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Abstract

One of the most critical variables in an engineering project is cost. In cost estimations this variable is studied, analysed, and optimized in order to predict the expected future cost for a project and to control the project execution. The estimated expected cost determines if a project will go ahead or not. It will set the frames for the design, and it provides the foundation of success. But, a cost estimat is only an estimate and have no value if the assumptions, complexity factors, risk and uncertainties haven't been assessed properly and documented as this is the basis for the investment's decisions. Adding the different complexity and risk factors requires a good knowledge of previous similar projects. Even though the cost estimates are predicting the future cost, the history can teach us about previous complexities and risks in order to make better expected estimates.

Apply, have since 1979 delivered engineering-, procurement, installation, commissioning and operations support for modifications and maintenance projects on offshore facilities for oil and gas companies in the Norwegian shelf in the North Sea.

Apply is now expanding and in 2018 new business area were defined; Studies, Large Projects and Technology. The objective is to meet the market requirements for more effective project execution.

Cost estimation in Apply is used as input to project planning and execution and are also providing essential information to the Clients decision gates. Good and accurate estimates are important for the business to avoid overruns. On the other hand, overestimating should also be avoided since this will bind up funds and resources that could have been utilised elsewhere. Cost estimation is also part of the tendering process and pay a large role in the company's competitiveness.

How can Apply meet the clients demand for better predictability in the estimates and increase the company's competitiveness considering the ongoing improvement processes and new business area?

Keywords:

Cost estimation, Oli and Gas, Offshore, Norwegian Shelf, North Sea, Cost Risk Analyses, CRA, Complexity Factors, Processes for Cost Estimation, Estimation Framework, Estimation Principals, Estimation tools, Norms, Manhours, Construction, Engineering, Benchmarking, Tender, Studies, Construction, FEED, Execution.

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1   Introduction

There is a variable that, if it's not analysed properly no engineering project will succeed. This variable is cost. It determines which projects will go ahead or not. It will set the frames for the design and once the project is completed and operations begin, costs determine whether it will be a success. A successful project is not necessarily the one that has the most sophisticated design but the one that makes the most money. If costs are not analysed and controlled, a project that was a technical success could be judged a business failure.(Westney 1997)

In cost estimation, cost is studied, analysed, and optimized like any other engineering variable. One could say that cost estimation is the hearts of all businesses as it provides the foundation of success.

> *(Greg Ray 2019)"Companies that fail to sponsor well-conceived data integration initiatives risk deteriorating capital project competitiveness within the next few years."*

And, how does Apply leverage the potential of transferring, exchanging, and storing the project data using digital technologies?

This master thesis, evaluates cost estimation in Apply, considering the company and clients objectives. The business management system in Apply has been studied, the governing documents, the processes, the estimation methods and tools, and how complexity and risks is handled in the estimation process. It has been interesting to evaluate how Apply is utilizing experience data to improve the estimates accuracy and estimation efficiency. The study has focused on the elements shown in Figure 2-1 Evaluation of Estimation in Apply.

Figure 1-1 Evaluation of Estimation in Apply

1.1   About Apply

APPLY is a multidiscipline engineering company specializing in contracts across all project phases, from concept development and studies to completion and commissioning. Apply currently has around 1000 employees with head office in Stavanger and with offices in Bergen, Hammerfest and Cracow, Poland.

The range of services is covering operations and maintenance and modifications of oil and gas production facilities on the Norwegian Continental Shelf (NCS)(Apply 2019).

Apply(APPLY 2019) works within the following business areas:

- Maintenance and Modifications (M&M)
- Operations and Technical Services
- Larger Projects
- Studies
- System Technology

Apply's clients are Oil and Rig companies in the oil and gas sector in the Norwegian North Sea Sector.

Typical for the oil and gas industry in the North Sea sector is the offshore installations or floaters which ties-in wells from several sub-sea templates and the infrastructure around. The on the process facilities the oil and gas is stabilized for further transportation. In addition to the structure work for the installations, the process facilities are centred on mechanical and chemical process equipment with a significant amount of piping, instrumentation, and process controls involved. The CAPEX (Capital expenses) estimates shall reflect this scope of work. But in addition to the CAPEX evaluations OPEX (Operational expenses) calculations and life cycle cost and environmental cost also needs to be presented to the client.

1.2   Apply Business Management System (BMS)

The BMS is defining how the work and activities shall be carried out and consists of policies, principles, requirements and processes. It comprises governing documents such as manuals, process descriptions, procedures and checklists.(APPLY 2019)
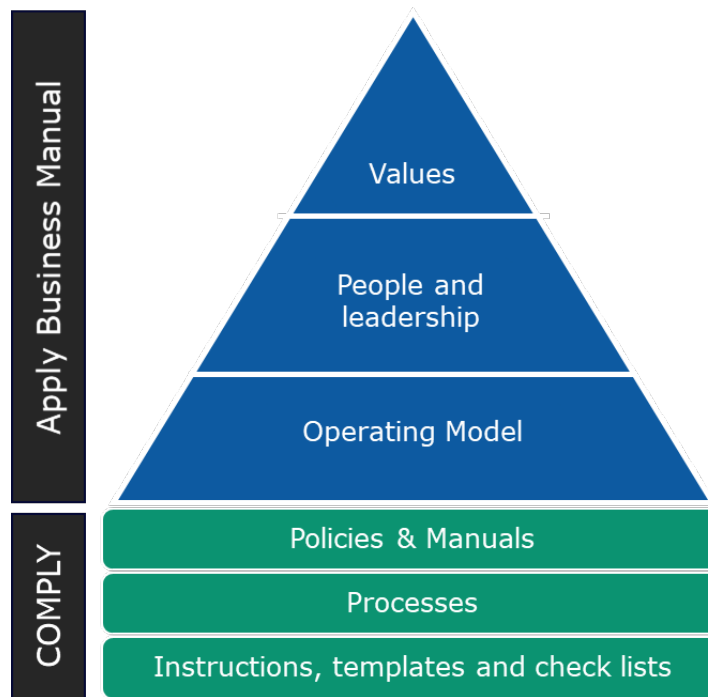
Figure 1-2Topics for the Apply Business manual(APPLY 2019)

COMPLY is the tool for the business processes and support functions where the Policies, Processes and supporting documents can be found.

(APPLY 2019)

> *"The process / process description is a description of a work process designed to undertake a specific task and produce a defined result with a defined quality. The process description includes description of:*
>
> - *Planned output*
> - *Required input*
> - *Requirements from legislation, customer and Apply*
> - *Required resources and competence*
> - *Interfaces with other processes*
> - *The process descriptions are owned by the owner of the process they describe."*

1.3   Apply Business Processes

The business processes in Apply reflects the services and products Apply deliver. The Apply business processes are reflected in the Value Chain business processes with support functions.

(APPLY 2019) (see figures below)
The Value Chain business processes are:

- Maintenance and Modifications (M&M)
    o Long term contracts comprising engineering studies, EPCIC projects, maintenance and operational support assistance for small and larger projects.

- Larger Projects
    o EPCIC projects are projects comprising Pre-engineering (FEED), Engineering, Procurements, Construction, Installation and Commissioning

- Operations and Technical Services
    o Services related to life cycle operations of an installation

- Studies
    o Provide the client with the best basis for their decision processes/gates which typically includes the following three phases: FEL0 – FEL3

- System Technology
o Provides projects including engineering and procurement, management of fabrication, installation, completion and start up, deliveries of technical and administrative services for two sub areas; Drilltech and GreenTech where the two digital, open source control system are developed.
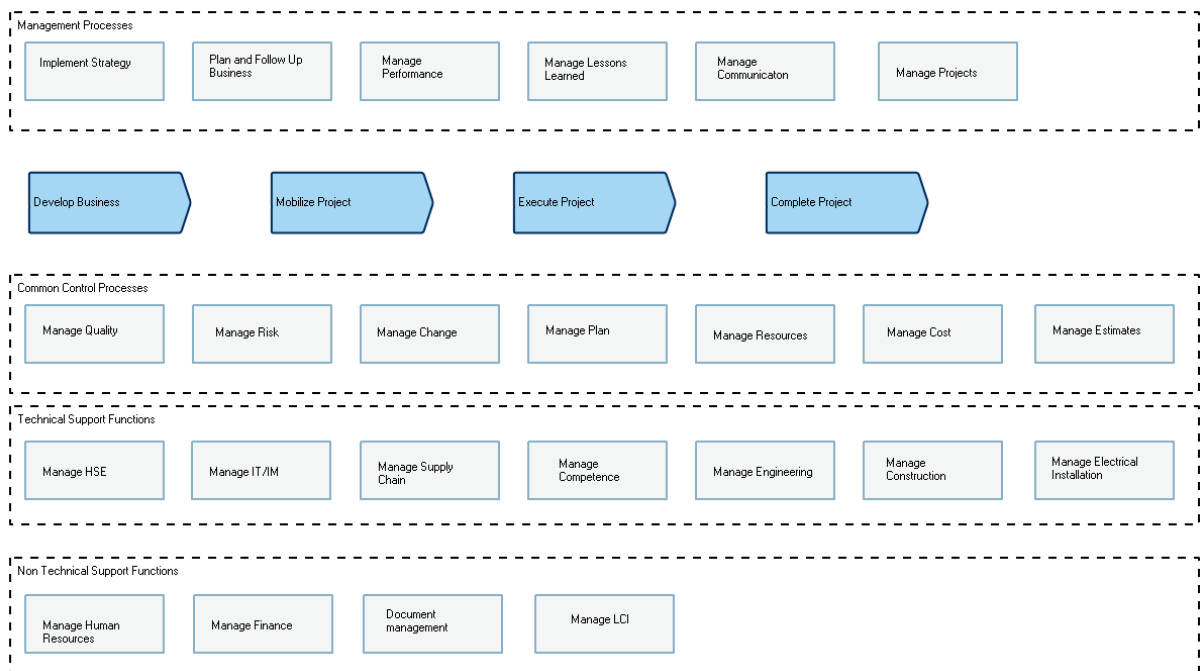
Figure 1-3Apply Value Chain Processes and Support functions (APPLY 2019)Apply Improvement projects

Apply has developed a standard model, "Apply Standard", (APPLY 2019)"…*for operation determining how work and activities are planned, executed and evaluated, and how experience gained is used to improve this process.*"

The figure below shows how learning and improvement is a central part of the business.
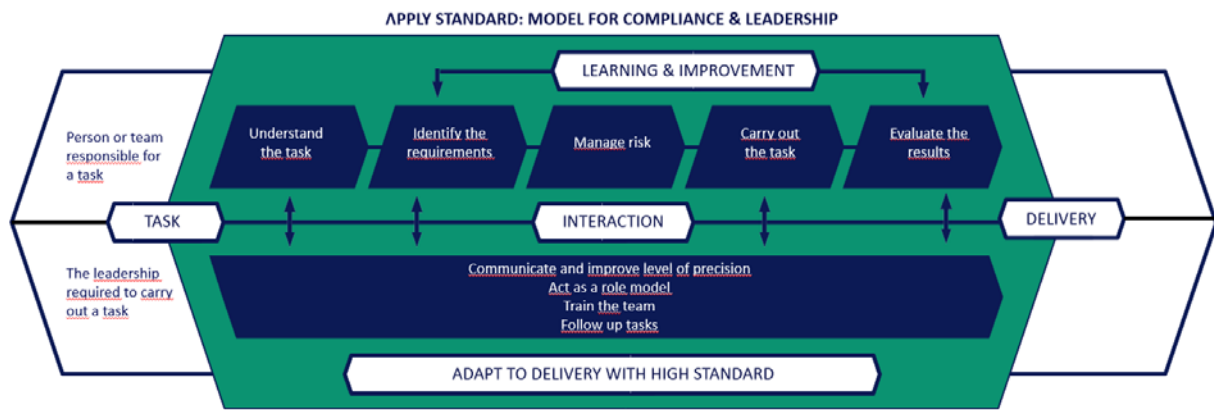
Figure 1-4 Apply Standard (APPLY 2019)

Apply has the last years been working on improving the cost estimation processes. The improvement project has been a part of Apply's LEAN process that started in Apply's Bergen office in 2015. As a result of this, the estimation sheets (TPL-004) for Level 4 CTR Man-hours Estimation at class D level have been superseded by an updated version. Now, when Apply is expanding with new business areas for Studies, Larger Projects and Technology, the processes and tools for estimation should be aligned with the new business area requirement

2   Method

The method used is qualitative evaluations of the applied praxis for cost estimation in Apply.

The main elements that has been reviewed is estimation methods, processes, documents, factors and tools.

Working together with the improvement group for cost estimation the Apply's Estimation processes guidelines and work instructions have been evaluated for further improvements. It has also given insight in the current situation and the wanted situation.

The complete estimation processes have been reviewed together with all the supporting documentations.

The procedures and documentation have been compared with the theory of the subject. To get an understanding of the client's requirements for cost estimation, some of the current contracts in Apply has been read.

The current tools (models) for cost estimation has been evaluated and new models have been developed for illustration and suggestion for further development.

