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Cost estimating for turnarounds

Cost estimates for refinery turnarounds can lack accuracy, but lessons learned from capital project estimating could improve matters

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Turnarounds are major events for refineries and other petrochemical facilities. They typically cost significant sums of operational expense (opex) and capital expense (capex) money to execute. They cause lost opportunity cost through lost production while the facility is shut down. If poorly managed, turnarounds offer significant risk of accidents. If poorly executed, they can also be the cause of significant production disruption after startup, due to leaks and other production trips. Hence, there is a potential to save significant sums of money, by ensuring turnarounds are run correctly.

However, despite the large potential for saving money, there has, until recently, been very little focus in the turnaround world on making sure turnarounds are run cost efficiently or on finding ways to improve cost estimating and execution skills. In the past seven to eight years, this attitude has begun to change and turnaround teams are beginning to look at how they can improve. One potentially rich source of ideas on how to improve is for the turnaround teams to examine how their capital project brethren estimate and execute projects. In the capital project world, the potential for "leaving money on the table" due to poor project estimating and execution has meant that decades of time and effort have been spent, and continue to be spent, on developing techniques to ensure that estimation and execution is carried out efficiently.

This article focuses on cost estimation. It does not presume to provide all the answers on how to improve turnaround cost estimates. Rather, it attempts to lay the groundwork for a discussion on how to improve cost estimating in process facility turnarounds. It highlights the point that cost estimating in the turnaround world is currently not very accurate. It then goes on to look at ideas on how to improve cost estimate accuracy, by looking at ideas that might be adapted from the capital project world. In particular, it looks at the stage gate approval system, the development of scope and estimate bases for different levels of estimate accuracy, and at the development of allowances for "known unknowns" and contingency for "unknown unknowns". Finally, it makes some suggestions for the next steps in developing better turnaround cost estimates.

What is a process industry turnaround?

A turnaround (in the context of the process industries) is defined by the American Petroleum Institute as "a planned, periodic shutdown (total or partial) of a... process unit or plant to perform maintenance, overhaul and repair operations and to inspect, test and replace process materials and equipment".[1] Refineries and other petrochemical facilities that run on a continuous rather than a batch production cycle must, every few years, shut down operations to provide access to the production units in order that essential maintenance, modification and inspection work can be carried out that could not be done while the units are in operation.

Turnarounds are events that are planned well in advance and typically take place on a four-to-six year cycle. The length of a typical turnaround execution phase (ie, the period when the facility is shut down and hydrocarbon free) is usually around three-to-five weeks.

The scope of a turnaround typically includes:

- Inspection of equipment to company regulations or governmental rules
- Inspection of pipework for corrosion and erosion damage, both internal (process weak points) and external (corrosion under insulation, or CUI)
- Cleaning, repair and maintenance of equipment, pipework and instrumentation (pulling and cleaning heat exchanger tube bundles, repairing leaks in pipework or checking of pressure relief valves)
- Minor upgrades and modifications to the facilities (items controlled under the "management of change" [MoC] procedures)
- Tie-ins for capital projects.

Historically poor estimation and execution efficiency

Historically, there was a tendency among operating companies to view turnarounds as an inevitable and necessary evil, and to accept that they would "cost what they cost" and "take as long as they take". However, in recent years, there has been a growing recognition that this attitude leaves "money on the table" in the form of the opportunity cost of lost production while the facility is shut down for longer than necessary; and unnecessarily excessive expenditure of money during the turnaround, through running the turnaround inefficiently.

In order to improve turnaround efficiency, there is a need to examine the estimation of costs for turnarounds, the estimation of schedule time, and the efficiency of planning and execution of the turnaround. This article focuses on the first of those three areas, the estimation of costs.

Accuracy of turnaround cost estimates

A cost estimate needs to be accurate in order to provide management with the information needed to decide how to proceed, to allow cash flow planning and to aid in firm control of expenditure.

In a survey of conference participants at the Turnaround Industry Networking Conference (TINC) — Europe, held in March 2011 in Amsterdam, The Netherlands,[2] 83% of respondents said that their turnaround control budget was intended to be a ±10% estimate (see Figure 1).[3] The remaining 17% said that their estimate was supposed to include sufficient contingency/reserve that it was a "not to exceed" number. None said that their budget was intended to be a ±30% estimate.

