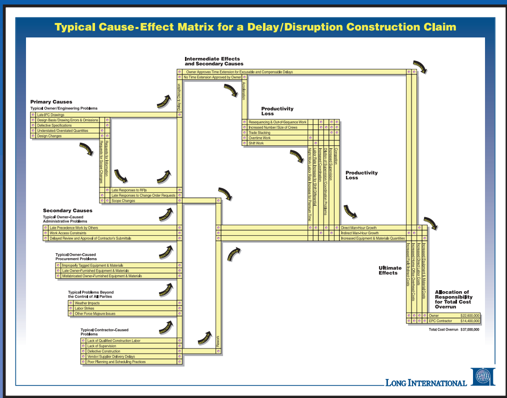

Evaluation of Changes in Process Plant Projects

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1. INTRODUCTION

Owners often issue basic design packages for process plant projects to pre-qualified engineering, procurement, and construction (EPC) contractors as part of a bid request. Owners may represent that the basic design is sufficiently defined to enable the EPC contractor to prepare a fixed-price bid for the final design, procurement, and construction of the facility. Despite these representations, and after the contract is signed, owners frequently initiate what they believe to be simple design changes to the EPC contractor's scope of work. Under most contracts, the EPC contractor is required to submit, in advance of performing the changed work, its change order price including all associated cost and schedule impacts. Cumulatively, design changes costing five to ten percent of the original contract price of a process plant project are not unusual.[1] However, the delay and disruption costs alleged to be associated with higher percentages of changes can be a significant and painful surprise to the owner should the EPC contractor submit a cumulative impact claim at the end of a project.

The price tag for such delay and disruption claims can rise to "unbelievable" magnitudes, especially when a significant number of the changes occur late in the final design work schedule or during construction and the cumulative direct cost of the approved changes is considerably greater than ten percent of the original contract price. In such cases, a comprehensive examination considering the overall cause-effect relationships of design changes, coupled with all of the other problems that occurred during the project, can be performed to determine whether the magnitude of the EPC contractor's alleged cost increases over its current contract price are reasonable and compensable. An equitable resolution of responsibility for these increased costs must also take into account the EPC contractor's responsibility for problems that occurred during the project. Allocation of the EPC contractor's increased costs that directly or indirectly result from the owner's design changes is central to the resolution of complex delay and disruption claims.

This article discusses the uniqueness of design changes on process plant projects and how such changes can have a significant ripple effect on the project's engineering, procurement, construction, and start-up work activities. First, the potential effect of changes on various equipment operations in a process plant is presented. Second is a discussion of the need to understand, agree upon, and analyze the totality of the scope of changes. Third, the effect of changes on the various process operating conditions of a process plant is examined. Fourth is a discussion of the various cost considerations that should be contemplated in evaluating changes to the design of a process plant. Next, the potential effect of a change on environmental and safety designs and hazardous operations reviews is addressed. Finally, the need for the owner and the EPC contractor to consider the effect of changes on multi-discipline design coordination and fabrication of specialty process equipment is emphasized. Accompanying this text is a diagram that illustrates the overall cause-effect relationships of design changes and other problems that can lead to delay, disruption, and increased costs of a highly impacted project.

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[1] William Schwartzkopf, *Calculating Lost Labor Productivity in Construction Claims* at p. 47 (1995).

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2. PROCESS EQUIPMENT OPERATIONS ARE CONNECTED

Process plants differ from other construction projects because they use mechanical, chemical or other process equipment to alter the state of matter or composition of the feedstock material streams (solid, liquid, or gaseous phase) to produce different products. The products are usually changed in their chemical composition through various process equipment, such as reactors, distillation columns, compressors, heat exchangers, furnaces, separation vessels, filters, kilns, pelletizers, crystallizers, and others. The products may also be different in their temperature, pressure, and state. In process plants, the chemical composition, temperature and pressure changes are usually accomplished using several process unit operations.