3   Definitions

As the Apply processes and work instructions for cost estimations is mainly based on the Equinor GL0430(Equinor 2018) and TR1244(Equinor 2018), the some of the definitions have also been adopted by Apply. Other definitions has been adopted form the (AACE 2016) Recommended Practice No. 18R-97: Cost Estimate Classification System – As Applied in Engineering, Procurement and Construction for the Process Industries. See table below for some of the most commonly used definitions:

Table 3-1 Definitions adopted by Apply from Equinor GL300(Statoil 2010)

"Term Definition	Explanation
Activity	An element of work performed during the course of a project. An activity normally has an expected duration, expected cost, and expected resource requirements
Allocation	Agreed booking of personnel to defined assignment.
Allowance	Covers additions that, based on experience is required to reach an expected level for identified quantities and costs.
Base estimate	The sum of identified cost elements defined at the time of estimating. The Base Estimate includes allowances but excluding contingency.
Benchmarking	Comparison of selected indicators for a project against corresponding indicators for compatible facilities, normalised for relevant parameters e.g. resource basis, capacities, product(s) etc
Contingency	The amount of money in a cost estimate to cover the difference between the Expected Cost and the Base Estimate. Contingency will typically cover (Equinor 2018): a) design development within agreed design basis/scope of work b) estimate adjustments c) bias, omissions and errors d) minor adjustments to execution schedules / milestones e) other risks within the control of the Project Team
Cost risk analysis (CRA)	Quantitative risk analysis for the cost estimates – primary purpose is to establish a cost distribution, expected values, accuracy and basis for contingency evaluations.
CTR sheet	Standard form (sheet) used to describe the contents of an activity and indicate cost, time and resource consumption for the activity.
Decision Gate (DG)	A predefined point in the project model where… appropriate decisions whether to move to the next phase, make a temporary hold or terminate the project

Design basis	A document that specifies basic requirements and frame conditions, including data on feed or reservoir conditions, products, capacities, performance, transportation, HSE, operation, maintenance etc.
Direct cost	Cost elements defined in material/equipment lists and progress related engineering and construction hours.
Estimate accuracy	The estimate accuracy is given by an upper (+) and lower (-) value, is a confidence interval corresponding with a confidence level of 80%. The latter means there is a probability of 80% for the final cost to be within the interval.
Estimating class	A classification system …, which gives requirements for basic assumptions, technical maturity, estimating method, level of detail, scheduling, risk analysis, etc. for investment and operational cost estimates.
Expected cost	The cost (real values – midyear) that is expected for the given scope of work and design basis, and representing the statistical mean value.
Facilities	The total systems from well-head to refined products, including equipment, systems and concepts for oil and gas production, processing, treatment, refining, transportation and export.
Indirect cost	Non-progress related man-hours for engineering, management and construction, construction temporary facilities costs etc., which complement the direct costs in an estimate.
Norm	Applied duration or number of man-hours per activity or unit/quantity, e.g. manhours/tonne, kg reinforcement/m3 concrete foundation etc.
Procurement	Generic term for all "purchasing and contracting activities", and includes: preparation of strategic market surveys, prequalification of suppliers, preparation of Invitations to tender, tender evaluation, contract signing and follow-up of the delivery until closing of contract.
Project	A one off task as part of the investment project with a given target that is clearly defined and limited with regards to content, time frame and cost.
Rate	Cost per unit, e.g. cost/man-hour, cost/kg etc.
Risk	Variation from the expected outcome or targeted objectives, both positive and negative. Positive outcome: Upside risk. Negative outcome: Downside risk. Comment: Definition of risk can vary from the above based on the context · Risk is the combination of estimated probability and impact.
Risk management	Establish context, identify and analyse risk, evaluate risk, decide action and implement action and follow-up of risk.
Technical allowance	The technical quantities shall be given as expected values including technical allowance. Technical allowance shall cover expected but

	unspecified requirements for a specific quantity. The amount of technical allowance should be stated specifically (e.g. in percentage).
Work Breakdown Structure (WBS)	A deliverable-oriented grouping of project elements that organises and defines the total scope of the project. Each descending level represents an increasingly detailed definition of a project component and is thus a system for dividing the project scope of work into Work Packages.
Work package	A deliverable at the lowest level of the Work Breakdown Structure (WBS). A work package contains only one discipline."

4   Literature

The Apply Business Management System comprises of the following documents categories shown in the Figure 2-1 below:
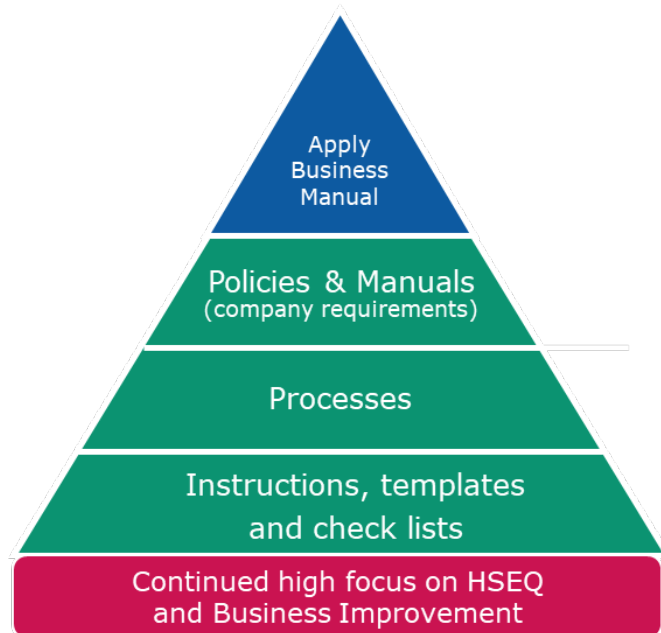
Figure 4-1 organisation of Apply Business Management System (APPLY 2019)

As part of the evaluation process I have reviewed all internal documents[1] in Apply that is related to the Cost Estimation. The documents are listed in Table 3-1. The Equinor V&M contract requires compliance with the Equinor governing documents and that Apply governing documents is largely based on these requirements. I have therefore reviewed these documents listed in also.

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[1] All company internal documents are confidential and will be submitted to sensor separately for reference.

Estimation in Apply

Table 4-1 Overview of the reviewed Apply Inhouse documents

Doc no	Description	Comments	Ref.
MAN-CR-001	APPLY BUSINESS MANUAL	Company Requirement	All documents Apply Sørco Management System Policies & Manuals
MAN-CR-004	PROJECT EXECUTION MANUAL	Company Requirement	All documents Apply Sørco Management System Policies & Manuals
F-PR-017	APPLY SØRCO'S CTR NUMBERING STANDARDS	Procedure for CTR numbering	Manage Engineering Common engineering processes Create engineering man hour estimate
F-TPL-004 superseded by F-TLP-005	ESTIMATION TEMPLATE	Excel template for Estimation of Engineering man-hours for CTR plan level 4	Manage Engineering Common engineering processes Create engineering man hour estimate
F-WI-019 (UA)	Estimation manual for construction (new, to be released)	Procedure for use of IFS for estimating Job card man-hours for CRT plan level 5	Manage Engineering Common engineering processes Create engineering man hour estimate
F-WI-014	COST ESTIMATES IN STUDIES	Work Instruction for estimates in studies	Manage Estimates Establish estimates
W-PR-002	WEIGHT CONTROL	Procedure for weight control and reporting	Manage Engineering Weight Estimate weight (Study projects / Bid work)
W-PR-003	WEIGHT ESTIMATING	Procedure for weight estimation for input to cost estimate	Manage Engineering Weight Estimate weight (Study projects / Bid work)
W-TPL-001	EQUIPMENT WEIGHT MEL FOR INPUT TO WEIGHT	Template for MEL	Manage Engineering Weight Estimate weight (Study projects / Bid work)
W-TLP-002	DISCIPLINE MTO FOR BULK INPUT TO WEIGHT	Template for MTO	Manage Engineering Weight Estimate weight (Study projects / Bid work)
WP-PR-001	PREPARATION OF JOB CARDS	Procedure for prep of job cards	Manage Engineering Common engineering processes Prepare job card - M10/MN

Table 4-2 Equinor Governing documents

Doc no	Description	Ref.
GL300	Handbook for facilities Projects	(Statoil 2010)
GL0430	Guideline for Facilities cos estimating (CAPEX). ver 2	(Equinor 2018)
GL0431	Guidiene to Cost Risk Analyses Ver. 2.	(Equinor 2018)
TR1244	Technical requirements for facilities scope and cost estimate classes - offshore projects Final Ver. 8.01	(Equinor 2018)

4.1   Cost Estimation Framework

The American Association of Cost Engineers, AACE has since 1956 been a body of knowledge within total cost management. The estimating framework is described in the (AACE 2016) Recommended Practice No. 18R-97: Cost Estimate Classification System – As Applied in Engineering, Procurement and Construction for the Process Industries. Apply's work instruction F-WI-014 Cost estimation in Studies is largely based on this recommended practice in addition to the Equinor's guidelines GL0430 Guidelines for facility cost estimation (CAPEX) and the TR1244 Technical requirements for facilities scope and cost estimate classes - offshore projects.

The GL0430 (Equinor 2018) describes the methodology for developing cost estimates (CAPEX) for facilities for oil, gas and new energy investment projects in Equinor and defines Equinor's estimation classes. The definition of the estimation classes in Apply is based on Equinor's definitions. The TR1244 (Equinor 2018) defines the activities and deliverables to define the technical basis for class A, B, C and D facilities cost estimates. Apply's requirements for deliverables for the different estimation classes is partly based on this document.

Equinor's TR1244 states that "The basis for execution of a project is developed through a series of studies and planning activities, where design basis, technical description/documentation together with a cost estimate are matured from the first conceptual idea to a firm basis for engineering, procurement and construction agreements"(Equinor 2018). The cost estimate is used for the different decision gates and is one of the parameters for the investment decision.

Cost estimation is defined in the RP10S-90 COST ENGINEERING TERMINOLOGY(AACE 2018) by the American Association of Cost Engineers, AACE, as;

"…*a compilation of all the probable costs of the elements of a project or effort included within an agreed upon scope*"

Apply has based the definitions on the AACE terminology in addition to the terminology.

4.2 Accuracy

In Clark and Lorenzoni's book; Applied Cost Engineering, (Clark, Lorenzoni et al. 1996) the authors point out that an estimate for a project is a prediction. It predicts what a project will cost and a scheduled for when it can be completed. As a basis for discussing the accuracy of an estimate Clark and Lorenzoni's defines standards for a bad estimate and a good estimate. (p17) A bad estimate has significant overrun on the original estimated value, it has inconsistent results (large overruns and underruns), few details are defined, it is poorly documented, is unreliable for funds allocation (does not have a good enough confidence) and is unreliable for project control. The reasons for a bad estimate could be poor estimate input data (scope definition and details), the estimation methods could be poor, and the estimator could be blamed. A good estimate has a frozen scope of work basis and a realistic execution plan, the estimating methods an input data is good and well documented, and the estimator is experienced in his field.

Clark and Lorenzoni (Clark, Lorenzoni et al. 1996) says that the accuracy of an estimate is important to know since it will affect the sensitivity of the economics in a project, it will have an influence of the cash flow and the budgeting and it develops confidence for the stakeholders. The requirements for accuracy will also determine the estimating method be used. An approach for determining an accuracy in advance, is to use historical data and test the sensitivity of the predicted investment against a potential variation. The example used in the book is an estimate with +-30% variability range (with a 50 probability of hitting an overrun or an underrun), the base number for the estimate should be tested for the possibility of 30% underrun and 30% overrun.

The Estimation Classes defines the expected accuracy range for each class. While the AACE International(AACE 2016) defines the estimation accuracy the range as the typical percentage variation of actual costs from the cost estimate after application of contingency (**typically at a 50% level of confidence**) for given scope, The Statoil's GL300 (Statoil 2010) defines "*the estimate accuracy is given by an upper (+) and lower (-) value, is a confidence interval corresponding with a **confidence level of 80%**. The latter means there is a probability of 80% for the final cost to be within the interval.*" The confidence level will be determined depending upon the Client's requirements.

In the AACE Recommended Practice18R-97 The Cost Estimate Classification System maps the phases and stages of project cost estimating together with a generic maturity and quality matrix (AACE 2016), see Table 4-3.

There are several other defined estimation classes. The requirements for accuracy vary slightly. But it is important to notice that these levels are only guidance and project specific requirements to accuracy must be evaluated from case to case.

The estimation classes in Apply is currently under revision and are now mainly based on the same classifications as the Equinor classification which is described in GL0430 Facility Cost Estimation (CAPEX) (Equinor 2018), with a fifth estimation class E for execution of construction (job cards) The Equinor classification is shown in the Table 4-4.

Table 4-3 AACE International COST ESTIMATE CLASSIFICATION MATRIX FOR THE PROCESS INDUSTRIES, Fig.1 RP 18-97(AACE 2016)

ESTIMATE CLASS	Primary Characteristic	Secondary Characteristic			
	LEVEL OF PROJECT DEFINITION Expressed as % of complete definition	END USAGE Typical purpose of estimate	METHODOLOGY Typical estimating method	EXPECTED ACCURACY RANGE Typical variation in low and high ranges [a]	PREPARATION EFFORT Typical degree of effort relative to least cost index of 1 [b]
Class 5	0% to 2%	Concept Screening	Capacity Factored, Parametric Models, Judgment, or Analogy	L: -20% to -50% H: +30% to +100%	1
Class 4	1% to 15%	Study or Feasibility	Equipment Factored or Parametric Models	L: -15% to -30% H: +20% to +50%	2 to 4
Class 3	10% to 40%	Budget, Authorization, or Control	Semi-Detailed Unit Costs with Assembly Level Line Items	L: -10% to -20% H: +10% to +30%	3 to 10
Class 2	30% to 70%	Control or Bid/Tender	Detailed Unit Cost with Forced Detailed Take-Off	L: -5% to -15% H: +5% to +20%	4 to 20
Class 1	50% to 100%	Check Estimate or Bid/Tender	Detailed Unit Cost with Detailed Take-Off	L: -3% to -10% H: +3% to +15%	5 to 100

Table 4-4 Equinor GL0430 Table 4.1 Estimate Class Accuracy and Contingency(Equinor 2018)

Estimate Class	Decision Gate *	Cost Estimate Accuracy At 80% Confidence	Accuracy Of Technical Information At 80% Confidence	Normal Level Of Contingency
Class A	DG0	N/A	N/A	Not given
Class B	DG1	± 40%	± 25%	25% - 40%
Class C	DG2	± 30%	± 15%	15% - 30%
Class D	DG3	± 20%	± 10%	10% - 20%

Table 4.1 Estimate Class Accuracy and Contingency

4.3 Contingencies, Cost Risks and Uncertainties

Hollman is in the AACE International paper Risk.1027 Estimate Accuracy: Dealing with Reality(Hollmann 2012), reviewing empirical cost estimate accuracy research with common management expectations. The aim for the paper is:

> "*Attendees will gain an understanding of estimate accuracy reality, the risks that drive it, management's biases about it, and methods that analyse risks and address the biases in a way that results in more realistic accuracy forecasts, better contingency estimates and more profitable investments*"(Hollmann 2012).

Evaluation of the complexity factors and contingency should therefore be carefully evaluated prior to inclusion to the estimate.

Using risk process to determine the project contingency is part of the Cost Risk Analyses that is described in the Equinor Guideline for Cost Risk Analyses GL0431(Equinor 2018). This guideline requires that a Cost Risk Analyses (CRA) for class C & D Estimates is performed using quantifying risk analyses and Monte Carlo Simulations.