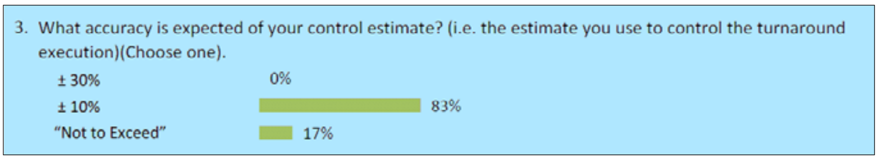

Figure 1 Expectation of accuracy in turnaround control estimates: *vox populi*

We then took a sample of 93 recent turnarounds and in each case compared the total actual cost for the turnaround (including both capital and maintenance work) with the control budget. Figure 2 plots the over- or under-run of the actual costs, expressed as a percentage of the control budget. It shows the mean (the horizontal bar) and 80% confidence range (the vertical bar) of the results in our sample set and compares it to the results we would have expected if the cost estimates truly were ±10%, or if they were ±30%.

Based on the results shown in Figure 2, we can say that turnaround cost budgets tend, on average, to under-estimate the actual cost by around 16% (the distance of the "mean" bar from the 100% point) and the budgets themselves show a variability of closer to ±30% accuracy than their purported ±10% accuracy (the vertical line shows the 80% confidence range around the mean).

Clearly, there is an opportunity to improve cost estimating accuracy in turnarounds.

Comparing capital projects with turnarounds

Cost estimating of capital projects in the process industries has gone through a number of improvements over the years. It may well be that some of the lessons and devices used in capital projects can provide a basis from which to develop a system for better turnaround estimates.

Stage gates

Capital projects

In the capital project world, it is now generally accepted that front-end definition is the key to a successful project. In order to achieve good front-end definition, capital project teams have largely moved toward a stage gated approach, whereby the design proceeds through three distinct stages of ever-improving scope definition.[4] Key points are:

- The length of each stage is a function of the work required to be completed in that stage
- The culmination of each stage is a cost estimate, with the estimates getting more accurate with each succeeding stage. Generally speaking, the feasibility stage of a project results in a ±50% accuracy estimate, the following conceptual design stage results in a ±30% estimate, and the final basic design stage results in a ±10% estimate. Hence, the focus of the stage is in developing a scope basis to meet the estimate basis requirements for the level of accuracy intended
- The project cannot proceed to the next stage without first going through a stage gate review to check whether it has achieved the required scope and estimate basis
- Full funding of the project is usually only received at the end of the third, basic design phase.

The focus, therefore, in the capital project world is on calculating "How much money do we need in order to carry out this scope?".

Turnarounds

In the turnaround world, there has been a movement in recent years towards a form of stage gated approach, in an attempt to improve front-end definition. However, the system is not yet as clearly defined as in the capital project world.

There are some key differences in the way the approach is applied. The length of each stage is (more or less) fixed, based on the amount of time remaining until the turnaround

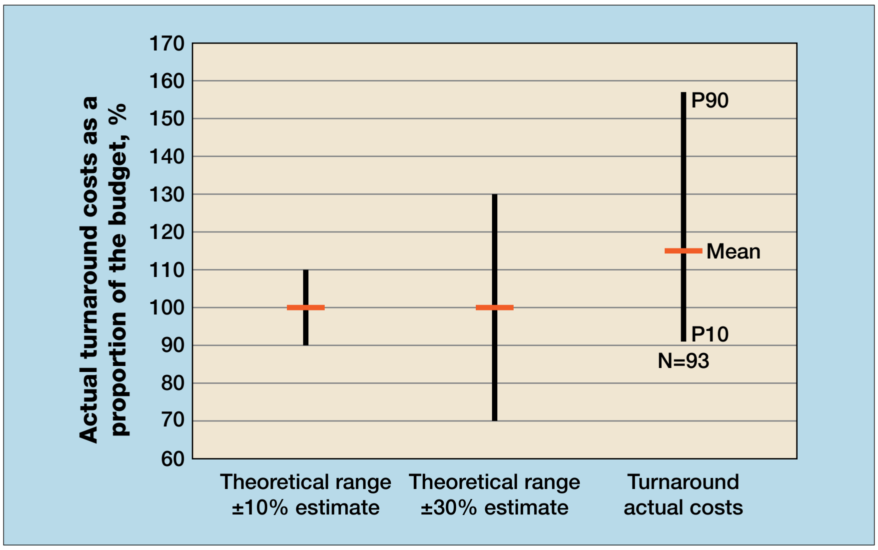

Figure 2 Accuracy of turnaround control estimates: expectation and reality

starts. Generally, by about 14–12 months before the turnaround, the first review of status will be held. A second review may be held around nine-to-six months before and the last review about three-to-two months before.

