Making Sense of Your Project Cost Estimate

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Using different estimation levels, determined throughout the engineering phase of a project, can save time and avoid surprises when it comes time to bid

If your estimate for a project's capital cost is too high or too low, incomplete or wrong, a poorly developed scope is the mostly likely cause. In almost all cases, project cost estimating is more accurate than the scope used to develop the estimate. (To develop a good project scope, please refer to "Get Your Scope Straight for Project Success," *CE*, February, pp. 36–38). Yet good scope definition is only part of the answer.

What happens in estimating?

A project estimate is a series of activities building on each other.

- Scope development, or defining what will be done, by series of specific engineering documents
- Estimating or gathering cost data and applying algorithms to determine costs based on experiential factors
- Applying risk-management methods to better define a cost basis for major impact items
- Developing a contingency based on the above

Each step depends on the prior steps. In practice, project estimating is more accurate than scope development because if we can think of something, we can usually place an accurate value on it based on experience. Most inaccurate estimates are caused by things we forgot to include, things we decided to leave out, wishful thinking, and things in the realm of "known unknowns."

Zeroing in on the uncertainty

A study undertaken in 2000 [*1*] looked at 24 variables and 84 contractors and determined that the following seven factors are relevant to producing a good project cost estimate. In order from most to least influential, they are:

- Project complexity
- Technological requirements
- Project information
- Project team requirements
- Contract requirements
- Project duration
- Market requirements

Even small projects can be very complex. In some cases, a project may have multiple stakeholders, each with a differing view of the project result. Managing multiple stakeholders complicates a project.

Technology requirements create complexity. Consider new technologies that may not be familiar to you, such as continuous emission monitors (CEMs) for flares, or technology for reducing NOx emissions or sulfur in fuels. Smaller companies without an environmental knowledge-base can be frustrated getting up to speed on these technologies, and that increases your project's complexity.

The next item of importance is project information. A good part of this requirement lies in *scope definition*, discussed in the article referred to above. A good estimate is not possible without good input, and a bad scope document cannot reasonably be expected to lead to a good project.

Project-team requirements may or may not influence your estimate much. Is your team local, or are you relying on distant team members with infrequent meetings? Is your team committed, or are you sharing members who have other important duties? You want to know who will be on your team, and to be sure of their commitment, so you can have confidence in them. Try to influence the makeup of the team so that you do have confidence and get them to "office together" for good communications — people on the team should be located near each other.

Timing is important

Project timing might be a problem if you are handed an old project and are told to do it at last year's estimated cost. A lot can change in a year. Metal and energy prices especially, have moved steadily upward. Look over the old project and re-estimate these items before committing to old cost numbers.

Look at schedule impacts, too, as current deliveries of pumps and vessels can take longer than your old plan anticipated. Some projects are currently paying premiums for shorter deliveries. Not only must the old numbers be brought up-to-date, but forward escalation will need to be added, too.

Cost estimators

Project-cost estimators look at the following things to develop the cost of your project, and each of these can be a source of uncertainty:

- Items that must be purchased, and how much they cost. (equipment, bulk materials and proratables)
- The sales tax rate and applicability (sales tax)
- Delivery costs for equipment and materials (freight)

TABLE 1. A MATRIX FOR ESTIMATING DELIVERABLES

The Estimate quality desired dictates the engineering deliverables required for sound price estimating. The matrix below can be used for planning your estimate package