In the AACE International paper RISK.1419.1 Managing Risk and Contingency from the Earliest Stages of Capital Planning (Poskie 2013), Poski discusses calculation of contingency for estimates derived from a historic sample and how contingency cam be manged by risk mitigations. To derive expected costs for projects with similar scope, the project can leverage the statistical sample of historical cost and estimation data, providing that there has been consistency in the cost and work breakdown structures. The statistical risk can then be calculated and planned for as contingency. (Poskie 2013)

> *"Application and Management of Contingency*
>
> *Following the recommendation to breakdown historical actual cost values into incremental scopes will result in each incremental scope carrying a different contingency amount. This can be attributed to different historical sample sizes and ranges in historical values. The ranges can often be reflective of the inherent risk for that particular scope. "*(Poskie 2013)

4.4   Estimation methods theory

The estimation classes have also a recommended approach to selection of estimating methods:

Top Down – Parametric or Stochastic estimation method could be using gross proportions (factors) or capacity curves for screening/ prospect studies (Class A - B in Apply and TR1244 or Class 5 in AACE)(APPLY , AACE 2016, Equinor 2018). The factored estimates are often called ratio estimates or scale of operations factors like, Lang factors, Guthrie factors and other.(AACE 2016).

"Parametric estimating techniques leveraging values from historical projects and experience can be effective."(Poskie 2013)

The Lang Factor can be used as a quick rule of thumb way to estimate the total installed plant cost of a process plant by using the sum of the plant equipment cost multiplied by a factor. It has its origin in the series of articles in 1947 – 1948 written by Hans J. Lang wrote a in the "Chemical Engineering" in the Chemical Week Associates, New York about the engineering approach, cost relationship and simplified approach to preliminary Cost Estimates. The calculated cost estimated by the Lang factor includes delivered process equipment cost. (Wolf 2013)

As per Wolf (Wolf 2013), the Lang factor has been elaborated in several studies, and the some of the results can be found in Perry's Chemical Engineers' Handbook in the chapter for Fixed capital Cost Estimation(Perry 1999). Wolf concludes that the Lang's factor, 4.74 for fluid process plant are extremely close, within 8% at an expected accuracy of +/-50% (Wolf 2013)

The author of the blog Chemical Engineering Plants (Saeed 2014) points out that the Lang factor does not take into account the equipment erection and foundations, piping, instruments and control, electrical and other required utilities, the facility structure or buildings etc. This needs to be adjusted for with other appropriate factors. And, that the factorial methods are best utilized when a preliminary flow diagram is drawn up and the main equipment for the process facilities are required.

The evaluations of the difference in the estimated project and the historical must also be carefully evaluated by the estimator.

Capacity curves can also be created to get an overview of the costs. These curves are created by collecting historical data like weight and time or cost, or capacity vs. cost etc. for typical segments and criteria for analogue projects and normalize these. By using these curves, one can scale the project cost. Sandberg (Sandberg 2019) shows in the compendium for cost estimation in IND530 V19 how these curves can be used.

Estimation in Apply

Semi detailed estimation (deterministic – stochastic)

Clark and Lorenzino (Clark, Lorenzoni et al. 1996) says that semi detailed estimates differs from factorized estimates by prediction of cost and quantities of the bulk items instead of factorize these. The bulk quantities and cost will be based on historical data for average bulk required per type of equipment. The AACE Cost Classification System requires this type of estimation method for a Class 3 estimate (Class B-C in Apply(APPLY)):

> "Class 3 estimates usually involve more deterministic estimating methods than stochastic methods. They usually involve a high degree of unit cost line items, although these may be at an assembly level of detail rather than individual components. Factoring and other stochastic methods may be used to estimate less-significant areas of the project"(AACE 2016)

Definitive estimates

Definitive estimates (Bottom up) requires detailing the SOW. This method is used for Class 2 -1 estimates (Class D in Apply (APPLY)). The AACE Cost Classification System (AACE 2016) requires this type of estimation method for a Class 2 estimate:

> "Class 2 estimates always involve a high degree of deterministic estimating methods. Class 2 estimates are prepared in great detail, and often involve tens of thousands of unit cost line items. For those areas of the project still undefined, an assumed level of detail takeoff (forced detail) may be developed to use as line items in the estimate instead of relying on factoring methods."(AACE 2016)

And for Class 1 Estimates:

> "Class 1 estimates involve the highest degree of deterministic estimating methods, and require a great amount of effort. Class 1 estimates are prepared in great detail, and thus are usually performed on only the most important or critical areas of the project. All items in the estimate are usually unit cost line items based on actual design quantities."(AACE 2016)

4.5   Standard Cost Coding System (SSCS)

The need for collecting experience data for predictions of cost for a project has required a standardisation of coding, recognised as the SCCS (Standard Cost Coding System), for cost and weight estimate and for of historical Asbulit data. The ISO 19008:20018 (ISO 2018)is the current Standard cost coding system for oil and gas production and processing facilities and supersedes the NORSOK Z-14(NORSOK 2012). However, the estimation processes, work instructions and procedures in Apply is based upon the 2012 version of NORSOK Z-014.

The Estimate Process in Apply is supported by the work instruction F-WI-014 Cost Estimates in Studies(APPLY).

The estimate classification given in the Apply's work instruction, F-WI-014 Cost Estimates in Studies(APPLY) will be adjusted to the Client contract requirements. For the Equinor contract the TR1244 ver 8.1 applies. The TR1244(Equinor 2018) is the Technical requirements for facilities scope and cost estimate classes for offshore projects and shall be applied for the Equinor projects. It has a systematic approach to the requirements for the technical deliverables for each estimate class.

In the AACE Recommended Practice 18R-97: Cost Estimate Classification System - As applied in Engineering, Procurement and Construction for the Process Industries(AACE 2016) sets an international standard defining the estimate classes. The TR1244 s dividing the estimation classes based on project technical maturity whereas the AACE 18R-97 is dividing the estimation classes based on maturity and the uncertainty of the input and the accuracy of the estimate.

The TR1244 also defines requirements for the technical basis that applies for the different estimation classes.

The Cost estimates are further used as input for the Client different decision gates (DG) and NPD's, "Veiledning til PUD/PAD(Regjeringen 2018)", states that cost reporting should be coded according to SCCS.

ISO 19008:2016 (NORSOK Z-014):

> *"The SCCS is designed to provide a uniform coding basis for the estimate preparation and to serve as a standard for collecting/collating historical data.*
>
> *"…standard describes a system for coding of cost and weight estimates and as-built/experience data."*

5 Analyses of Cost Estimation in Apply

Cost estimation is required in all project stages, from feasibility and concept studies to EPCI execution. Cost estimation is required at different stages of a project and will therefore require different methods and tools depending on the level of technical maturity, availiable information, estimation accuracy requirements and for different purposes. The cost estimates are an important part of the Clients decision analyses and it is therefore important to understand the requirements for the different estimates how the cost estimates are prepared. See in Figure 2-1 Evaluation of Estimation in Apply. This shows the recommended methods, work-instructions and estimation tools and templates. It also gives an overview of which process to be used.
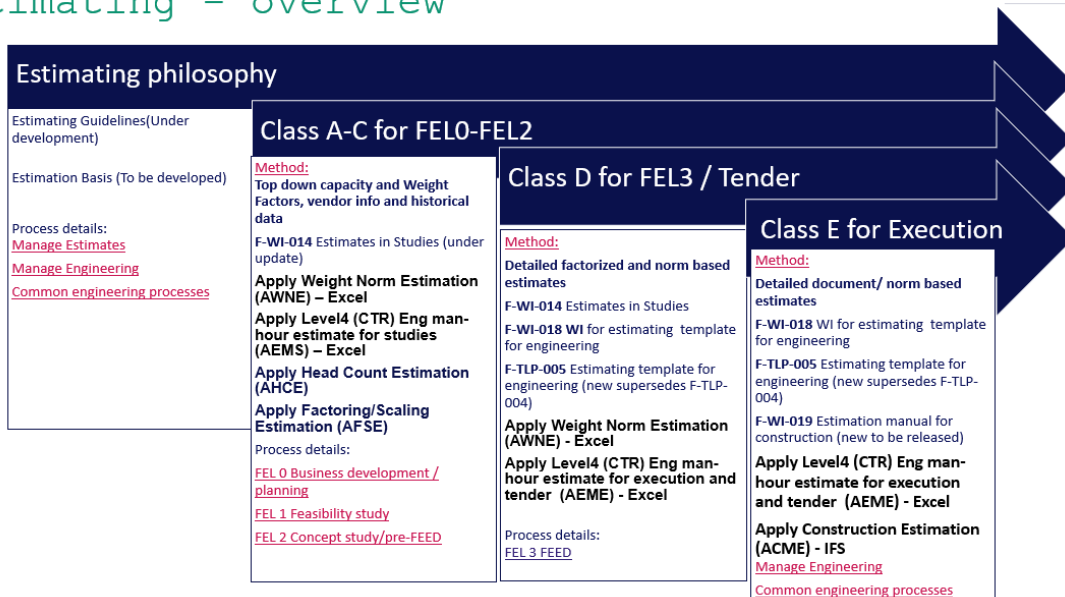
Figure 5-1 Overview of estimation in Apply (Egeland 2019)

5.1 Estimation Framework

The estimation framework in Apply is described in the processes given in COMPLY (Apply's process tool) And in the work instruction for Estimation in Studies in Apply F-WI-14.

> *"The purpose with the present document is to provide that all study cost estimation work in Apply Sørco is carried out in accordance with official Apply Sørco approved methodologies, tools and practices."* (APPLY)

This document describes the basis for the norms and rates for the main cost groups for onshore and offshore construction. It provides instruction for contingency and uncertainty. The estimate content requirements are to represent the contractors cost and man hours for project management, engineering, procurement (equipment & bulk), onshore construction, offshore construction and contingency for both modification projects, module type projects and new platforms.

The work instruction also describes the type and requirement for input data per study phase, the estimation principles to be applied and the estimation tools to be used together with a description of the execution of the estimation work. It also gives the requirements for the presentation of the cost estimates.

5.2   Estimation Processes

The cost estimation process in Apply was based on Statoil V&M Cost Estimation Methodology and ConocoPhillips V&M Cost Estimation Methodology.

The estimation processes are described in "COMPLY" – Apply's internal process tool (APPLY), where the work Instructions are also linked into the process.

The Apply cost estimation processes describes how to manage estimates, and work instructions has been developed in order to comply with the client's expectations and requirements given in the contracts.
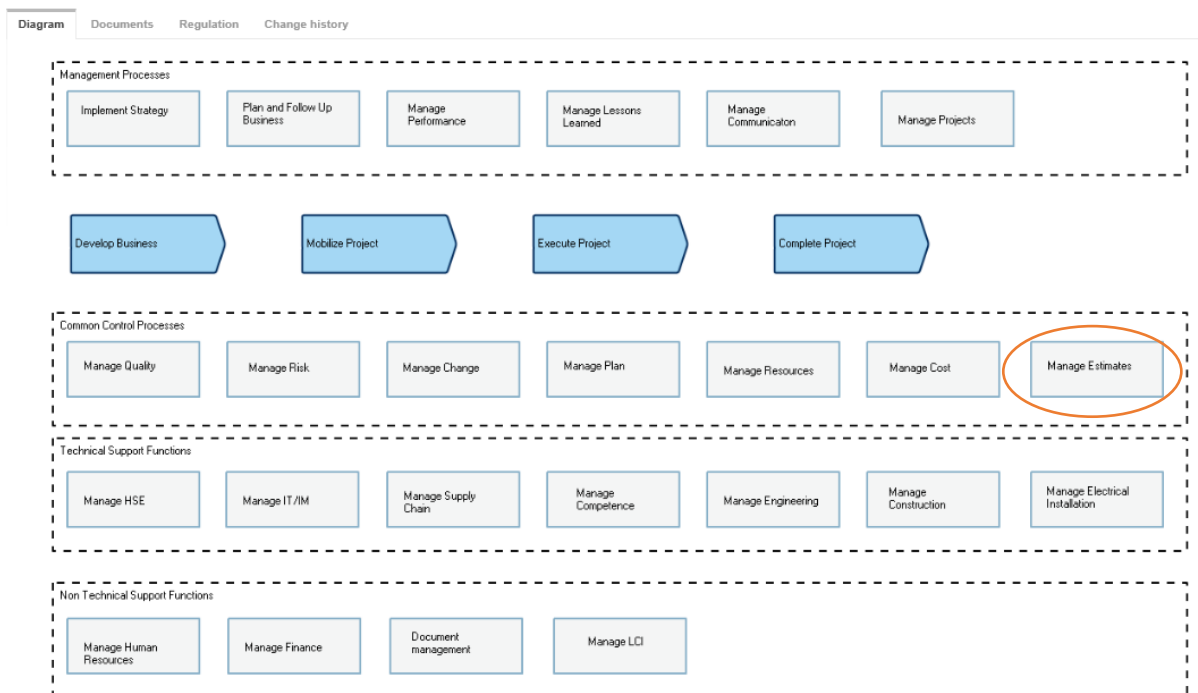
Figure 5-2Apply Management System in COMPLY(Apply 2019)

The processes for cost estimation can be found in COMPLY under Manage Estimates

Input to the Manage Estimates process comes from Manage Engineering -> Execute project – FEL0-FEL3 Studies, Manage Supply chain, Manage Construction

Output from Manage Estimates is man-hour Estimates for Plan, Cost estimates for Tender, Studies and Projects.