Process unit operations are like a manufacturing assembly line with the output of the previous process operation or equipment item becoming the input or feed to the next process operation or equipment item. Therefore, the impact of a design change to one process operation and its associated equipment can have a ripple effect[2] on the design of successor process equipment. As design changes occur, the effect on the design of successor equipment must be constantly evaluated. This means that, beyond defining the design aspects of the process equipment, the process engineer also must coordinate with all other engineering disciplines to ensure that the proper design basis is considered in the civil, structural, mechanical, electrical, and instrumentation designs. Likewise, changes to the process design will often have a ripple effect on the work performed by other engineering disciplines. Such ripple effects often manifest themselves as delays, disruption, loss of productivity, and related increased man-hours and costs if the changes are numerous or significant in overall magnitude, and particularly when the changes occur late in the design process or during construction.

3. SCOPE OF CHANGES MUST BE UNDERSTOOD, AGREED UPON, AND ANALYZED

A change in the material properties from upstream process unit operations may affect and change not only the very next process unit operation in the chain, but also equipment design and unit operations several steps downstream in the overall plant operation. For example, a change in the temperature of a liquid process stream flowing out of a reactor may not only require a design change in the water-cooled heat exchanger that is used to cool the reactor product, but the design of the cooling tower may also need to be altered as a result of this change. This change might affect not only the size, civil design, and electrical requirements of the cooling tower, but also the size of the water pipelines circulating cooling water to the process equipment.

Thus, another important and unique characteristic of process plants is that the scope of the change may not be limited to the directly affected process equipment or even the next downstream process equipment item. The scope of the change must be identified and analyzed

[2] Ripple effects are also referred to as knock-on effects or impacts.

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for its potential impact on each downstream process equipment operation and all utilities affected by the change, such as fuel gas and oil, cooling water, steam systems, inert nitrogen systems, plant air requirements, and electrical power requirements. Each process equipment item has different operating and design factors (temperature, pressure, composition, flow rate, etc.) that affect its metallurgy, desired operation and products, including design considerations of cost, environmental emissions, and safety.

Not all changes to a process plant are process changes. This point is made because the impact of process changes on the overall multi-discipline design integration of equipment, piping and instrument systems can be significant, whereas non-process changes may not affect more than one equipment, piping, or instrument item. Process changes include changes to the process flow diagrams (additional or deleted equipment) that change the chemistry, heat and material balance, flow rate, pressure, and temperature, and changes to the primary process control instrumentation. Changes to the P&IDs involving manually operated valves, maintenance piping, local instrument indicators, and other instrumentation that does not automatically control the process conditions, as well as changes to structures, insulation, painting, civil, and electrical systems, are not process changes. However, these non-process changes may result from process changes and, therefore, need to be considered in the overall cost and schedule impact of a process change.

For example, adding a drain valve on the low point of a piping system to drain the fluids during a maintenance shutdown would not be a process change even if it affected piping in the processing part of the plant. Adding local instruments, such as a pressure or temperature indicator, also would not be a process change. Another example of a non-process change would be adding a utility station that supplies air for pneumatic maintenance tools or water pipes for safety showers and wash down stations. Commonly, these types of non-process changes may not be changes in scope. Instead, owners may argue that the incorporation of these items into the final engineering design is design development and should have been included in the EPC contractor's scope of work, schedule, and costs.

The time and resources required to evaluate the potential cost and schedule impact that a change may have on the engineering, procurement, and construction of a process plant may not be fully predictable. This uncertainty is caused by the equipment, material, instrument, utility, and design and operational variables that may result from a change. For example, a change in the operating temperature of a reactor may also change:

1. The steam requirements to heat the reactor, which could change the size of the boiler, fuel gas or steam piping;
2. The cooling water requirements to cool the product stream exiting the reactor, which in turn might change the size of the cooling tower, cooling tower circulating pumps, water pipelines, and associated electrical, structural, and civil design requirements;

3. The insulation requirements for the affected equipment and pipelines;
4. The reactor steel and pipe metallurgy design requirements; or
5. Potentially, other equipment, instrument, and other changes.

