procedures

HAZARD REVIEW ESTIMATES

	Conceptual	Preliminary	Detailed	Construction	Pre-Startup	Total
Meeting Time	1 week	3 weeks	5 weeks	3 weeks	3 weeks	15 wks
Team Size	8	8	8	6	6	
Staff Hours Total	164	1152	2120	864	984	5284
Cumulative Schedule	2 months	6 months	14 months	18 months	22 months	24-30 mon
Focus	Plot plans, process options, tie-in options (WI and some modeling)	Cursory HAZOP, FMEA, and WI	Rigorous HAZOP, FMEA, and WI; start checklists	Changes since previous; finish checklists	SOP Hazard Review & Changes since previous	

Example 2 shows that for a **small process** (much less than $100 million USD of installed cost and 1 year of project time) that is **relative simple** (conveying of iron ore from a port to a steel plant) and that **handles low hazard material** (i.e., rock/ore), only two Risk Reviews are needed, each low intensity efforts. **Example 2** shows actual expenditures of Risk Review team labor expended for each Risk Review. This expenditure includes the time to document the Risk Review.

Example 2: New Ore Conveying

- Size: 10 nodes of equipment (nodes are conveyors, screen, crushing, storage, dedusting, etc.) plus the typical number of operating and maintenance procedures

HAZARD REVIEW ESTIMATES

	Detailed	Pre-Started	Total
Meeting Time	2 days	2 days	4 days
Team Size	10	10	
Staff Hours Total	218	202	419
Cumulative Schedule	3 months	9 months	10-11 mon
Focus	Rigorous WI, some FMEA; start checklists	SOP Hazard Review & Changes since previous	

Conclusions

For new process units, only one opportunity may exist to adequately assess and manage risk, and that is during the project phases before start up. Sound industry practices have existed for some time pertaining to managing the risk of the final process operation by risk management efforts during a major capital project. Many have learned these lessons, but many have not. The renewed focus on designing inherently safer and more reliable processes and renewed focus on controlling risk during non-routine modes of operation may not have migrated to the project control system of some companies. There are many key points related to controlling risk during the design and startup of a new process unit, but the most important appear to be:

- Effective company leadership and effective project management, where the primary goal is an efficient operating unit (long-term process reliability and safety) – where this primary goal far exceeds the secondary goals of bringing in a project on schedule and on budget.
- Including experienced operators and experienced process engineers on the risk review teams, from the very start of the project.
- Developing and applying PSM elements at each project phase to better design the project for process safety.
- Having subject matter experts develop procedures (operating, maintenance, and lab procedures) and having the risk review of each of these procedures to ensure there are sufficient safeguards to protect the new process when the imperfect humans have to follow the procedures perfectly.

One "unwritten" deliverable from a project team (including the risk review teams) is a process and related procedures that will sustainably control human error during all modes of operation. The project team cannot ensure these safeguards will stay in place long-term, but if human error is predicted and controlled at each phase of a project, by following the steps outlined here and elsewhere, the control of human error, and therefore the control of accidental losses, will at least have a good start.

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