The stages are not focused on scope definition for cost estimates of a given accuracy. Instead of the issuance of an estimate marking the end of a stage, the ends of these stages are delineated by their proximity to the start date of the turnaround. There are guidelines on what level of scope definition should be expected at each of these turnaround stage gates, but these guidelines are not as universally adopted as their counterparts are on capital projects.

By the nature of a turnaround, refusing to let a turnaround team proceed to the next stage because it is insufficiently prepared at the time of the stage gate review is not usually a feasible option. The budget tends to be fixed back at the ±30% or even ±50% estimate stage. Consequently, with turnarounds, the focus tends to be on "How much scope can we carry out for this amount of money?" rather than the capital project paradigm of "How much money do we need in order to carry out this scope?".

Scope basis and estimate basis

In this section, we make a distinction between the scope basis (the level of definition of the design deliverables and documents) and the estimate basis (the methodology used to calculate costs, based on those deliverables).

Capital projects

In the world of process industry capital projects, the scope basis and the estimate basis are both relatively well defined for various levels of estimate accuracy, from ±50% down to ±10% or better. One well-known example of where this is documented is AACE International Recommended Practice No. 18R-97.[5] Lawrence also lists typical requirements.[4] (Table 1 and Table 2 are adapted from Lawrence, 2008.) In addition, it is accepted practice to document the cost estimate in a written "basis of estimate" document.

	±50% ROM estimate	±30% ROM estimate	±10% control estimate
General project data			
Project scope description	General	Defined	Defined
Facility capacity	Assumed	Defined	Defined
Facility location	General	Specific	Specific
Ground surveys	None	Defined	Defined
Project execution plan	None	Defined	Defined
Contract strategy	Assumed	Preliminary	Defined
Project schedule	Level I milestones	Level II preliminary	Level III – detailed resource loaded schedule
Cost estimating plan	None	Defined	Defined
Engineering deliverables			
Block flow diagrams	Outline	Complete	Complete
Plot plans	None	Preliminary	Complete
Process flow diagrams	None	Complete	Complete
Utility flow diagrams	None	Preliminary	Complete
Project execution plan	None	Preliminary	Complete
P&IDs	None	Preliminary	Complete
Heat and material balances	None	Preliminary	Complete
Process equipment list	None	Preliminary	Complete
Utility equipment list	None	Preliminary	Complete
Electrical single line diagram	None	Preliminary	Complete
Process engineers equipment datasheets	None	Preliminary	Complete
Mechanical engineers equipment datasheets	None	Preliminary	Complete
Equipment general arrangement	None	Preliminary	Complete

Table 1

Early estimate: ±50% — rough order of magnitude

In capital projects, the first cost estimates are usually highly deterministic, using high-level factoring methods rather than the stochastic approach of calculating from the bottom up. The cost of a facility is typically factored off such details as, for example, the production capacity of the new facility, with adjustments made for inflation and location. Such estimates generally have little in terms of scope basis, often merely an outline of the facility capacity

	±50% ROM estimate	30% estimate	±10% control estimate
Basic design	Factored, based on previous, similar facilities (based on production capacity, facility surface area similar metric)	Detailed estimate	Complete
Engineering		Budget estimate, or factored off equipment	Firm quote
Equipment		Budget quotes for major items; database costs for remainder	Firm quotes for major items; budget quotes for remainder
Bulk material		Factored off equipment	Budget quotes based on detailed material take-offs
Construction labour		Factored off equipment	Budget quotes based on detailed material take-offs

Table 2

required. The estimate basis relies on historical data of the total cost of the entire facilities rather than detailed cost data.

Conceptual estimate: ±30%
In capital projects, a considerable amount of work would be completed on the scope basis, coming close to freezing the overall scope and developing many of the design drawings by the time this estimate was prepared.

The estimate basis would have moved from a high-level, deterministic estimate to a mix of the stochastic and deterministic, and the team moves towards Lang factors or other, similar methods to calculate the project cost (factoring off one element of the project scope, most typically the equipment cost).