The EPC contractor's change order proposal usually must contain the following information:

1. The initiator – owner or contractor;
2. Reason(s) for change (operability, maintenance, safety, environmental; engineering or construction errors by others, etc.);
3. Description of the change with respect to facilities and services;
4. Impact on the contract price including all direct, indirect, delay, loss of productivity, acceleration, and impact costs;
5. Impact on the project completion date with supporting schedule documentation;
6. Impact on the project's utilities or process requirements, as applicable;
7. Definition of any impact on the contractor's guarantees; and
8. Definition of the latest date for the owner's approval of the change without affecting the project completion date.

When the EPC contractor submits its change order proposal to obtain the owner's approval to proceed with the change, the EPC contractor may not be able to satisfy the contractual requirements to include all such cost and schedule impacts in its change order proposal. This problem occurs because, at the time that the change order proposal is submitted, the contractor may not be able,[3] or does not apply the needed resources and take the time, to accurately estimate the materials, man-power, and schedule impact required by the engineering, procurement, and construction disciplines to accomplish all of the items of work affected by such changes.

The owner's decisions about performing the change may be, in part, based on minimal or no effect of the change on the project schedule. When a contractor has deliberately misled an owner regarding the schedule impact of a change, the contractor may not later be able to benefit from the owner's detrimental reliance on the contractor's misrepresentation of schedule impact.

[3] Typically, the Contract specifies the amount of time that the contractor is allowed to prepare its response to the owner's Change Request. The amount of time allowed may not be sufficient to fully evaluate the requested change.

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4. PROCESS OPERATING CONDITIONS

Unlike other engineered projects such as highways or buildings, process plants must be capable of being started up, shutdown, and operated safely and efficiently under a variety of temperature, pressure, and flow rate conditions. Because process plant operating conditions are dynamic, the scope of a change and the appropriate design modifications for all affected equipment and utility systems must be evaluated under start-up, normal/steady state, turndown, and upset or abnormal operating conditions. The design considerations that are used for evaluating the impacts of each particular change on a process plant are fundamentally the same as those used in the original design process to confirm that the equipment designs are still valid, safe, and optimal for the new process conditions created by the change. Whenever a change is introduced, each operating parameter of the process plant must be evaluated in order to determine not only the required equipment and material changes, but also the engineering, procurement, and construction resources required to accomplish the change.

- **Steady State Design.** The initial operating parameter considered in the design of process plants is "steady state," or normal operating conditions. Steady state design considers the design process conditions for each process step to operate as planned, transferring usually by pipelines the output product(s) from the initial process equipment operation and feeding those products to the downstream process equipment. Equipment and instrumentation are designed such that the required process conditions (temperature, pressure, flow rate, and composition of the process solids, liquids, or gases that are created or used in each process step) will produce the intended product streams. "Steady state" implies that there is no change in the process conditions over time, and that there is balance between the sum of all material and energy entering and exiting each process equipment operation and the entire process plant as a whole. Process engineers refer to this fundamental condition of the steady state design as *"the design heat and material balance."* These balances often involve hundreds of process and utility streams and energy (heating and cooling) inputs and outputs.

  When a process change occurs, the EPC contractor must first evaluate the effect of the change, if any, on the steady state heat and material balance. Changes could affect the size of equipment, piping, and control valves as well as civil, structural and electrical requirements.

- **Maximum Product Output and Turndown.** Process plant production facilities may need to be operated at increased or reduced production flow rates compared to "steady state" flow rates. For example, market conditions may require higher or lower quantities of products to be produced during certain periods of the year, requiring an adjustment to inventory or production rates. Also, there may be a disruption in the product distribution facilities or other processes supporting the process plant operations, such as water, fuel, or power supply. Significant time is required to completely shutdown and start-up a large process plant such as an oil refinery, ethylene plant, or a fertilizer plant. Unplanned start-up and shutdowns of process plants also can result in degradation of product quality as well as an increased risk of emissions or accidents. The need to reduce production is often only temporary. For example, the economics of a complete shutdown and start-up of a large oil refinery unit may require the coker to operate safely and efficiently at reduced rates rather than to shut the unit down when full capacity operations are not required.