Estimate classes:	Class V	Class IV	Class III	Class II	Class I
Descriptions:	Order of magnitude estimate	Preliminary estimate	Budget estimate	Control estimate	Definitive estimate
Also called:	Curve quality estimate or cost capacity estimate	Equipment factored estimate or conceptual estimate	Software conceptual estimate	Modified software estimate or project estimate	Detailed estimate or check estimate
Typical purpose:	Early cost indication/planning	Studies/planning/ evaluate alternative processes	Studies/planning/ some AFEs	AFE estimates/ cost-plus bids	Lump sum bids
Method of preparation:	Cost-capacity curves, historical or published data (dollars per barrel, etc.)	TIC factored from equipment cost using Lang/Guthrie factors via est. pro program	Estimator, with perhaps minor amount of manual estimating. Adjusted at summary level for unit rates	Combination of computer and manual methods. Fewer quotes used than in class I	Primarily manual, using in-house programs, but other software may be used as supplemental tool
Normal accuracy range:	+50%/-30%	+35%/-20%	+25%/-15%	+15%/-10%	+10%/-5%
General information	**V**	**IV**	**III**	**II**	**I**
· Plant capacity	X				
· When & where plant will be built	X	X	X	X	X
· Narrative scope of work				X	X
· Process flow diagrams (PFDs)		X			
· Plot size		X			
· Plot plan			X	X	X
· General arrangement dwgs.				X	X
· Project schedule			X	X	X
· Project execution plan				X	X
· P&IDs			X	X	X
· Soils & other site data			X	X	X
Process equipment	**V**	**IV**	**III**	**II**	**I**
· Sized equipment list		X	X	X	X
· Equipment layouts				X	X
· Equipment data sheets/specs.			X	X	X
· Equipment pricing			X	X	X
· Equipment setting manhours			X	X	X
Electrical	**V**	**IV**	**III**	**II**	**I**
· Electrical equipment list		X	X	X	X
· Electrical layouts/sketches				X	X
· Electrical equipment pricing			X	X	X
· Electrical one-line drawings			X	X	X
· Electrical bulk MTOs			X	X	X
· Electrical bulk-pricing			X	X	X
· Electrical manhours			X	X	X

(Continues on p. 56)

- The timing of the project and the possibility that costs might rise before purchase orders are placed or before labor is expended (escalation)
- Site preparation requirements (hours and direct labor/hour, rentals, sub contracts)
- Equipment-installation costs (hours and direct labor/hour, rentals, sub contracts)
- Installation costs for bulk materials (piping, foundations, structural steel, and so on; hours and direct labor/hour; "tagged" items, such as electrical equipment, instruments, DCS, and so on; hours and direct labor/hour)
- Construction-indirect costs (construction equipment, temporary facilities, small tools, and so on)
- Engineering cost (engineering)
- Management team (management)
- "Known unknowns," such as bad weather, labor problems or material shortages (contingency)
- Permits, legal costs and other overhead (overheads)
- Non-direct field labor
- Insurance

To assist in getting a good estimate, you must understand how risky each one of these line items is to your particular project.

Risk management

You understand the Pareto principle, which states that 20% of causes drive 80% of outcome, or that 20% of your project activities will account for roughly 80% of the potential risk. The trick is to identify the few items that can break your budget and focus more attention on them. The common denominator of these items is that:

- A wrong decision is very costly and may throw you over your budget if you guess wrong, and
- They can be anticipated and dealt with by not wearing blinders and using knowledgeable resources in the scope development and estimating stages

To use risk management to reduce project risk, look at your estimate by line item and identify those items with the most uncertainty and having a large cost risk. Your project-cost estimator can help you identify these items. They can tell you which items have a fuzzy basis and can easily get more expensive if the assumptions are wrong. An example might be whether