Authorisation/control estimate: ±10%
By this stage, the scope basis on a capital project is generally very detailed, with completed P&IDs, order specifications for major equipment and so forth. The estimate basis is now stochastic, built bottom up from the material take-offs and using market cost data rather than historical database information.

Turnarounds
There appears to be no document equivalent to AACE International Recommended Practice No. 18R-97 for process industry turnarounds. In the absence of such a document, we have informally surveyed a number of turnarounds to look at the various scope and estimate bases used by the turnaround teams to develop estimates of nominal accuracies of ±50%, ±30% and ±10%.

The first problem we have encountered is that there is some variation in the methods used. Second, the concept of writing down a detailed "basis of estimate" document is something that still has to take root in the turnaround world; hence, understanding how each estimate was developed is difficult. (We were occasionally given documents described by the team as the "basis of estimate", but these were generally extremely simple, high-level notes on the estimate spreadsheet itself rather than a formal and detailed document.) Nevertheless, we have attempted to provide a general overview of the methods being used by turnaround teams for the various estimates.

Early estimate: ±50% — rough order of magnitude
The early estimate is frequently merely the cost of the last turnaround, adjusted for inflation, with perhaps an educated guess as to how the scope may have grown or shrunk since the last turnaround. The scope basis is therefore merely the previous turnaround scope, and the estimate basis uses that historical total cost.

Conceptual estimate: ±30%
On turnarounds, teams appear to aim to have the overall scope frozen and challenged by this point. However, this has not always been achieved. In terms of deliverable documents for the scope basis, the mechanical workpacks are usually developed. The estimate basis is a mix of deterministic and stochastic, as the mechanical work packs are costed (in-house) in some detail, but the other work (electrical, instrumentation scaffolding, insulation, and so on) is usually factored off the mechanical costs, using historical factors.

Authorisation/control estimate: ±10%
Some turnaround teams do now have all discipline scopes developed and externally costed. However, in our experience, the number of teams that take their estimates to this level of detail are relatively few, despite the fact that most teams claim their control estimates are ±10% or better.

Work breakdown structure
Capital projects
All companies have their own variations on how they prefer to break down costs within the estimate. Indeed, the work breakdown structure (WBS) may differ slightly, from project to project, depending on the scope. Nevertheless, at a high level, there is a measure of agreement across the industry on how to break down capital project costs. The breakdown tends to be as shown in Table 3.

Turnarounds
At present, there is no clear, common agreement across the process industries on a high-level WBS for turnaround costs. Most turnaround teams split costs into direct costs — costs that can be specifically assigned to a cost object, such as an item of existing plant — and indirect costs — costs that cannot easily be directly attributed to a cost object. However, the definition of what should be considered direct or indirect cost varies from site to site (presumably

because of different internal accounting practices).

The costs of owner supervision are generally agreed to be indirect, since at any hour of the day a team could be supervising work on a range of existing plant areas. Contracted labour on tasks that can be assigned to specific existing plant items is generally categorised as direct cost. Furthermore, tracking this cost by plant unit/area and by equipment class/type and by equipment number is relatively common.

However, costs such as rented equipment (cranes, heat exchanger bundle pullers, and so on) are less consistently assigned to either direct or indirect categories, presumably because such items can only sometimes be attributed to a specific plant item (for instance, if a crane is only needed to work on a specific item).

Theoretically, it should be possible to assign bulk material (pipe, valves, for instance) to specific plant items and hence categorise the material as direct. However, this is not always done. One would logically expect consumable materials such as welding rods to be indirect costs because of the difficulty of assigning them to specific plant items. However, the situation can be clouded by the fact that consumables and bulk materials occasionally are not separated.

Allowances for uncertainty

Any cost estimate, by nature of it being an estimate, requires funds for the uncertain elements of the scope. These uncertain elements can be divided into "known unknowns" and "unknown unknowns". The "known unknowns" are allowances for items or quantities that the estimator knows, from historical evidence, will be needed in a specific line item of the estimate. The "unknown unknowns" are the items or quantities that were under-estimated or completely overlooked in the estimate. The estimator does not know exactly in which line item the funds will be needed, but history tells the estimator that some funds will be needed to bring the estimate to the P50 point. These "unknown unknowns" are contingency funds. The need for contingency is a hotly debated subject, but has been discussed elsewhere[6] and we do not propose to explore this topic here.