Therefore, all components comprising each process operation (piping, equipment, materials, utilities, instrumentation, pressure relief devices, etc.) must be designed and sized to operate and control at the full production capacity and at reduced operating rates. The affect of changes on equipment and materials designs for maximum and reduced product flow rates must also be considered when evaluating changes to process plants. Failure to evaluate the effect of process changes on maximum and reduced flow rate conditions could cause costly field modifications, delays in the completion of construction, and start-up and operating problems.

- **Maintenance and Unusual Operations.** Almost every process plant has unusual operations designed to produce special products or operations connected with the maintenance of the facility. For example, the design of certain reactors must facilitate catalyst removal and change-out. Common design considerations for process plants also include the safe use of isolation equipment during maintenance, the design of separate utility connections such as inert gas (nitrogen), steam, and plant water to enable special operations, and additional piping and tankage used during unusual operations.

  Therefore, changes to the design of process plants must be evaluated for their potential effect on unusual and maintenance operations. Failure to evaluate the effect of process changes on unique or maintenance operations can lead to any number of expensive later changes.

- **Dynamic (Unsteady State) Design.** Process plants must also be designed to operate safely at dynamic (unsteady) state operations, including cold start-up, recovery from process operating problems, and planned shutdown conditions. Under unsteady state design situations, the process units are not operating in balance and the process conditions (temperature, pressure, and flow rates) within the process steps may fluctuate.

Therefore, designers of process plants must consider unsteady state operating conditions whenever a process change is made. Design considerations should be reviewed under the unsteady state design process conditions to ascertain which systems might be affected by a change. Such reviews should include considering increased utility amounts (steam, power, cooling water, inert gas such as nitrogen), changes to the operating characteristics of mechanical equipment (kilns, reactors, pumps, furnaces, compressors, etc.), diverting of off-specification products during start-up and shutdown, and evaluations of temperature increases and decreases of process material in the pipelines and equipment to reduce stress on piping, connections and vessel metallurgy.

Unsteady state operations may require additional equipment, instruments, and piping or even additional process operations. The effects of a process change on unsteady state operations must be evaluated by the process and other discipline engineers to avoid extensive delays in the commissioning and start-up of the facility, production loss, unsafe operations, environmental problems, or late field modifications.

5. EFFECTS OF DESIGN CHANGES ON PROJECT COST

The owner and the EPC contractor should both be concerned about the cost impact of a change. The owner should evaluate whether the EPC contractor's engineers have optimized the design resulting from the change, and have charged a reasonable price for the changed work. In addition to the direct cost of the changed work, the EPC contractor's estimators and schedulers must also quantify the indirect cost and schedule impacts to the project that result from implementing the change. To ensure that a complete evaluation of a change is addressed before its implementation, three cost variables should be considered in evaluating changes to the design of a process plant:

- **Capital Cost.** Design requirements are the primary factor that influence the initial capital cost of a process plant. The design phase is the optimum time to address constructability considerations that can save both time and cost during construction. Major equipment items and bulk materials comprise the largest individual cost elements of the process plant. For example, the diameter of the process pipes, the material types (stainless steel v. carbon steel), the need for insulation or heat tracing and the use of control valves in the lines must all be optimized in order to mitigate project cost. A change that increases the diameter of just one pipe run by one inch can have a cost impact of tens of thousands of dollars and cause significant delay if the change occurs during the construction phase. To further this example, a construction phase change in pipe size may cause significant delay and disruption and increased costs as a result of the need to: purchase additional pipe, flanges, gaskets, and fittings; re-engineer pipe supports; re-calculated pipe stress values; resize and repurchase control valves; and re-fabricate pipe connections to vessels or other equipment.