TABLE 1. A MATRIX FOR ESTIMATING DELIVERABLES *(Continued from p. 55)*

Estimate classes:	Class V	Class IV	Class III	Class II	Class I
Instrumentation	V	IV	III	II	I
· Instrument list /MTO			X	X	X
· Instrument pricing			X	X	ENG/PUR
· Instrument MTO			Computer	EST/ENG	ENG
· Instrument bulk pricing			Computer	Computer	PUR/EST
· Instrument manhours			Computer	Computer/EST	EST
· DCS/control system pricing			Computer/ENG	ENG	ENG/PUR
Structural	V	IV	III	II	I
· Structural sketches/definition				ENG	ENG
· Structural MTO			Computer	Computer/EST	EST
· Structural materials pricing			Computer/EST	PUR/EST	PUR
· Structural manhours			Computer	Computer/EST	EST
Civil	V	IV	III	II	I
· Concrete sketches					ENG
· Civil/sitework definition			ENG	ENG	ENG
· Concrete & civil MTO			Computer	Computer/EST	EST
· Concrete & civil materials pricing			Computer/EST	Computer/EST	EST/PUR
· Concrete & civil manhours			Computer	Computer/EST	EST
Architectural	V	IV	III	II	I
· Building sizes & descriptions			ENG	ENG	ENG
· Building pricing			Computer/EST	EST/SUB	SUB
Piping	V	IV	III	II	I
· Piping sketches					EST
· Piping & fitting MTO			Computer	EST/Computer	EST
· Valve MTO (incl. PSV & CVs)			Computer	EST	EST
· Valve pricing (large bore)			Computer/EST	PUR/EST	PUR
· Offsite pipe fabrication pricing			Computer	Computer/EST	EST/PUR
· Pipe material pricing			Computer/EST	PUR/Computer	PUR/Computer
· Piping manhours			Computer	EST/Computer	EST
Protective coatings	V	IV	III	II	I
· Paint, Insul., FP MTO			Computer	Computer	EST
· Paint, Insul., FP pricing			Computer	EST/SUB	EST/SUB
Overhead & indirects	V	IV	III	II	I
· Indirect cost estimate			Computer/EST	CONST/EST	CONST/EST
· Eng. / home office estimate			Computer/ENG	X/ENG	X/ENG
· Escalation			Computer/EST	EST	EST
· Contingency/risk			Computer/EST	EST	EST

CONST = by Construction; PUR = by Purchasing; ENG = by Engineering; SUB = by Subcontracts; X = by Project; TIC = total installed cost; EST = by Estimating; AFE = authorization for expenditure

a single large reactor or two smaller ones will be used, and not having a solid estimating basis for how the larger one can be shipped, transported to the site and rigged into place.

In many cases, instrumentation and electrical work and materials are the biggest risk factors in a project. Instrumentation/electrical (I/E) is often the last thing to be engineered. It can represent 20% (or more) of the total project cost. In addition, it isn't well understood by the average person, so it often doesn't draw the attention it needs at early project stages. Finding out after you bid on a project that you will need a new electric substation, motor-control center (MCC), process-control-computer components, new underground conduit or new cable racks in tight racks can add cost quickly. Do some homework here, and it will be time and money well invested.

Pipe racks represent another early risk item, especially if a lot of big-bore pipe is required and racks are nearly full.

Contamination remediation for lead paint, asbestos and contaminated soils can drive up costs if not anticipated. Don't forget permits. You will require permits to have contaminated materials handled and disposed of legally, and remediation companies may do the actual work at hourly rates above your local-labor rate.