Estimation in Apply
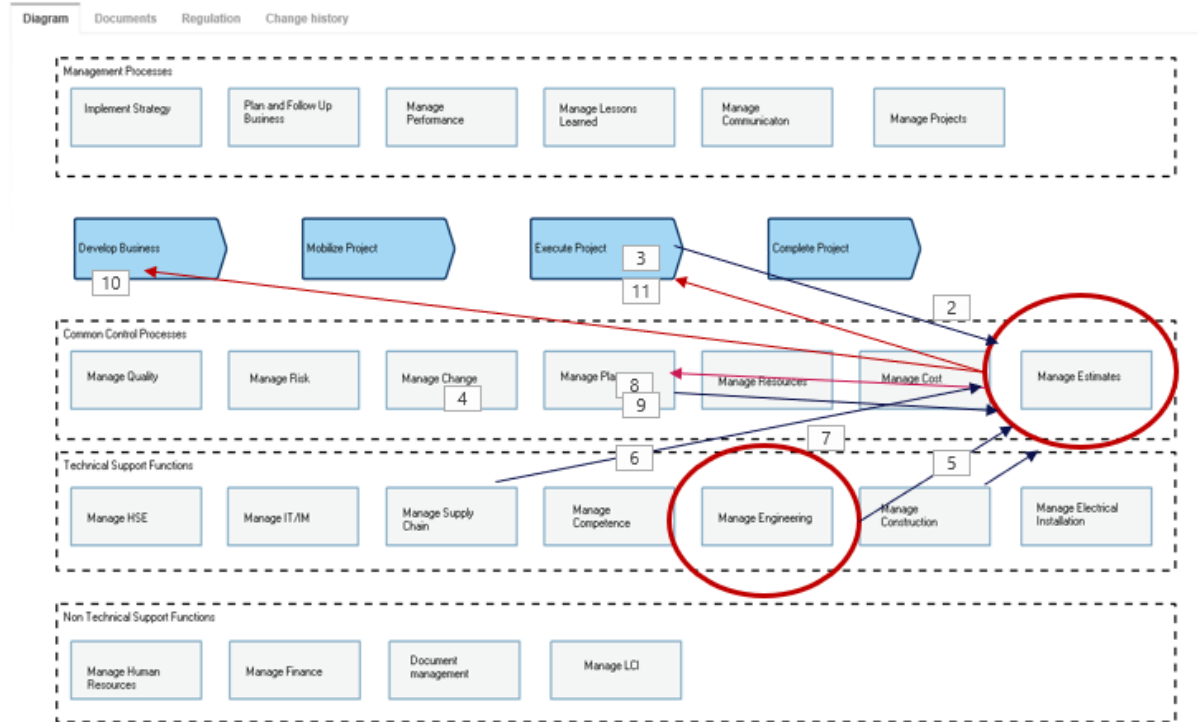
Figure 5-3 Manage Estimates dependencies

The Mange Estimates diagram is currently divided into 3.

- Evaluate project complexity and decide estimate method (for tenders)

- Perform project maturity verification (for call-offs)

- Establish estimates

Fist the purpose for the estimate must be evaluated, e.g is it for a tender or for a project call off in a M&M contract. The one would select either to evaluate complexity and decide estimate method (for tenders) or to perform project maturity verification (for call-offs). After completing the process for one of these purposes one should then go to establish estimate.
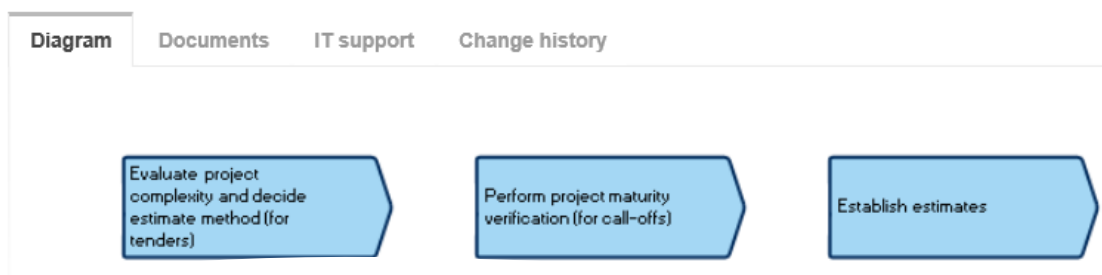
Figure 5-4Manage Estimates Diagram

Estimation in Apply

The above process could be drawn like this for tender:
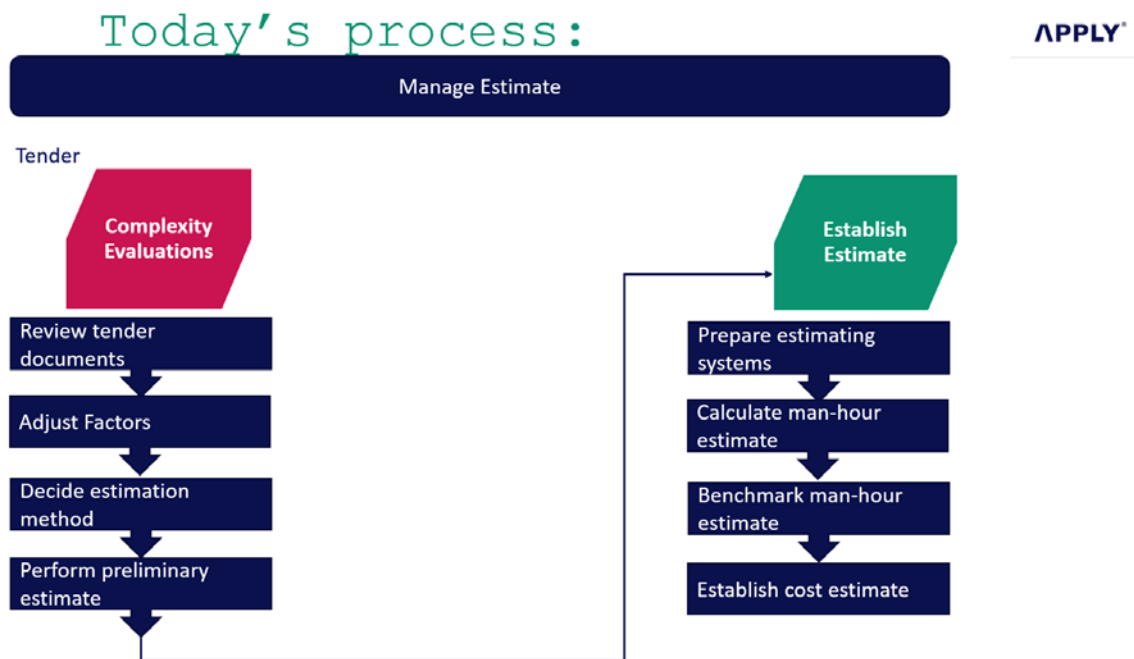
Figure 5-5 Manage Estimate for Tender - including the Establish estimate process

Looking at the process "Complexity Evaluations" for tender it points out the tendering documents shall be reviewed. The bis/no-bid decision has already been made in the process for "Develop Business" prior to "Prepare tender".

The Factors and Rates shall then be adjusted. This step does not have any supporting description nor documents. It is not clear which factors or rates that shall be adjusted or by whom. It is assumed that a complexity evaluation of the project is performed. Today, there is no catalogue for complexity factors within Apply. These complexity factors should be based on experience data. Historical cost records are currently not retained in a systematic, standardised way. Currently there is no strategy for how and where this should be done.

It is recommended to analyse the company's need and then determine which projects data that should be captured. As a minimum is should include the engineering data such as weight, capacities, equipment type, and basic project information such as location and other complexity factors in addition to detailed cost and schedule information. This is further discussed under section 6.9 Big Data Collection / value-added data integration.

For the process step "Decide estimation method", there is no supporting documents.

Estimation in Apply

For project call-off in an existing contract the current process goes like this:
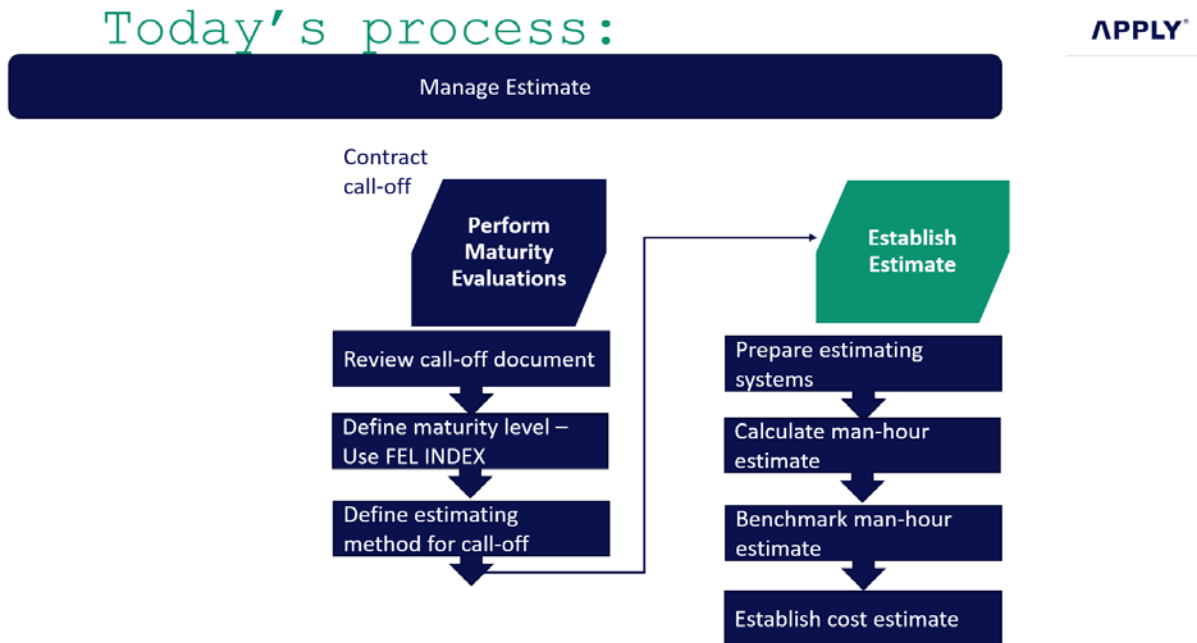
Figure 5-6 Manage estimates for project call-off - including the Establish estimate process

Looking at the current process "Perform Maturity Evaluation" it requires a review of the call-off documents. Then define the maturity level by using the FEL index and use this for selection of estimation method. However, is has been found that there are no supporting documents like procedures, work instructions or checklist to support the selection of estimation method.

These processes do not show how the cost estimation in studies should be performed nor the methods and tools to be used.

The new business areas in Apply; Larger Projects, Studies and Technology should also be covered by the processes. This could be done by adding a 3'rd estimation purpose: Studies. See Figure 6-10.

Figure 5-7 3 Proposal for adding Purposes to Manage Estimates

For Larger Projects estimation for tendering for FEED + EPCI should be covered. The process and methods for tender estimation is covered by the process, but an overall estimation philosophy is missing describing the methods, tools and required input. This has been identified by the cost estimation improvement project and is currently under development.

Estimation for project execution should cover both call-off to an existing frame agreement or contract.

In COMPLY the process Manage Estimates requires some interaction and is complex. The sketch below shows the complexity:
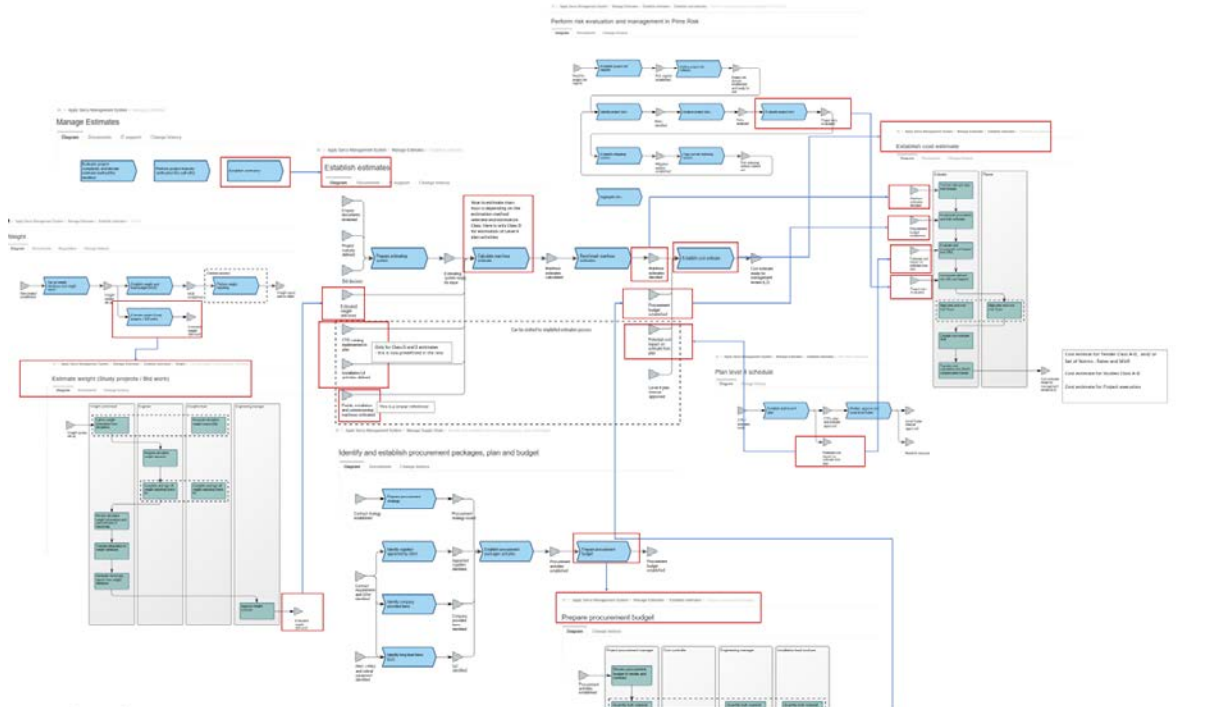
Figure 5-8 The Manage Estimation – Establish Estimate complexity picture