In addition to the cost of installed equipment and materials, the cost of spare parts and operating equipment should be factored into the on-stream reliability of the operating facility. Design changes can also affect the need for and cost of spare equipment and materials.

- **Operating Cost.** Operating costs are also considered in the process design. The effect of process changes on operating costs should also be evaluated, such as the need for insulation to conserve heat, utility consumption, and added operating personnel or control instrumentation. For example, adding piping insulation or heat tracing in a late field modification, in order to reduce operating costs, is often more costly than if these costs were included during the design phase of the project or when the change order was approved.

- **Maintenance Cost.** The cost to maintain operating equipment and instrumentation for the intended life of the process plant is also a major design factor. Changes made to process plants must consider these design characteristics to minimize unexpected increased costs of field modifications to provide a maintainable facility. For example, the direct cost of adding a control valve late in the design phase may be covered in the cost of a change order. However, the cost of the structural modification to provide for access to that control valve may not be considered when the change was approved, but will certainly be brought to the attention of the EPC contractor by the operating and maintenance personnel of the plant prior to or during start-up and commissioning. Making late field modifications to allow for such access is often more costly than the cost would have been if these access considerations were included during the design phase of the project or when the change order was approved.

6. ENVIRONMENTAL AND SAFETY DESIGN AND HAZARDOUS OPERATIONS REVIEWS

Owner specifications, industry standards, and governmental regulations dictate numerous environmental and safety design requirements in process plants. For example, minimum distance requirements from a fire source affect the location of instrumentation and equipment. Safety and environmental requirements define the need for back-up emergency equipment. Requirements are often compounded such as when fire protection design requirements influence the need for alarms, analyzers, and fire protection coating on structural steel. "Hazardous Operations" reviews employ special procedures to evaluate hazards associated with operation of the process plant.

These same environmental and safety requirements may need to be considered when changes are incorporated into a process plant design. Failure to do so may result in more costly field modifications, delayed construction, and accidents and injury to personnel and/or property when these missing items are eventually discovered.

7. THE EFFECT OF CHANGES ON DESIGN COORDINATION, PROCUREMENT, AND FABRICATION OF SPECIALTY PROCESS EQUIPMENT

A process change may also impact multiple engineering disciplines, vendors and suppliers who are performing other planned work to complete the project. This impact is in addition to the operational effect that an upstream process operational change may have on downstream process equipment and operations. The personnel performing this "other planned work" are also controlled by budgets and time constraints to complete their part of the project. The time and cost for these disruptions to the unchanged part of the project are often not fully considered in the direct cost of a change.

As the effects of change impacts are determined, multiple engineering disciplines and specialists in certain process operations may need to be called upon to identify and analyze any necessary design adjustments. These analyses include how the system will be designed and constructed as well as how the changed plant will react under different operating parameters. Such analyses can be time-consuming and, as a result, may well delay critical engineering deliverables that are needed for procurement of equipment and materials or Issued for Construction drawings.

Changes can also have detrimental effects on fabricators of specialty equipment used in a process plant. Production schedules require fabricators of specially designed equipment to operate their facilities in a production line mode. If a change requires a hold to be placed on equipment, that equipment may be pulled from the fabrication assembly line so that other equipment can be fabricated. Therefore, the overall delay to specialty equipment can often be more than the time required to provide the changed specification to the fabricator. These increased fabrication costs and schedule impacts need to be considered as part of the change order costs. If the change is not coordinated with the vendor, modifications must be made in the field or new equipment and materials must be purchased and delivered, adding further delay and disruption to the project.