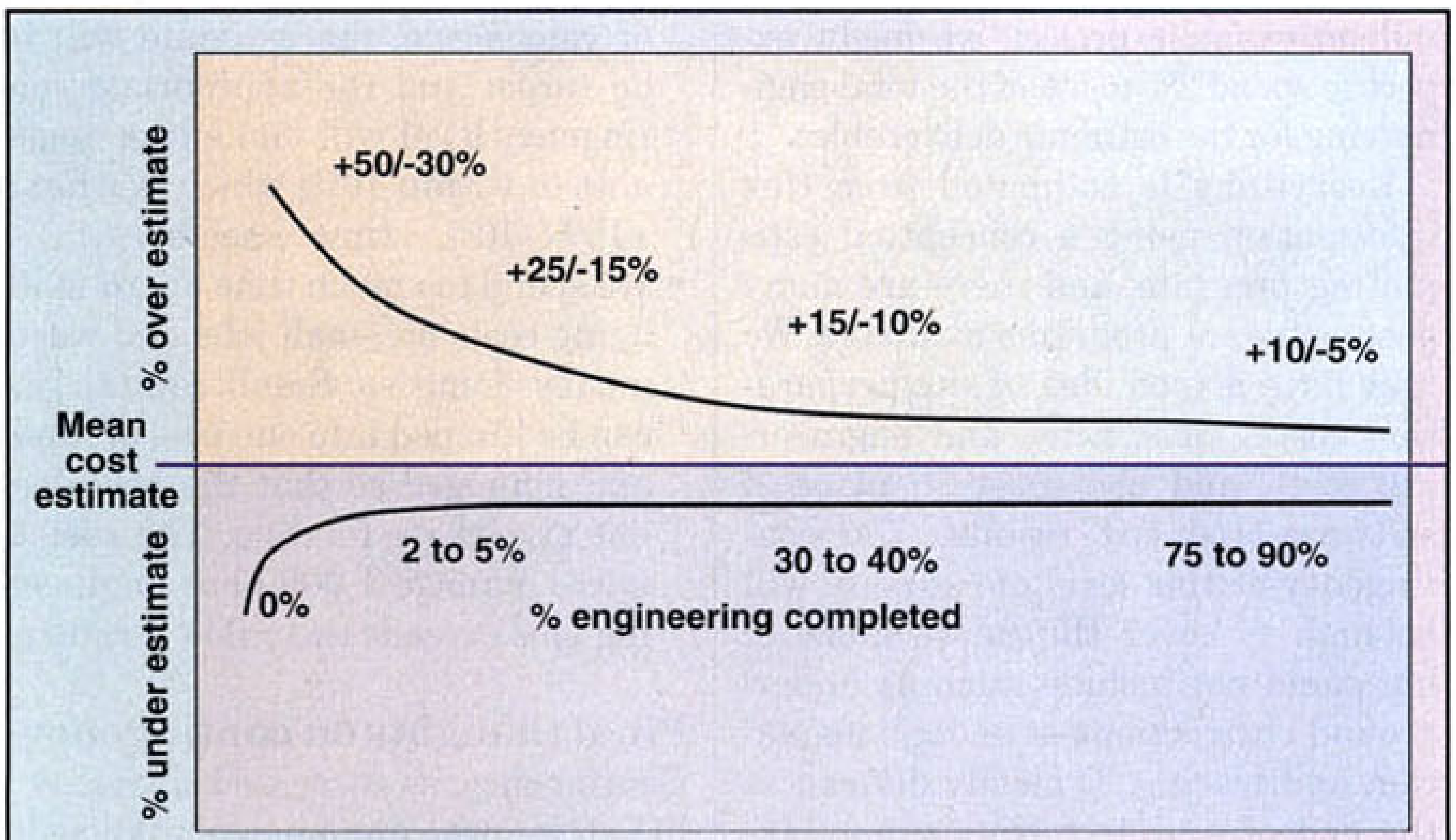
New flares and process-discharge points will require a lot of preliminary effort to secure state and federal permits. Don't forget required analyzers for point sources, such as CEMs for flares.

Your project-cost estimator can show you the line items that might be problematic. These are cost risks that you can mitigate by doing more targeted engineering work, such as: getting a better idea of field electrical capacity; checking for additional breaker space in the MCC; getting a better look at that 24-in. valve capacity; getting your annual temperature profile for your cooling water tower; or obtaining your cooling-water-pump curves to see if you can really make capacity in summer. By identifying such major risk items and further working to define them, you reduce your estimate risk.

As a guideline, watch any single items approaching 0.05% of your total estimate. On a $100-million project, these are items exceeding $500,000. A 20% uncertainty on such an item's cost is $100,000 at risk! Of the thousands of total items, only a few — about 20% — will be at this level. You can surely justify some engineering time to mitigate a $100,000 risk.