Capital projects

Known unknowns

The "known unknowns" in capital projects take the form of "design allowances" allocated to each line item for the "known unknown" of that line item (for instance, wastage in the piping material take-off, design development in equipment).

The amount of design allowance to include is usually determined through expert judgment based on historical data.

Unknown unknowns

"Contingency" is for the "unknown unknowns" in the estimate (for instance, it is discovered during construction that the need for an electrical transformer was overlooked in the design).

As discussed by Burroughs & Juntima,[7] the amount of contingency to include is typically calculated in one of four ways:

- As a predetermined percentage (of the base estimate)
- Through expert judgment (gut feeling/experience) based on historical data
- Through a Monte Carlo-type review of the cost effect of expected risks
- Through use of a regression model, based on historical data.

Turnarounds

In the case of funds for uncertainty, there is a little more general agreement than perhaps in other areas of estimating for turnarounds, in as much as it is generally accepted that funds are needed for "unknown" items.

Known unknowns

In turnarounds, the "known unknowns" are (a) "emerging work" (work to repair items that have broken/failed between the completion of the estimate and the start of the turnaround); and (b) "discovery work" (repair work that is discovered during the turnaround once equipment or pipework is opened up for detailed inspection).

In common with the design allowances on capital projects, estimates of likely emerging work and discovery work should (in theory) be calculable and assigned to specific estimate line items. (For instance, we can expect other X valves to fail between now and the shutdown, or based on past experience we should

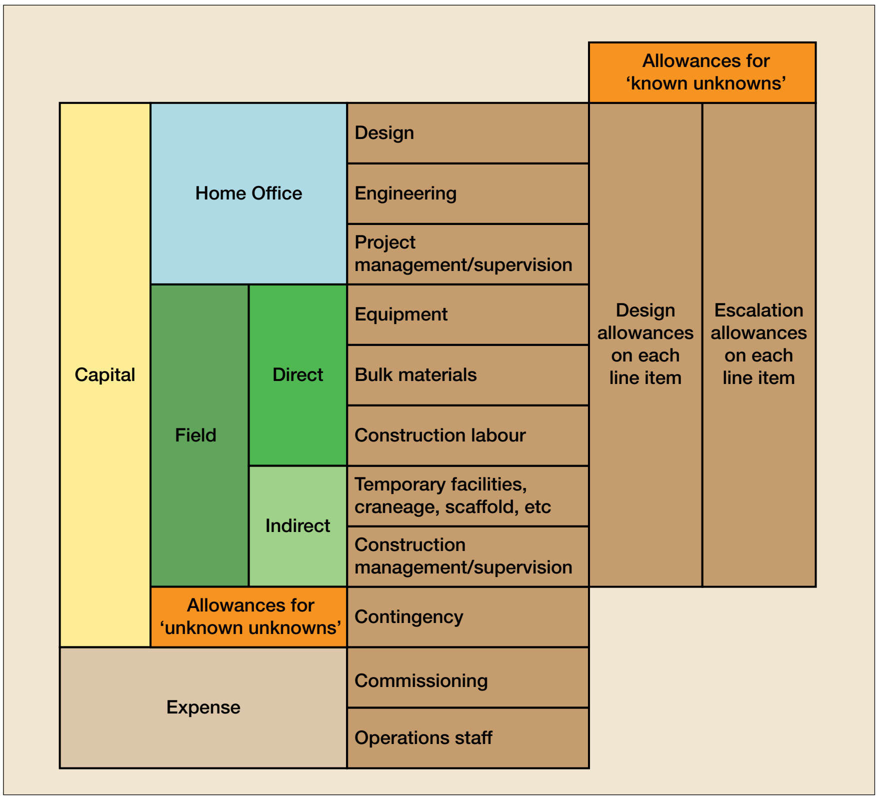

Table 3

expect that the trays in column Z will be discovered to be damaged when we open it up.)

However, what we have observed is that very often such items are not reported in the estimate to this level of detail. Instead, they tend to be listed as single line items on their own. In addition, anecdotally, we observe that very often the discovery work in particular appears to be underestimated — an optimism about what is likely to be found seeming to prevail.

The amount of emerging work allowance and discovery work allowance appears to be calculated on the basis of experience from previous turnarounds or from intimate knowledge of the state of the facility. But when it is based on experience of previous turnarounds, this experience is rarely backed up by hard numbers, showing what was spent in previous turnarounds as a percentage of the base scope cost.