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8. SUMMARY AND CAUSE-EFFECT MATRIX

A single change – and especially a blizzard of changes – introduced late into the design of a process plant project can extend the contractual completion date of a project, cause significant delay and disruption, and significantly increase project costs. The multiple layers of review and analysis that are required for the implementation of changes within a process plant project are common, unlike many other sectors of the construction industry. What at first might be considered a simple change may well result in numerous design, procurement, and construction modifications because of this complex cause-effect relationships so unique to process plants. Failure to fully evaluate the cause-effect relationships may have unknown or unintended results on the final cost and schedule of the project. Therefore, each change introduced into a process plant project must be carefully analyzed for all design, procurement, construction, turnover, pre-commissioning, start-up, operations, maintenance, safety, regulatory, and environmental considerations. The later in the project a change is introduced, the more disruptive the change implementation becomes to the already completed design, as well as to the already constructed components of the plant affected by the change.

If the EPC contractor is experiencing multiple changes to its scope of work emanating from process, scope, and other types of changes, as well as other delays and performance problems, sorting out the cause-effect relationships in order to allocate responsibility for delay and loss of productivity often cannot be accurately determined until after the completion of the project. As previously stated, the EPC contractor may be contractually obligated to include all schedule and cost impacts in its original change order pricing. Such contractual requirements complicate the contractor's recovery of change order impact costs.

Design changes are usually not the only cause of delay and disruption to the engineering, procurement, and construction of a highly-impacted process plant project. Other contributors often include errors and omissions in the basic design package supplied by the owner, defective specifications, late owner responses to the EPC contractor's requests for information, late and defective owner-furnished equipment and material, weather impacts, strikes, force majeure events, underestimated quantities, and EPC contractor performance problems during the engineering, procurement, and construction phases of the project. Sorting out these variables in order to properly and equitably allocate the responsibility for delay and increased costs for all problems that have occurred during the project can be a complicated challenge.

When delays and disruption occur, contractors often submit requests for time extensions. If the owner refuses to grant a time extension for excusable delays, the contractor may be directed to accelerate to mitigate the excusable delays and avoid liquidated damages for delays that were caused by the contractor. Such acceleration often leads to loss of productivity, which results in increased construction man-hours and costs. Therefore, while the design changes may start out as the primary causes of delay, disruption, and increased costs on a project, the effects of these changes on the overall time and cost for completion of a process plant are typically intertwined and may be concurrent with all of the other problems that have occurred during the project. Diagrams such as in the Cause-Effect Matrix shown in Figure 1 are helpful in tracing the responsibility for the design changes and other primary and secondary causes of delay and disruption, intermediate effects and other secondary causes, and the ultimate effects and associated increased costs of all problems that occurred during the execution of the project

A thorough understanding of the engineering, procurement, and construction sequences and procedures for a process plant project is vital in order to comprehensively quantify all potential schedule and cost effects during the change order pricing, review and approval process. This understanding is also essential to avoid and/or resolve disputes over the alleged cost of such changes at the end of a highly-impacted project, one that usually involves claims and costly arbitration or litigation.

About the Author

Richard J. Long, P.E., P.Eng., *is Founder of Long International, Inc. Mr. Long has over 50 years of U.S. and international engineering, construction, and management consulting experience involving construction contract disputes analysis and resolution, arbitration and litigation support and expert testimony, project management, engineering and construction management, cost and schedule control, and process engineering. As an internationally recognized expert in the analysis and resolution of complex construction disputes for over 35 years, Mr. Long has served as the lead expert on over 300 projects having claims ranging in size from US$100,000 to over US$2 billion. He has presented and published numerous articles on the subjects of claims analysis, entitlement issues, CPM schedule and damages analyses, and claims prevention. Mr. Long earned a B.S. in Chemical Engineering from the University of Pittsburgh in 1970 and an M.S. in Chemical and Petroleum Refining Engineering from the Colorado School of Mines in 1974. Mr. Long is based in Littleton, Colorado and can be contacted at rlong@long-intl.com and (303) 972-2443.*