Below is a closer view of the Establish estimates process. This process is however only showing how to estimat a Class D cost estimate.
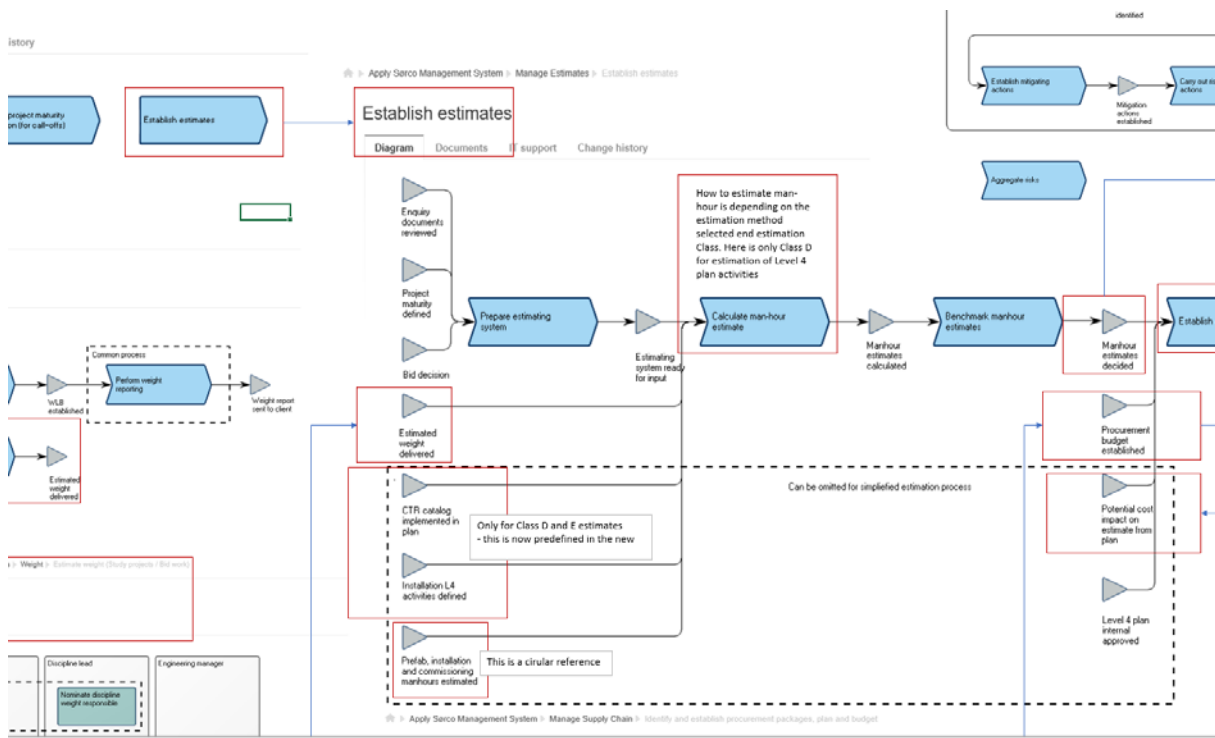
Figure 5-9 Establish estimates process

Estimation in Apply

The "Manage Estimate" process in Apply(Apply 2019) – "Establish estimates" is divided into 4 main steps:
Prepare estimation systems – Calculate man-hour estimate – Benchmark manhour estimates – Establish cost estimate. The "Prepare estimation systems process" is pending on input of client documents and whether the estimation is for a study or for a tender. Then estimation tools are set up accordingly. In the process for "Calculate man-hour estimates" the input requirements are defined. And in the process for "Benchmark man-hour estimate" the required workflow is described.
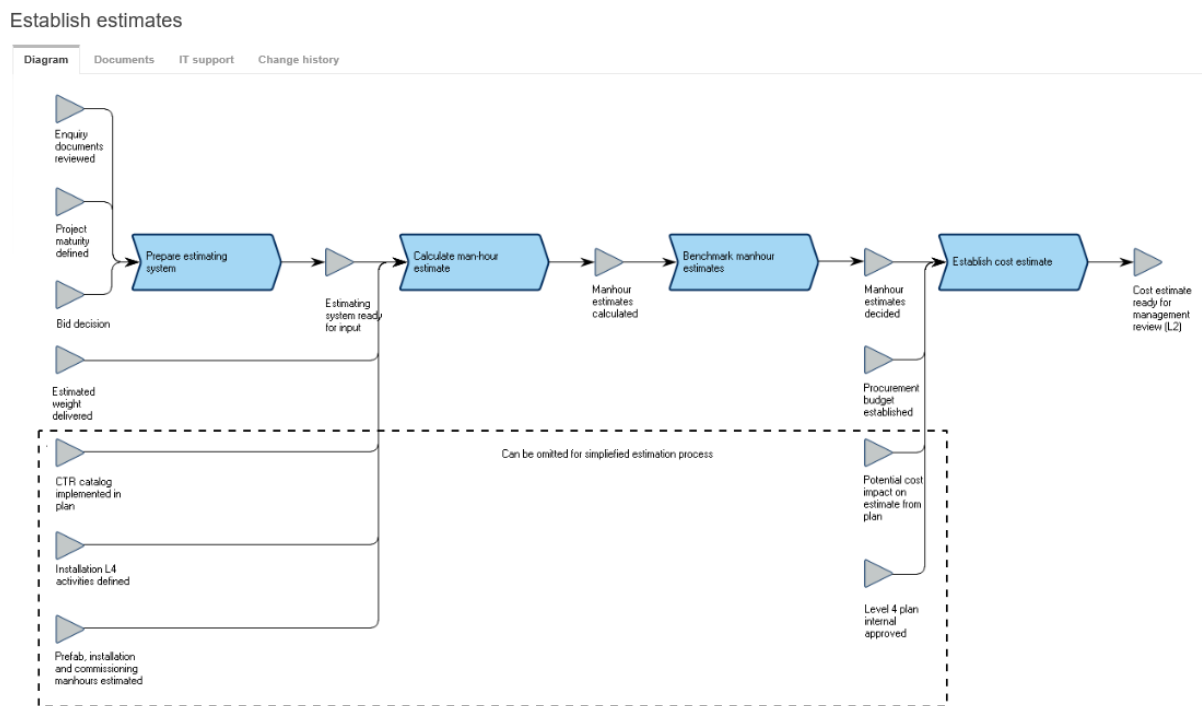
Figure 5-10 Apply Process for Establish Estimates(Apply 2019)

The New York City Department of Environmental Protection, Bureau of Engineering Design and Construction, has is their guideline for the Cost Estimation Process(DEP 2008) are proposing steps for a cost estimating process:

1. *Scope Input from Engineer to Estimator – Communication of Project Scope to the Estimation team*
2. *Estimate Preparations – Estimate structure and WBS (Work Breakdown Structure)*
3. *Develop estimate*
4. *Risk Analyses and Contingency Development*
5. *Estimate Output*
6. *Documentation of the Basis for the Estimate (BoE)*
7. *Quality review*
8. *Submit Estimate*

This has been used as a guidance when developing the proposal for updating the "Manage Estimate" process shown in Figure 6-8 but adding more steps between step 1 and 2 that is relevant for Apply's industry.
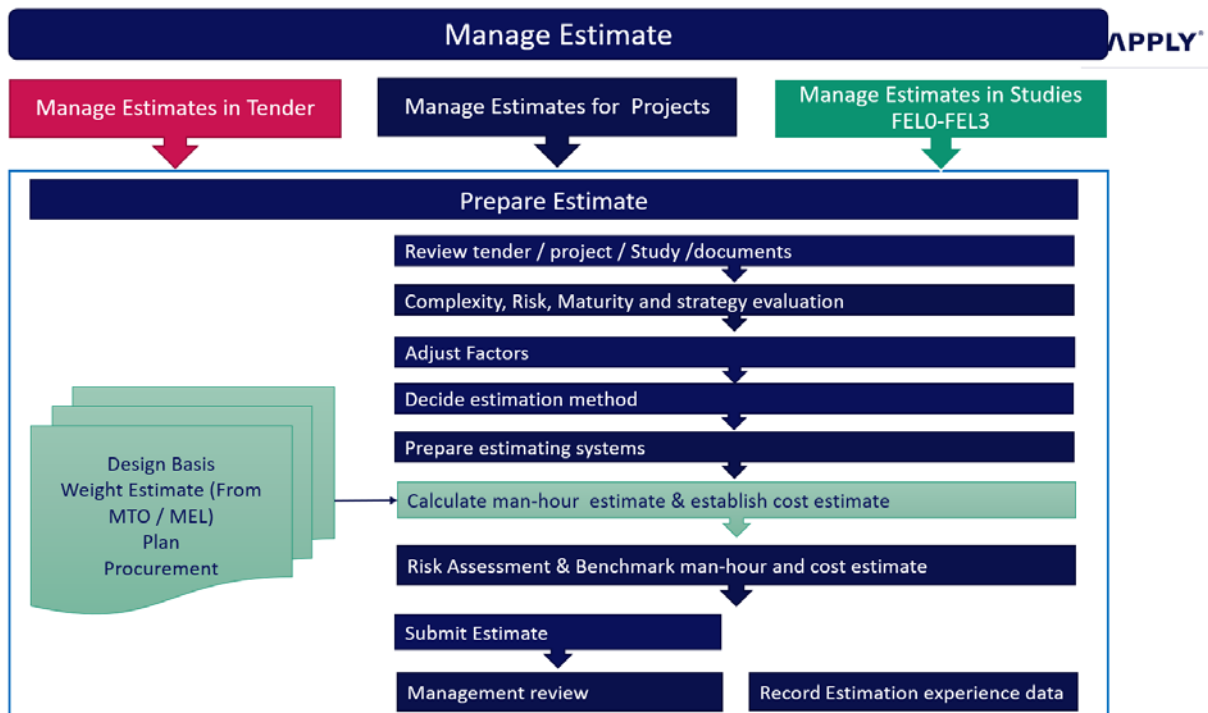
Figure 5-11 Proposal for updated "Prepare Estimate" process

It is also recommended to update the "Prepare estimate" process so it covers all three estimation purposes.

The first step will then be to review the availiable documents to define the tender/ project requirements. Then complexity mapping, maturity evaluations and risk assessment is proposed to be done. At this stage a strategy evaluation must be done by the management to evaluated whether there is a requirement to adjust the global complexity factors. Note: If the complexity factors should be adjusted one must first have experience data from similar projects in order to be able to know how the adjustment should be.

The tool for complexity mapping for setting the experience factors does not currently exist in Apply. It is therefore recommended to evaluate which complicity factors that should be evaluated, e.g the same parameters as in the FERM database.

The Estimation Method selection could now be made based on the purpose of the estimate, the phase the project is in along with the maturity. There is a need for a guideline and a checklist for selection of the Estimation Method and estimation modelling tool. See Figure 6-9 for estimation method selection. The Estimation Method selection should be documented in the Basis of estimation

document (BOE).
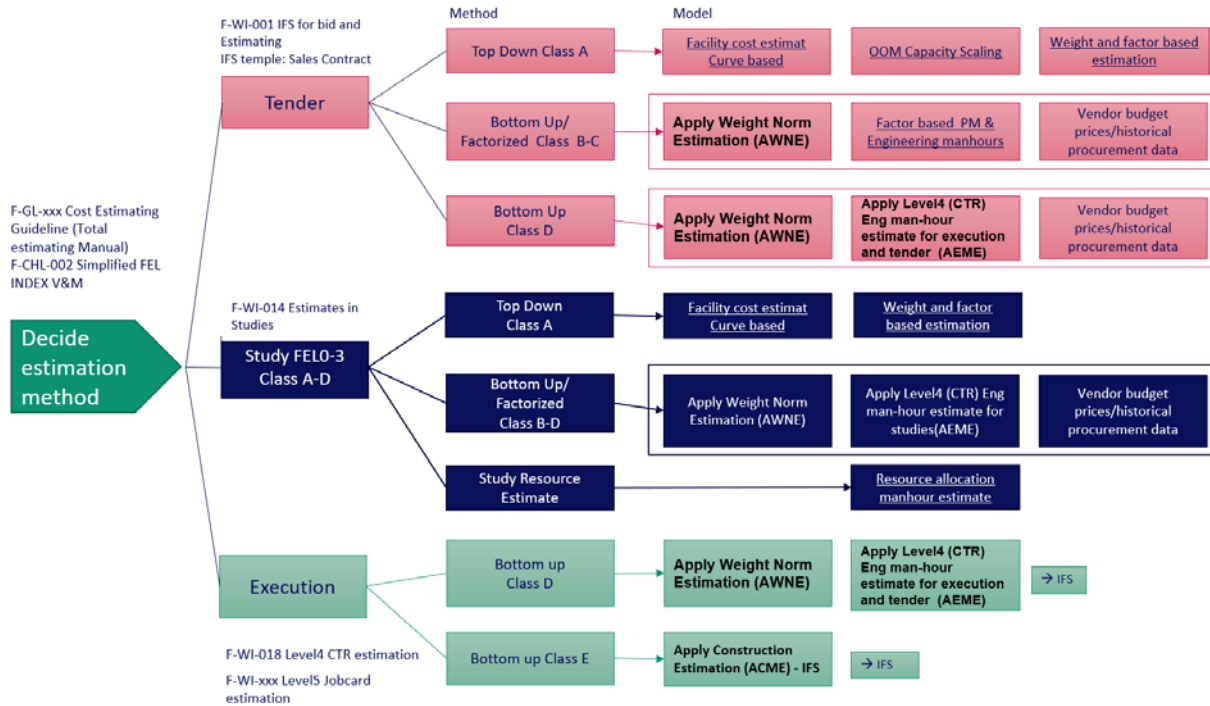
Figure 5-12 Proposed process for "Decide estimation method"

For preparing the estimation systems input, Work Brake-down Structure should be set up based on the client's contractual requirements. This step is already in the process today. The WBS and CTR structure is in Apply is described in 6.11.
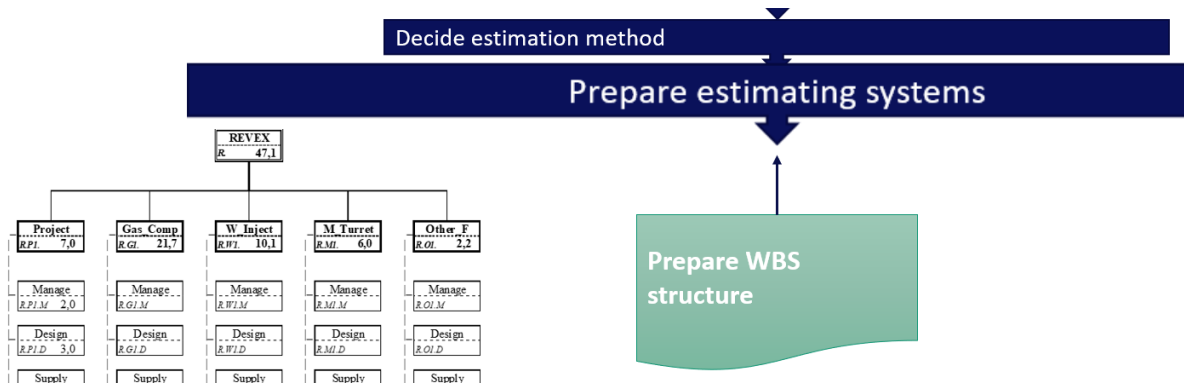
Figure 5-13 Prepare WBS Structure as input to Prepare estimation systems

When the estimation systems are prepared the calculation of manhours can start providing that the required input is given. The input is pending on the estimation class and method selected. The input can be design basis and technical input, weight estimate from MTO / MEL, schedule input from plan, procurement items information.