Unknown unknowns

In turnarounds, just as in capital projects, a contingency for the items that were overlooked or completely unforeseen at the time of the estimate issue is required. (For instance, money was included in the "discovery work allowance" to spend three days repairing trays in column X, because the column was old and was operating at low throughput. However, it took two days longer than expected to repair the trays in column X. That extra two days' cost comes out of contingency.)

Whereas in capital projects contingency is calculated on the basis of one of four methods, each of which has at least some logical foundation to it, in turnarounds we observe that contingency often appears to be calculated simply as the difference between the current base estimate plus discovery and emerging work allowances and the original, rough estimate quoted to management (assuming the rough estimate to be a higher number!).

Quantification of turnaround allowances

We then looked further into how much allowance for uncertainty was included by turnaround estimators and how much was actually used.

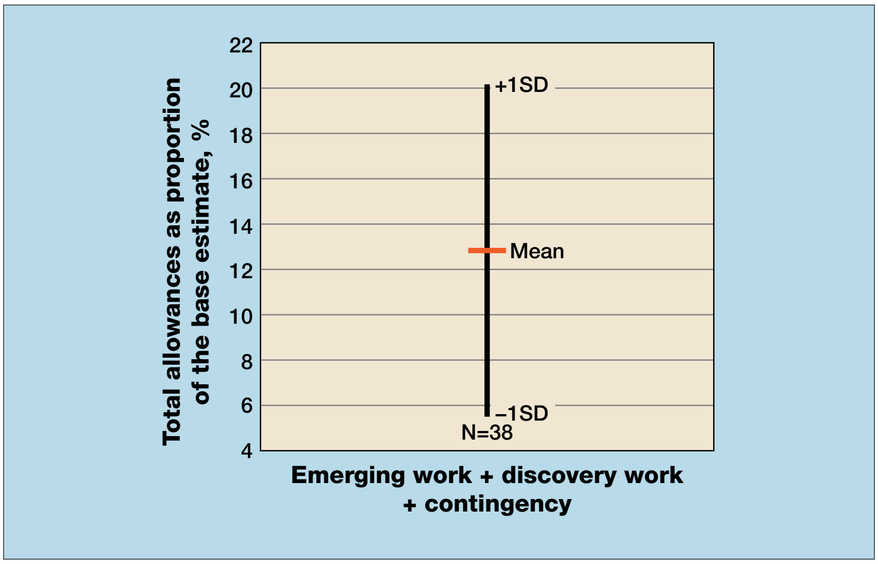

Figure 3 Uncertainty allowance included in estimate

How much is included?

The first problem that we encountered in this study was that while most turnaround teams recognise the three main areas of unconfirmed scope that need funding as being (1) emerging work, (2) discovery work and (3) contingency for the unforeseen, few teams clearly differentiate between them in their estimates. Indeed, in a survey that we carried out, out of 216 turnarounds, only 34 (or 16%) could give a clear differentiation in their cost estimate between these three areas and the main estimate.

Nevertheless, from the data gathered we are able to show (see Figure 3) that teams typically include a total of just under 13% of the base estimate (where base estimate = the total cost estimate before the three uncertainty allowances are included) as a total of all three allowance amounts.

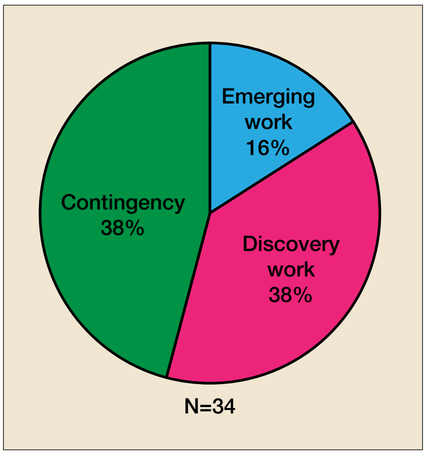

Figure 4 Breakdown of uncertainty allowance into emerging, discovery and contingency

That funding breaks down in turn into an average of 16% for emerging work, 38% for discovery and 46% for contingency (see Figure 4).

How much is spent?

We then attempted to look at how much in each category is typically consumed. From this information, we hoped to begin developing guidelines on calculating how much should be included in an estimate. However, we found that although some teams have begun to track the consumption of the three elements in their actual costs this practice is still immature within the turnaround community.