Typical Cause-Effect Matrix for a Delay/Disruption Construction Claim

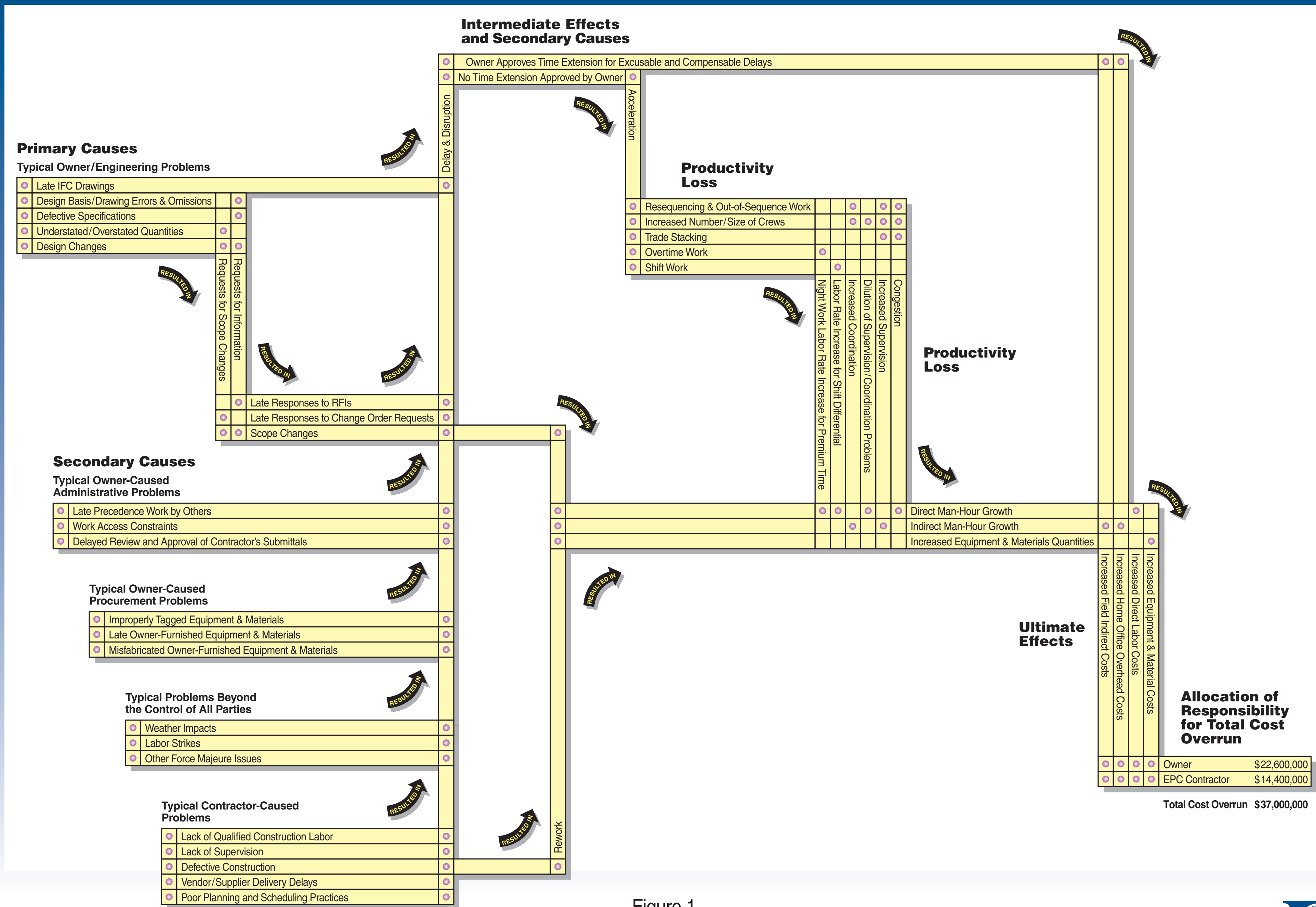

Figure 1