The discipline weight allowance is set in the MTO and MEL. Evacuation of how the engineers have set this allowance should be carefully followed up by the project management to avoid inflation on allowances and complexity factors.

Once the weight input has been added to estimation tool, the calculation of manhours for construction (direct work) can start. This is the basis for calculating project management and indirect work manhours. See section 6.10.2 for more detail about Norms.
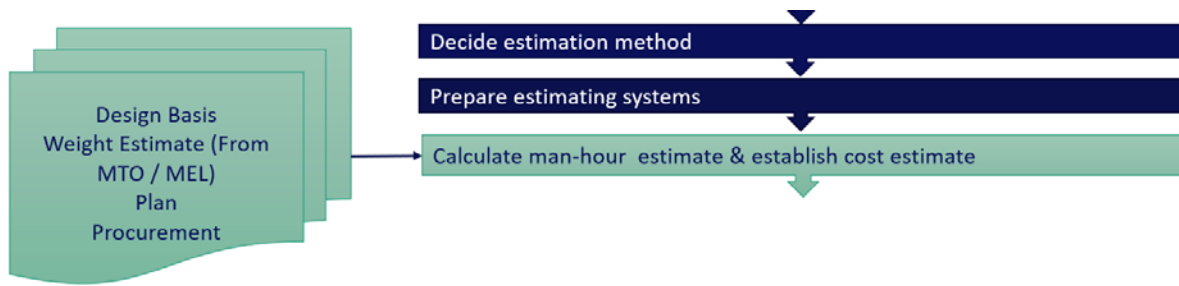
Figure 5-14 Input to Calculation of man-hour estimate prior to establishing a cost estimate

When the man-hour estimate is prepared, this information is sent to plan in order to plan installation time and the required engineering and purchase activities.

The timing of the projects is extremely important in the North Sea sector. The project installation is normally planned around the Production Shut Downs. And, the availability of personnel on board (POB) will dictate the timeframe and this will also give impact on the cost estimate. So, after the man-hour estimate is done, plan need to make a manpower histogram. This may result in requirements for change in the original schedule. And changes in the schedule will affect the cost estimate.

Figure 5-15 Finalising the estimate

The Cost Risk Analyses CRA is required for all class C and D estimates. Using a quantitative method for calculation the contingency is recommended. A proposal for a CRA model using @Risk has been made for this thesis. See section 6.7 for description of the model.

Then the cost estimate can be submitted to management review before being submitted to the client. The estimation experience data should then be recorded.

Estimation in Apply

5.2.1   Recommendations to the Estimation processes

The Manage Estimate process should be updated to reflect the three applications / purposes for a cost estimate:

Figure 5-16 The 3 proposed purposes for estimation

And the Prepare Estimate process should be updated with the following steps:
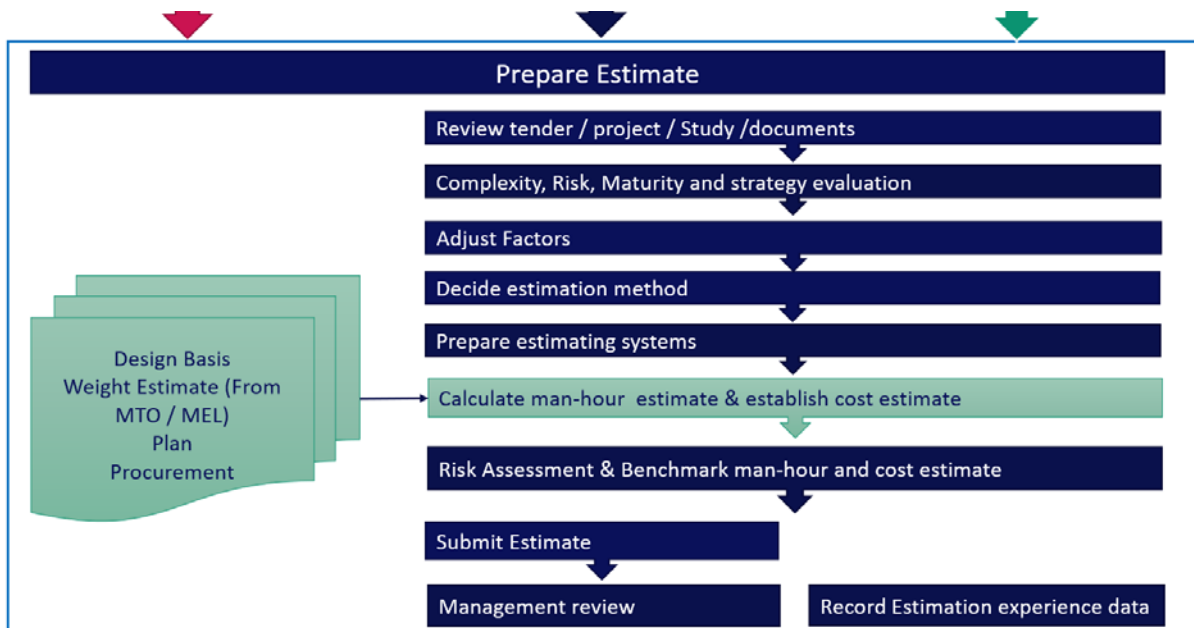
5.3   Estimation Classes

Cost estimates are prepared based on:

- Purposes
    - o   Tender (Frame agreement, FEED+ EPCI)
    - o   Study, FEL - FEL3
    - o   Project Execution
- Assumptions and Scope definition
    - o   Maturity of technical input and availiable information
- Accuracy
    - o   Clients requirements for accuracy level

In Apply's work instruction, F-WI-014 Cost Estimates in Studies(APPLY), the estimate classifications are defined by the study phase. It serves as basis for cost and weight estimation in studies, defined in Apply as FEL0 Early phase, FEL1 Select Concept, FEL2 Consept Study/ Optimisation, FEL3 FEED/ Further optimisation. However, the cost estimation improvement project has suggested to change these estimation classes to be aligned with the Equinor Estimation Classes for the first four classes A-D, with a fifth class E for the purpose of estimating manhours in the execution phase (on job card level).

 The proposed new Estimation Classes is shown in Table 7-1 Apply Cost Estimation Classes (Under development) .

Table 6-1 Apply Cost Estimation Classes (Under development)

Estimation Class	Phase	Methodology	Decision Gate	P80 Cost Estimate Accuracy	P80 Technical Maturity	Typ. Allowance	Normal level of Contingency
Class A	FEL 0	To down Capacity based Factors	DG0	NA	NA	NA	Not Given
Class B	FEL 1-2	Top down capacity and Weight Factors, vendor info and historical data	DG1	+/-40%	+/- 25 %	20%	25%-40%
Class C	FEL2	Top down / bottom up Weight factors, vendor info and historical data	DG2	+/- 30%	+/- 15%	15-20%	15%-30%
Class D	FEL3	Bottom up Norms, factors and doc. CTR's	DG3	+/- 20%	+/- 10%	10-15%	10%-20%
Class E	Execution	Bottom up Norms, factors and doc. CTR's		+/- 5-15%	Frozen	0%	0%

Estimation in Apply

Compared to the AACE Estimation Classes the classes can be compared as shown in Table 7-2 Estimation Classes AACE vs. Apply as follows:

Table 6-2 Estimation Classes AACE vs. Apply

Apply Estimation Class	Apply FEL study phases	Apply Accuracy CI 80%	AACE	AACE Accuracy
A	FEL0 (business case)	NA	5	L: -20% to -50% H: +30% to +100%
B	FEL1	-40% / + 40%	4	L: -15% to -30% H: +20% to +50%
C	FEL2	-30% / + 30%	3	L: -10% to -20% H: +10% to +30%
D	FEL3	-20% / +20%	2	L: -5% to -15% H: +5% to +20%
E	Detail engineering	Not defined	1	L: -3% to -10% H: +3% to +15%

The technical maturity is depending on how well the scope of work is defined. In Apply this is measured in a FEL INDEX.

Table 6-3 Scope Definition and Availiable weight data vs. Estimation Method and Class

Apply Estimation Class	Data input	Available weight data	Method
Class A	Data for Reserves / Capacities	NON	Top down Capacity curves
Class B	Capacities block diagrams /PFD's /MEL	MEL, historical data	Top down Capacity curves, factors and equipment scaling
Class C	PFD/ P&ID's	MTO & MEL, vendor data or historical data	Top down/ bottom up weight norms for installation direct work, factored estimate for indirect work, engineering and management
Class D	Frozen P&ID's and Layout	Vendor information, MTO and MEL	Document based CTR's and weight norm based, detailed vendor info
Class E	Frozen SOW	Vendor information, MTO and MEL	Job Card

Table 6-4 gives an overview of the estimation classes and with the respecting propose (study phases, tender or execution). It also shows what input is required and what tools the different groups (PM & Admin, Engineering, Procurement, Construction/Installation). The different Estimation methods and Estimation tools are described in 6.5 The estimation methods.

Table 6-4 Estimation Class and input and tools for estimation of Project Management (PM) and Admin, Engineering, Procurement, Construction / Installation

Estimating Class	PM & Admin		Engineering		Procurement		Const./Inst.	
Class A-C FEL 0-2	Hrs/ Ton	Factors rel. to Eng/Inst Calc. in AWNE	Hrs /To n	Factors rel. to Inst Apply Level4 (CTR) Eng man-hour estimate for studies (AEMS) – Excel or Apply Head Count Estimation (AHCE)	NOK/Te Input to AWNE	MEL	Hrs/ Ton	Mhrs est. Apply Weight Norm Estimation (AWNE) – Excel or Apply Factoring/Scaling Estimation (AFSE)
Class D FEL 3/ Tender	Nor ms/ CTR	Factors rel. to Eng/Inst Calc. in AWNE	Nor ms/ CTR	Documents/Tags Apply Level4 (CTR) Eng man-hour estimate for execution and tender (AEME) - Excel	NOK/Ton ne Input to AWNE	MEL/MTO / Bid	Hrs/ Met. Unit	Mhrs est. Apply Weight Norm Estimation (AWNE) – Excel
Class E Execution	Nor ms/ CTR	Factors / org. chart Calc. in AWNE	Nor ms/ CTR	Documents/Tags Apply Level4 (CTR) Eng man-hour estimate for execution and tender (AEME) - Excel	Actual NOK Input to AWNE	Bid/PO	Nor ms & fact ors	Workorders Apply Construction Estimation (ACME) - IFS

5.4   Estimation Principle

The normal cost estimation principle is based on the principle of using the following main input data in addition to scope of work and general project information:

- Equipment cost (budget prices from vendors).
- Equipment weight
- Bulk weights estimated partly by technical disciplines and partly by experience factors related to total equipment weight

The cost estimates by Apply(APPLY) is representing the contractors cost and man hours, is normally containing the following main CAPEX cost elements:

- *Project management*
- *Engineering*
- *Procurement (equipment & bulk)*
- *Onshore construction*
- *Offshore construction*
- *Contingency*

The estimates are normally exclusive Clients cost & man hours.
Excluded:

- *Clients project management*
- *Clients engineering*
- *Clients construction*
- *Commissioning (only commissioning assistance covered by Contractor)*
- *Supply vessel*
- *Stand-by vessel*
- *Onshore supply base*
- *Helicopter*
- *Catering*
- *Accommodation Project budget reserve*
- *Insurance*
- *Taxes and fees*
- *FEL-studies incl. FEED*

5.5   Estimation Methods

Depending on the project phase, maturity and availiable information, the estimation methods used in Apply is:

- Top down capacity and Weight Factors, vendor info and historical data – for Class A-C

- Detailed factorized and norm-based estimates – for Class D and Tender

- Detailed document/ norm based estimates – for Class E (job cards)
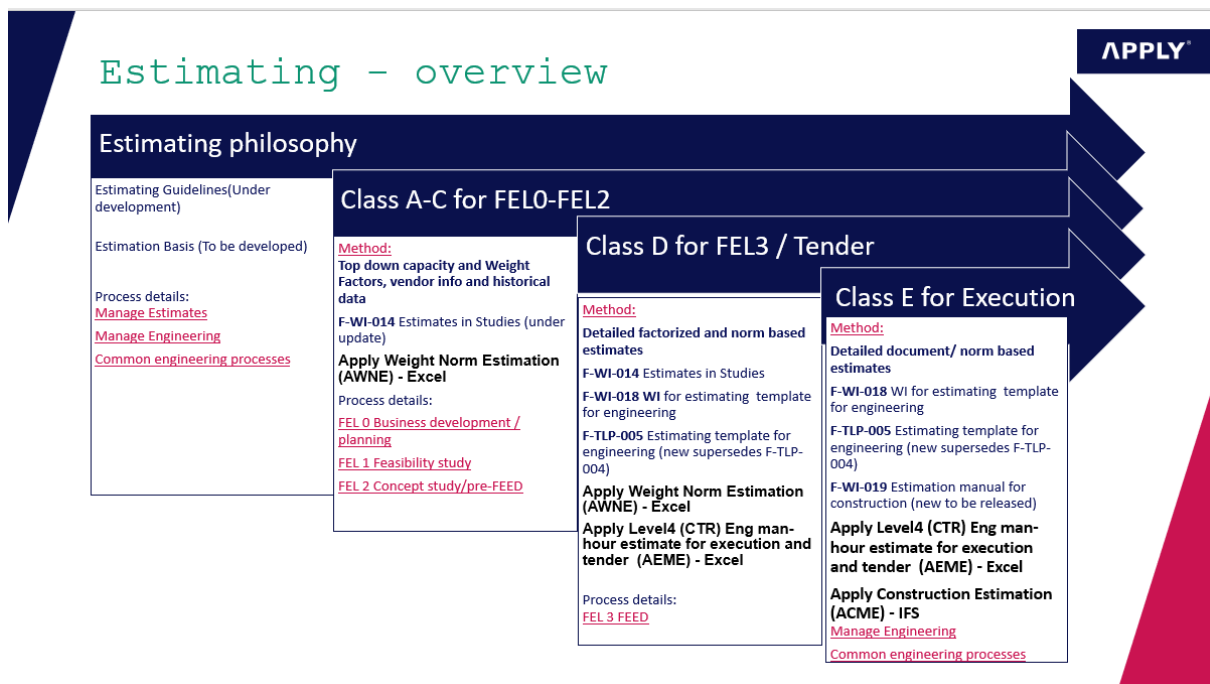
Figure 5-17 Estimation methods vs. Estimation Classes

See also Table 6-3 Scope Definition and Availiable weight data vs. Estimation Method and Class and Table 6-4 Estimation Class and input and tools for estimation of Project Management (PM) and Admin, Engineering, Procurement, Construction / Installation.