Contingency

Contingency is the last item you will determine for your estimate. Contin-



Estimate qualities are standard. Percent engineering completion is an approximation and somewhat project dependent

FIGURE 1. Shown here is a so-called estimating tunnel. Different estimation levels are used during the course of a project. As the engineering gets closer to completion, the cost estimate approaches the actual project cost to +10/–5%

TABLE 2. ESTIMATE LEVELS AND WHEN TO USE THEM

Type	Range	Used for
Order-of-magnitude estimate	+50%/-30%	Early-cost indication/ planning
Preliminary estimate	+35%/-20%	Studies/planning/evaluating alternative processes
Budget estimate	+25%/-15%	Studies/planning/some AFEs*
Control estimate	+15%/-10%	AFE estimates/cost-plus bids
Definitive estimate	+10%/-5%	Lump-sum bids

* AFE = authorization for expenditures

gency represents "known unknowns". Contingency must be protected and used properly.

For example, contingency is *not* used for the following:

- Additions to the project scope; these are handled as scope changes, and are estimated separately for cost and schedule impacts using project-change notices
- Handling last-minute changes to governing standards or regulations; these should be handled as scope changes as in the point above
- Making up for time lost to avoidable interferences, such as rework for engineering error; these are variances and may or may not be compensated based on your engineering and construction (E&C) contract. They are also handled as project changes
- Acts of God (or force majeure)

Contingency *is* used for:

- Anticipated but immeasurable impacts due to storms. Excessive rain outs or hurricanes in the U.S. Gulf Coast, tornadoes, and floods all qualify
- Labor strikes
- Vendor problems, such as bankruptcy
- High labor turnover due to market forces creating high labor demand and high wages

Known items are things we tried our best to estimate, but upon which we need to hedge our bet: Examples include price adders for expensive equipment that must be fully engineered before you can get a locked-in cost; or things you are negotiating for, such as rights of way.

Known-unknowns are items that can happen, but you aren't sure will happen, such as bad weather, labor shortages and labor turnover.

Unknowns are things with a very low probability of occurring, but that are very expensive when they do. Ordinarily we use insurance as much as possible to cover the likelihood that these occur, but we do not budget contingency money in the estimate for these items. Acts of God (force majeure) fall into this category.

Look for Monte Carlo methods on the Internet that can assist you to determine contingency. Entering "project contingency" into a search engine is a good start.

A last contingency issue is the use of hidden contingency to fatten an estimate. Each line-item cost must have an auditable basis, such as feet of pipe (dollars per linear foot) or labor hours ($/h), so that management can review the estimate and make rational judgments on its validity. So do not use hidden contingency; keep it as a single line item.

What estimate level to request?

Preparing an estimate costs time and money. Not only do you have the costs of preparing the estimate, reviewing it and finalizing it, but you also have the costs of all the engineering work required to prepare the estimate deliverables. Ask yourself why you need a project estimate, and whom it will be presented to. This is a good way to determine the accuracy level you will require. The matrix provided in Table 1 shows what deliverables are normally required for each level of estimate, although this distinction is subjective and varies somewhat by estimator, company and job. Estimates typically fall into standardized ranges (percentage over/percentage under estimated) based on what they will be used for, as shown in Table 2. These estimate levels are explained further below.

Order-of-magnitude estimate (+50/–30%): For an order-of-magnitude estimate, very little is required except for the desired plant capacity and the location of where the plant will be built. The estimate validity will be based on how closely this project follows past similar projects.

Order-of-magnitude estimates are sometimes called cost-capacity estimates, being based on a new process unit costing, say $X per barrel of product produced daily. But they can also be produced by factoring from the cost of a known unit of a given cost, installation date, capacity, and location. For example, you might say, "a similar project back in 1990 that was half of this capacity and was built in the Northwest instead of Gulf Coast cost us $48 million, so this one is about:

$$\$48,000,000 \cdot f_e \cdot f_l \cdot (2.0)^{0.6} = \$76,000,000$$

where:

f_e = factor for 15 years of escalation (in this example, f_e = 1.1)

f_l = factor for location adjustment (in this example, f_l = 0.949 because its cheaper to build in the new region)

$(2.0)^{0.6}$ = capacity factor to the 0.6 power (0.6 is a commonly assumed exponent for total plants. Tables can be found for various equipment types.)