Without historical data on actual expenditure in these three categories, it is impossible to "close the loop" and begin developing guidelines on how much should be included in each category in an estimate.

Conclusions

The problem

Currently, turnaround cost estimates are inaccurate in that, on average, turnaround costs overrun their estimates. They are also highly unpredictable in the level of their inaccuracy (that is, the overrun does not remain within the claimed ±10% accuracy of most estimates).

	±50% ROM estimate	±30% ROM estimate	±10% control estimate
General turnaround scope data			
Equipment count	Preliminary	95% complete	99% complete
Turnaround premises	Preliminary	100% complete	100% complete
Risk Based Inspection (RBI) data	Listing – high level, based on asset management strategy	80-90% complete	100% complete
Maintenance turnaround backlog	Listing – little definition	60-70% complete	99% complete
Hazard and Operability study (HAZOP)	Listing – high level	60-70% complete	100% complete
Process Hazard Analysis (PHA)	Listing – high level	60-70% complete	100% complete
Management Of Change (MOC) design changes	Listing	40-60% complete	100% complete
Capital projects	Listing – various stages	80-90% complete	100% complete
Plant projects	Listing	80-90% complete	100% complete
Plant engineering design changes (expense)	Listing – not all inclusive	60-80% complete	100% complete
Leak Detection And Repair (LDAR)	Listing – preliminary	Listing – preliminary	Complete listing
Previous turnaround scope	Listing – 90%	Listing – 90%	Listing – 90%
Engineering deliverables			
Plot plans – logistics markups	Baseline – no markup	Partial markup	Complete
Turnaround boundaries	None	Preliminary	Complete
Process engineering design basis for plant engineering capital	None	Partial	Complete
Plant engineering design packages	None	Partial	Complete
Major capital project engineering design	None	Partial	Complete
Heat transfer data	None	Preliminary	Complete
P&ID markups	Original baseline	Partial turnaround markups	Complete
Original Equipment Manufacturer (OEM) specifications & drawings	Baseline – none for new capital	Partial for new capital	Complete
Startup procedures – maintenance (new equipment)	None	Partial	Complete
Utility plan	None	Partial	Complete
Oils plan	None	Partial	Complete
Flare minimisation plan	None	Partial	Complete

Table 4

Furthermore, there is no clear agreement on the definition of what information a cost estimate should be based upon in order to allow it to be defined as a ±10% estimate.

There are no guidelines on how to calculate uncertainty allowances for emerging work, discovery work and contingency. Nor are many teams gathering the actual cost expenditure data that would allow such guidelines to be developed in the future.

Learning from capital projects

The capital project world historically had similar problems with cost estimating. Over the years, it has improved through:

- Tying estimates to stage gates
- Clearly defining the scope basis and estimate basis required for a certain level of estimate accuracy
- Using similar work breakdown structures, allowing comparison benchmarking of data
- Gathering data on allowances for uncertainty and developing logical methodologies for estimating those allowances.

The turnaround world has already begun to learn from capital projects by copying the stage gate approach. There seems to be little reason to suppose that turnaround teams cannot continue to learn from capital projects in order to develop turnaround-specific standards for scope basis, estimate basis and calculation of allowances.

Recommendations for immediate action

If the estimation of turnarounds is to become more accurate and predictable, we recommend that, as a first step, a series of actions should be adopted within the turnaround community.

Define the scope and estimate basis

There should be wide agreement on what the scope and estimate basis is for calling an estimate 50%, 30% or 10% accurate. The capital projects community has such agreement in documents referred to earlier. Suggested outline versions for turnarounds are given in Tables 4 and 5, respectively.

Standardise the WBS

Move towards a common standard layout for cost estimates. The capital projects community has such a standard (see Table 3). A suggested outline version for turnarounds is shown in Table 6.

Track the uncertainty allowances

If the turnaround community is ever to develop even rudimentary rules of thumb for estimating emerging work, discovery work and contingency for the unforeseen, it must begin to track expenditure in these areas. This will require two responses from the community: a willingness to differentiate clearly the three categories in cost estimates; and a willingness to accurately track actual expenditure from these three categories during a turnaround.

Tie the estimates to the stage gates

In the world of capital projects, the stage gate culminates in a cost estimate. Currently, the typical review stages for preparation and planning of a turnaround are not tied to a cost estimate. Tying the estimate and stage gate together could improve review of planning and preparation progress.