5.6   Estimation Tools

The different cost estimation methods require different estimation tools. The figure below shows the current availiable estimation tools in Apply. The input required for the estimation tools is shown in 5.7.

Estimation tools p.t.

ΛPPLY

Template	Name of Tool	Dataplatform	Application	Estimate Class	Template	Methodology	Work Instructions	Comments
TLP-xxD	**Apply Weight Norm Estimation (AWNE)**	Excel	Studies/ Execution	B, C, D	TLP-D	Detailed weigth norm based, vendor info	Missing WI	Input weight from MEL& MTO
TLP-004 (005)	**Apply Level4 (CTR) Eng man-hour estimate for execution and tender (AEME)**	Excel / IFS Database	Execution / Tender	D,E	TLP-004 (005)	Bottom up, detailed document and tag based	**F-WI-018** Estimation template work instructions / **ENG-WI-002** IFS Work instructions for planning engineering hours	Input no of tags from MEL & MTO & Line List and documentes (MDL) per discipline Ref.**F-PR-017** Apply Sørco's CTR num std
IFS	**Apply Construction Estimation (ACME)**	IFS database	Execution (JobCard)	E	IFS	Bottom up, weigth norm based	**F-WI-019** Construction Estimation	Input weight from MEL& MTO ref. **WP-PR-003** Input to Weight Estimating

Figure 5-18 Current Estimation tools in Apply

The Apply Weight Norm Estimation (AWNE) is an excel workbook. It does not jet have a template number, and there is no work instruction to support the use of this estimation workbook.

The Apply level4 (CTR) Engineering Manhour estimate for execution and tender has been updated and TLP-005 is now superseding TLP-004. The excel tool for estimation can now be used for input by engineering disciplines prior to export into IFS where the norms and rates are defined.

As it is only on the Apply Level4 (CTR) Eng manhours estimate for execution and tender (AEME) and the Apply Construction Estimation (ACME) the IFS database is used, it is recommended to evaluate other estimation tools that has a database.

Evaluating the different estimation methods, it is suggested that the following tools has been is missing or under development:

Estimation tools Missing / UA

APPLY®

Template no	Name of Estimating Tool	Dataplatform	Application	Estimate Class	Methodology	Topside	Sub structure	Sub surface	Offshore modifications for platforms	Onshore	Comments
NA	Que$tor	Database	Studies	A, B	Top Down	x	x	x	x	x	Not availiable
NA	AIPCE Aspen In-Plant Cost Estimation	Database	Studies	B, C, D	Bottom up, norm based	x			x	x	Not availiable
TLP-xxx	Curve Estimation	Excel	Initial Field development/ benchmarking	A	Topdown (synthetic), curves and factorized	x	x	x	x	x	To be further developed with historical data Input capacities
TLP-xxA	Apply Factoring/Scaling Estimation (AFSE)	Inhouse - Excel	Studies	A, B	Topdown (synthetic), curves and factorized	x			x	x	To be further developed with historical data
TLP-xxB	Apply Head Count Estimation (AHCE)	Inhouse - Excel	Tender for Studies	A	Top down Headcount method	x	x	x	x	x	Under development
TLP-xxC	Apply Level4 (CTR) Eng man-hour estimate for Study bid (UA) – (AEMS)	Inhouse - Excel	Tender for Studies	B, C, D	Bottom up -Study deliverables	x			x	x	Input activities / deliverables Under development

Figure 5-19 Missing Estimation tools

5.6.1 (AEME) The Apply level4 (CTR) Engineering Manhour estimate for execution and tender

Input and output for Apply Level4 (CTR) Engineering Manhour estimate for execution and tender model is shown in the figures below:

Figure 5-20 (AEME)

- Input quantity of documents/ tags and activities
- Input form Design basis, Study report, MDL (Master Document List), MEL, MTO

5.6.2   (ANWE) Apply Level5 Norm Based Weight Estimate

Input and output required for Apply Level5 Norm Based Weight Estimate (ANWE)
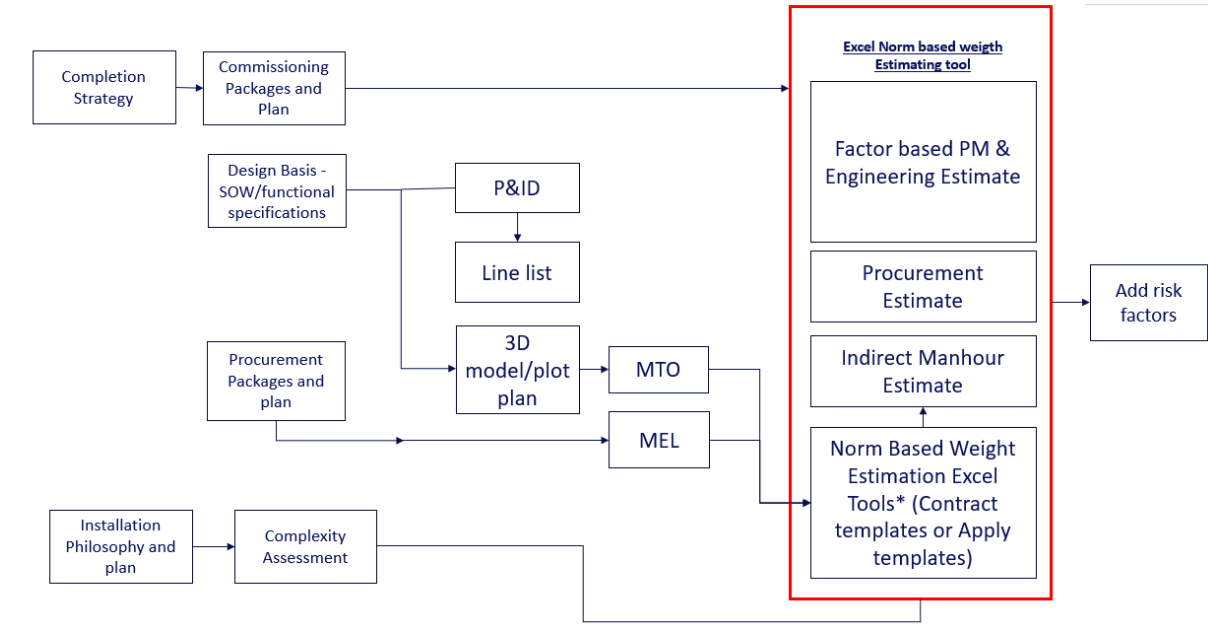
Figure 5-21 (ANWE)

The weight input is given in MTO (Material Take Off sheets) for bulk material and valves, and on MEL (Master Equipment List) for equipment. Each item will be defined of how the weight shall be handled, e.g. prefabrication, temporary removed or permanent removal, re-installation or install new, either onshore or offshore. The allowance on the weight is added in the MTO and MEL

In the MEL the budget price for the equipment is filled in if available.

Below is a screen prints of a typical MTO and MEL. For details see Attachment B

Figure 5-22 Example of MTO

Figure 5-23 Example of MEL

The weight data is then transferred manually from the MTO and MEL into the weight estimate discipline by discipline, items by items as shown below:

Figure 5-24 Example Detailed Weight input

The weight input is then summarized and shown as below:

WEIGHT ESTIMATE :   - I01QR 002 - REV. 00- OPTION 1

Summary	Perm. 1	Temp. 2	Moved 3	Replaced 4	Rebuilt 5	Tot. Install [1+2+3+4+5] 6	Prefab. 7	Module 8	Mods. [6-8] 9	Perm. Dem. {exc. 2+3} 10	Total Dem. [2+3+10] 11	Net. Install [6-11] 12	Handled [6+11] 13
Equipment \ Mechanical	6.100	0.000	0.000	2.270	0.000	8.370	0.000	0.000	8.370	5.900	8.170	0.200	16.540
H.V.A.C.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Piping	5.299	0.000	0.000	2.088	0.000	7.387	3.818	0.000	7.387	1.760	3.848	3.539	11.235
Electrical	0.180	0.000	0.000	0.120	0.000	0.300	0.000	0.000	0.300	0.000	0.120	0.180	0.420
Instrument	0.445	0.000	0.000	0.335	0.000	0.780	0.000	0.000	0.780	0.165	0.485	0.295	1.265
Structure : Steel	0.000	0.000	0.000	0.200	0.000	0.200	0.000	0.000	0.200	0.000	0.200	0.000	0.400
Structure : Aluminum	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Insulation	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Painting	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
P.F.P	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
SUM	#####	0.000	0.000	5.013	0.000	17.037	3.818	0.000	#####	7.825	12.823	4.214	29.860

Figure 5-25 Summary of the most likely weight estimate (summary)

The construction direct manhours are calculated using the above weight input multiplied by the norm. The indirect work man-hours are derived from these calculated direct work manhours.

APPLY

Apply Level5 Norm Based Weight Estimate

- Calculate Direct man-hors offshore based on handled weight using a weight norm multiplied by rate

- Indirect manhours is a % factor of direct man-hours

stallation - Offshore	UoM	Qty.	Norm	Hours	Rate	NoK
Module Installation	Te	0.000		0.0		
Electrical	Te	0.450	3	362.0		235,
HVAC	Te	0.000		0.0		
Inst. \ Telecomm (exc. Valves)	Te	3.900	8	3,236.1		2,109,
Piping exc. Valves	Te	8.600	7	1,812.2		1,181,
Valves (ALL)	Te	4.500	4	379.8		247,
Equipment (all disciplines)	Te	33.500	2	1,916.0		1,249,
Structure (Steel & Aluminum)	Te	26.100	4	2,438.7		1,590,
Architectural (inc. in Structure)	Te					
Demolition (all disciplines)	Te	35.800	3	2,157.9		1,406,
Other ...	Te		%	1,845.4		1,203,
um Direct	Te	112.850	4	14,148.0		9,224,
Foremen	Hours	14,148.0	%	0.0		
Other Indirects	Hours	14,148.0	%	212.2		138,
UP&WT	Hours	14,148.0	%	212.2		138,
Safety Orientations, Drills etc	Hours	14,148.0	%	212.2		138,
Other : Helicopter time	Hours	14,784.7	0	1,068.0		696,
um Non-direct				1,704.7		1,111,
ontainers etc. (dayrate)	15,852.7					158,
um Installation - Offshore	Te	112.850		15,852.7		10,494,

Figure 5-26 Calculation of construction direct and indirect man-hours

APPLY

Apply Level5 Norm Based Weight Estimate – comissioning

- Commissioning direct hours is calculated using a weight norm multiplied by rate
- Indirect commissioning is a % factor of direct man-hours

Commissioning - Offshore	UoM	Qty.	Norm	Hours	Rate	NoK
Electrical	Te	0.450	3	11.4	3	8,186
HVAC	Te	0.000	0	0.0	3	0
Instrument & Telecomm.	Te	3.900	9	471.4	3	338,464
Piping (Leak test)	Te	8.600	0	215.0	3	154,370
Equipment \ Mechanical	Te	33.500	0	1,005.0	3	721,590
Other (exc. M&M Services)	Te	0.000	0	0.0	5	0
Sum Direct Manhours	Te	46.450		1,702.8		1,222,610
Foremen	Hours	1,702.8	%	0.0	2	0
Other Indirects	Hours	1,702.8	%	25.5	2	16,653
UP&WT	Hours	1,702.8	%	25.5	3	18,339
Other : Helicopter time	Specify	1,753.9	0	132.0		94,649
Sum Non-direct Manhours				183.1		129,642
Hired Equipment	1,885.9				5	47,147
Sum Commissioning - Offshore	Te	46.450		1,885.9		1,399,399

Figure 5-27 Calculation of commissioning man-hours

The procurement estimate based on bulk cost and equipment cost input.

Apply Level5 Norm Based Weight Estimate – Procurement

APPLY

- Bulk cost is calculated based on weight multiplied by a MUR (Material unit rate NOK/Ton))

Procurement - Bulk Material	UoM	Qty.	Rate NOK/Ton	NoK
Electrical	T	0.450		100,427
HVAC	T	0.000		0
Instrument (exc. Valves)	T	3.900		1,895,473
Instrument Valves	T	3.300		2,706,000
Piping exc. Valves	T	8.600		2,827,474
Piping Valves	T	0.000		0
Structure - Steel	T	6.100		435,511
Structure - Aluminum	T	0.000		0
Surface Protection	T	0.000		0
Safety	T	0.000		0
Insulation	T	0.000		0
Passive Fire Protection	T	0.000		0
Architectural	T	0.000		0
Other: Company Provided items	Spe	0.000		0
Sub-total Bulk Material		2.350		7,964,885

Procurement - Total	U	Qty.		NoK
Sub-total Equipment	T	6.050		37,254,000
Sub-total Bulk Material	T	2.350		7,964,885
Total Procurement		8.400		45,218,885

Figure 5-28 Procurement cost

Apply Level5 Norm Based Weight Estimate

APPLY

Figure 5-29 (ANWE) Estimate output

The above excel tools will require manual weight data transfer from the MTO and into the weight estimation sheets. This could be improved by modifying the calculation sheets so that the weight input is transferred directly from E3D or directly from the MTO.