The estimate mean value is $76 million with a range of + 50% (or $38 million) and –30% (or $22.8 million). Pay particular attention to the +50% side of the number; this is the upper 95% confidence limit. There is only a 5% chance of exceeding $114 million, but there is a 50% chance of going over $76 million. In fact, it is an even bet that the project will exceed $76 million.

Preliminary estimate (+35%/–25%): A preliminary estimate is used to compare competing project options. In a gated-project process[1], alternatives are compared using project-economic indicators, such as net-present value (NPV). NPV requires installed cost and annual operating/maintenance costs for its evaluation.

A few engineering deliverables, typically by process engineers and piping designers are sufficient for this level of estimate. A plot plan, PFDs, sized-equipment list, and a preliminary motor H.P./electrical-load list are enough.

Budget estimate (+25/–15%): An estimate of this level is often used for detailed studies or for project funding authorization. This level estimate requires significant preliminary engineering by all disciplines. Refer to the cost estimate matrix (Table 1) for details of engineering deliverables required. For our $76 million example project, we might expect to spend 2% to 5% of the total engineering for the estimate deliverables.

Everything is estimated from this information using a conceptual estimating program, and there are many good software programs available. We may have a good idea of site preparation costs, labor rates and engineering costs, and use these in place of software-produced results. The contingency at this level of estimate will be high to cover things we know of but could not include, such as underground obstructions or enough insulation and tracing. Typically defined at the end of a project, they simply are not known at this point and we will use factors[2] to create a dollar value for these things. With a good software program, if we tell it that a new DCS or substation is needed, it will estimate those items based on the motor and other power loads and the instrumentation required. If we proceed to authorize the project with this estimate, we would find that while we are only likely to exceed the upper limit 2.5% of the time (5%/2), we have a 50% chance of exceeding the mid point.

Definitive estimate (+10/–5%): The definitive bid is used for lump-sum bids and funding authorization. As the estimate matrix shows, a lot of engineering is required to produce this quality of estimate. Figure on being 75% to 90% complete with engineering in order to have the information required. You are essentially complete with engineering at this stage.

What estimate level to pay for?

I can't answer this question for you. I can, though, give you some opinions to help orient you. In general, the estimate mean value will not change very much if your scope is good. The estimate bands, or uncertainty will improve however, as the engineering is closer to complete.

- It is my opinion that a good +25/–15% estimate can be a useful authorization estimate. If you are certain of your scope, the estimate will be on target and the appropriate contingency level will make it manageable to within 10%, which is what a +15%/–10% estimate achieves
- We spend too much time micro-managing costs on small jobs and waste money doing so. Small capital jobs can be lumped into one pool of funds and managed so that the pool does not exceed its funding. The cost to micro-manage 1,000-hour engineering jobs exceeds the value it returns

Final thoughts on contingency

Contingency, as discussed above, is a list of "knowns and known unknowns" that you are aware of, don't expect to happen, but could happen. You estimated that local productivity is 80% but it can be as low as 70%, so you will cover this in the contingency. If you build in the Gulf Coast area during hurricane season, you might want to add the cost of battening down the hatches and stopping work for three to four days to your contingency allowance. If there is a pending labor strike, add some contingency for loss of time, possible extra security, and so on. Contingency is not the sum of all "knowns and known unknowns", but a percentage to cover the statistical likelihood that some on the list will come true. Many Monte Carlo packages exist to help you determine an appropriate contingency percentage based on your analysis of how good your scope is in most areas. ■

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1. "Construction Management and Economics," *Routledge*, Vol. 18, No 1, January 1, 2000.

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1. A gated-project process is a sequential methodology used by management to evaluate a project at critical points to determine whether to commit additional funding to it or to cancel it.

2. Factored estimates depend on databases of experience to predict things, such as how much insulation and tracing will be required. Factors being factors, the estimator and engineer must collaborate to determine if the result makes sense. Consider personnel-protection insulation as well as hot-cold insulation.