Recommendations for longer-term next steps

This article covers only the first steps in improving the accuracy and predictability of turnaround cost estimates. Further steps need to be taken. Once there is common agreement on the minimum standard of scope basis and estimate basis for turnaround estimates, and once turnaround teams begin gathering actual uncertainty allowance data, the community will then be in a position to begin developing logical methodologies for calculating more accurately the required level of allowance for uncertainty in emerging work, discovery work and contingency for each turnaround.

	±50% ROM estimate	±30% ROM estimate	±10% control estimate
Mechanical work	Cost of the last TA, adjusted for inflation	Quantities for mechanical work from workpacks, but then priced in-house	Quantities for all disciplines calculated and priced by contractors, based on workpacks
Other disciplines		Other disciplines factored from mechanical, based on history	

Table 5

Acknowledgements

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References

1 http://www.api.org/aboutoilgas/sectors/refining/refinery-turnaround.cfm.

2 http://ap-networks.com/latest-news/tinc-europe-2011-summary.html.

3 We are very aware of the fact that in recent years the preference within project cost estimating circles is not to talk of a typical ±10% or ±30% estimate, but rather to talk of "classes" of estimates. This is because of the need to recognise that for the same level of scope definition, two projects could have different levels of estimate accuracy because of the inherent risks in their characteristics. For example, a new technology project probably carries more risk than a similar-sized project expanding an existing plant. However, the turnaround world has not yet reached that level of sophistication. Hence, for the survey, we used terms that are readily recognised, such as ±10% estimate.

4 Lawrence G R, Stage gated approval processes — a practical way to develop and filter capital investment ideas, *Pharmaceutical Engineering*, vol 20, No 2, March/April 2008.

5 AACE International Recommended Practice No. 18R-97; cost estimate classification system, as applied in engineering, procurement, and construction for the process industries.

6 Lawrence G R, The use and misuse of contingency — or why cutting contingency makes projects more expensive, not less. *Pharmaceutical Engineering*, vol 27, No 5, Sept/Oct 2007.

7 Burroughs S E, Juntima G, *Exploring Techniques for Contingency Setting*, AACE International Transactions, Washington DC, 2004.

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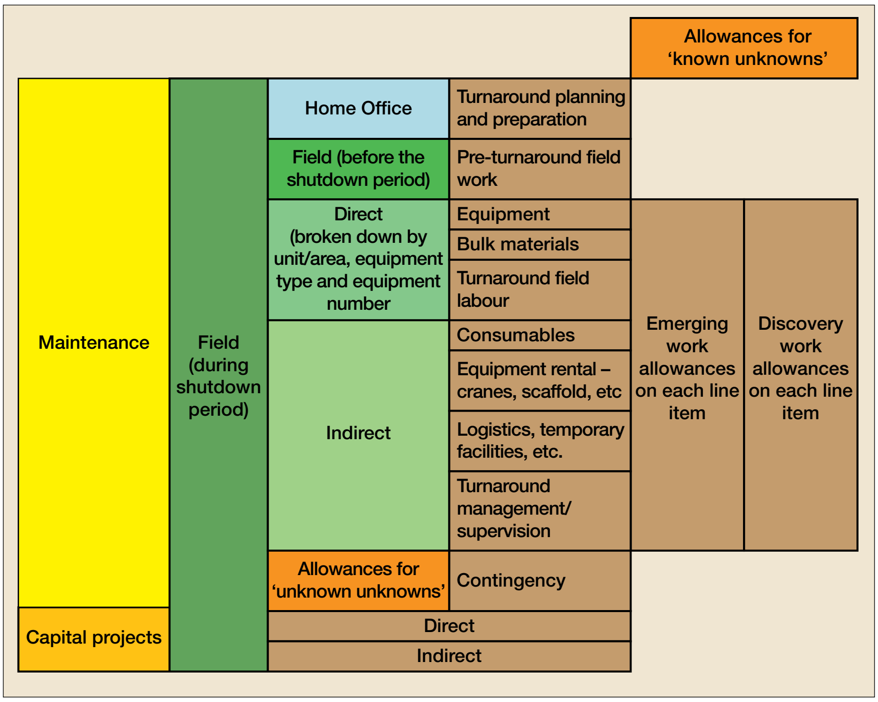

Table 6