5.6.3   Apply Curve estimation Class A – Under development

Curve and factor-based estimates can be used for top down estimation for new facilities for Class A estimates ins studies. It could be used for cost indication for facilities when the input data only consist of field reserves and required processing capacities

There are currently no tools for curve-based estimation in Apply to be used for early phase class A estimates. But there is an excel workbook under development. This workbook will require input from historical data from similar projects. When this tool is developed it and be used for benchmarking.
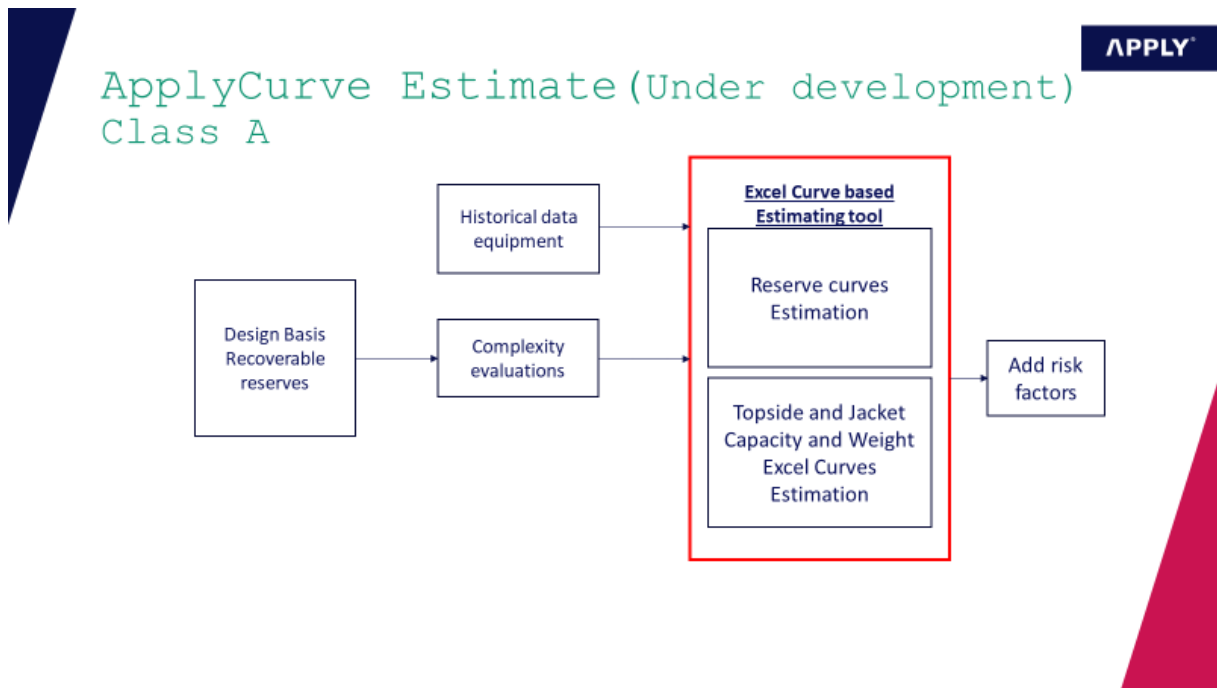
Figure 5-30 Apply Curve-based Estimation tool

The charts can give an indication of

- Topside efficiency : weight vs. capacity

- **Unit cost for topside** (cost/weight) – E.g. : Gina Krogh: **275 NOK(2003)/kg**

- Jacket efficiency : weight vs. topside weight*water depth

- **Unit cost for Jacket** (cost/weight) – E.g.Gina Krog Jacket : **47.7 NOK(2003)/kg**
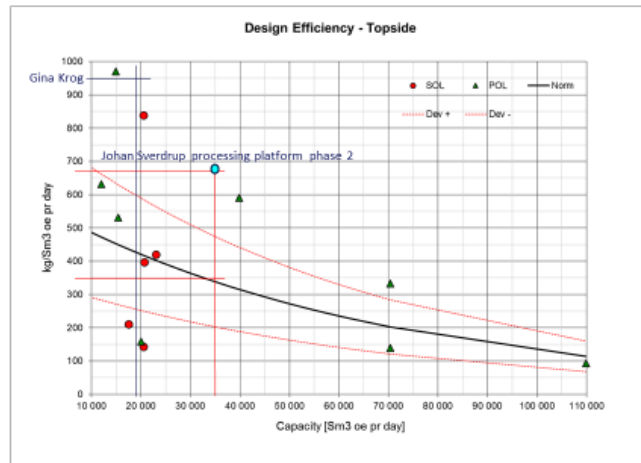
Figure 5-31 Curve based estimation - Topside efficiency
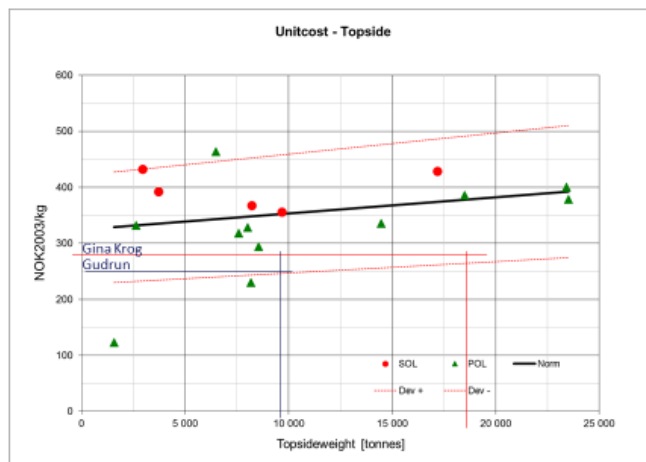
Figure 5-32 Curve estimation - Unit cost Topside

An example for curve estimation for Gina Krogh using the estimation tool under development:

Figure 5-33 Example form the curve- based estimation tool under development

5.6.4 (AFSE) Apply Factoring/Scaling Estimation

Order of Magnitude OOM estimation is called Factoring /Scaling estimation in Apply.

- Order of magnitude estimating method is used when very little information is available. Typically only a reference case is known.

- It is often called the "six-tenth rule" because the exponent n has an approximate value of 0.6

Application:

- Mainly Class A estimates, Occasionally class B

- Cost estimation of single equipment and all types of facilities

- New plant / greenfield and plant modification

Currently Apply don't have a estimation tool for this. The thesis has developed at proposal for such a factoring model. It is recommended to develop this model further, but again, this will require availiable historical data in order to derive the Apply factors. See figures below:

Apply OOM Capacity Scaling Estimate Class A (Under Development)
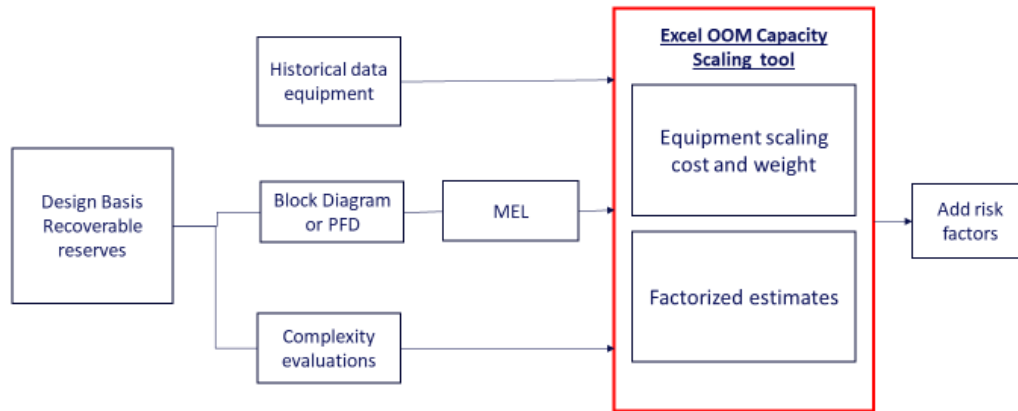
Figure 5-34 (AFCE) - Under development

Below is an example of cost scaling of equipment based on capacity :

CAPACITY SCALING -Six-tenth method

PROJECT	AAA
OPTION	A
Estimation date	dd.mmm.yyyy

Element	PRESSURE VESSELS/TANKS		
INPUT		Comments	Datasource
Required Capacity	150		
Capacity 1	100		
Exponent n (0.6 if unknown)	0.67		Garret / Guthrie other
Cost at Capacity 1	32.9		Historical prices form IFS
OUTPUT			
Calculated			
Cost at Required Capacity	43.2		

Element	HEAT EXCHANGERS		
INPUT		Comments	Datasource
			must be calulated based on temp requirements
Required Heat Transfere Area	1000	ft^2	
Constant	0.462	Shell & Tube	
Exponent n (0.6 if unknown)	0.5		T.Brown
Material Factor Shell & Tube	1.7	CS/SS	
Shell & Tube Factors	1	U-tube	
Pressure Factors	1.26	600#	
OUTPUT			
Calculated			
Cost at Required Capacity	31.3		

Figure 5-35 Capacity Scaling - Six- tenth method - under development (Egeland 2019)

Estimation in Apply

Cost for equipment can also be scaled by using a factor n derived for historical data

- Input is cost and capacity of several similar equipment's.

- The Apply n-factor is then derived.

- The required capacity of the new equipment is then used to calculate the new equipment cost

Note: This will need collection of historical data for cost and capacities

PROJECT	AAA
OPTION	A
Estimation date	dd.mmm.yyyy

Element	PRESSURE VESSELS/TANKS
INPUT	

	Capacity	Cost
2	2000	20000
1	500	9450
Required capacity	900	
Data source/date		

OUTPUT	
Exponent n	0.54
Cost at required capacity	12986

Cost vs. Capacity Pressure vessels

$y = 327.95x^{0.5408}$

Element	HEAT EXCHANGERS
INPUT	

	Capacity	Cost
2	2000	20000
1	500	9450
Required capacity	900	
Data source/date		

OUTPUT	
Exponent n	0.54
Cost at required capacity	12986

Cost vs Capacity Heat Exhangers

$y = 327.95x^{0.5408}$
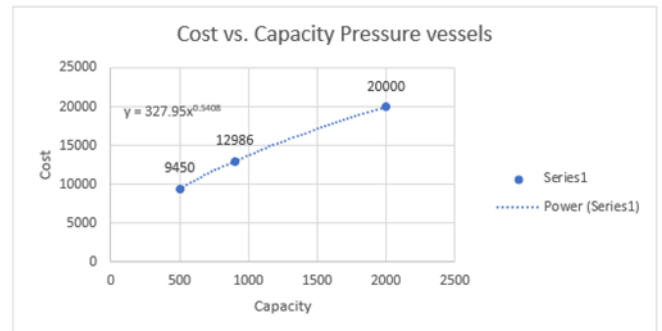
Element	PUMPS
INPUT	

Cost vs. Capacity Pumps

Figure 5-36 Capacity scaling - deriving Apply's n-factor (Egeland 2019)

Estimation in Apply

Factor based estimates for Class A-B is using modified Lang and Guthrie factors. (Perry 1999)

Factors to convert delivered equipment into Fixed - Capital Investment Cost

Details	Lang factor (Bauman) ref Perry table 9- Fluid processing	Comments	Apply factor assumed	(NOK) Cost	(NOK/hr) Norm	(%) Persentage of total	(kg/hr) Norm	(kg) Weight
Equipment delivered	1		1	100		24.3		100
Installed	0.27-0.47		0.47	47		11.4		47
Piping	0.66-1.2		0.66	66		16.1		66
Structural steel fondations	0-0.13		0.13	13		3.2		13
Electrical	0.09-0.11		0.11	11		2.7		11
Instruments						0.0		
Batterylimits building and services	0.18-0.34	NA	0			0.0		
Excavation and site prep	0.1	Structural site prep	0.1	10		2.4		10
Auxiliaries	0.7	afety equipment et	0.7	7		1.7		7
Total physical plant	3.5		3.17	317		77.1		317
Field expence	0.41		0			0.0		
Engineering	0.33		0.33	33		8.0		33
Direct plant costs	4.24		3.5	350		85.2		350
Overhead	0.21		0.21	21		5.1		21
Contingency	0.42		0.4	40		9.7		40
Cfc Total fixed capital investment Lang factor	4.87		4.11	411		100.0		411

Guthrie Factors for individual items

Details	Exhangers Shell and tube	Apply	Vessels Vertical	Appy vertical	Horisontal	Apply Horizonta	Pump and driver	Apply Pump and driver	Comressor and driver	Co...
FOB Equipment	1.00	1.00	1.00	1.00	1.00	1.00	1.00		1.00	
Piping	0.46		0.61		0.42		0.30		0.21	
Concrete	0.05	0.00	0.10	0.00	0.06	0.00	0.04		0.12	
Steel	0.03		0.08		0.00					
Instruments	0.10		0.12		0.06		0.03		0.08	
Electrical	0.02		0.05		0.05		0.31		0.16	
Insulation	0.05		0.08		0.05		0.01		0.03	
Paint			0.01		0.01		0.01		0.01	
Total Materials = M	1.71	1.00	2.05	1.00	1.65	1.00	1.70		1.61	
Erection and setting L	0.63		0.95		0.59		0.70		0.58	
X, excluding site prep and auxilia	2.34	1.00	3.00	1.00	2.24	1.00	2.40		2.19	
Freight and insurance,taxes home office, construction	0.05		0.08		0.08		0.08		0.08	
Overhead or field expence	0.95		1.12		0.92		0.97		0.97	
Total module factor	3.34	1.00	4.20	1.00	3.24	1.00	3.45		3.24	

From Guthrie chem eng 76, 114-124 (march 24, 1969) Based on FOB equipment cost = 100 (CS)

5.6.5 Recommendations estimation tools

To increase the credibility for performing field development studies Apply should invest in a well-recognised databased estimation tool. For class A studies, Qustor or similar program should be evaluated purchased.

It is also recommended to develop inhouse estimation tools and databases or further develop the proposed curve-model and the factor scaling model (AFSE). This can be useful tools for future benchmarking as well as for quick preliminary estimates when the input data is scares.

For class D studies (FEED and tenders), the AIPCE Aspentech In-Plant Cost estimation tool should be evaluated as this has the benefit of estimation on equipment level.

However, further development of the inhouse tools will require a database with experience data.

5.7   Factors

5.7.1   Accuracy

Apply's clients are oil and drilling companies. The client's requirements and expectations to the estimate accuracy is given in the contracts.

The estimate class and study phase give a proposed accuracy level for the cost estimate. This is shown in the Table 6-1 Apply Cost Estimation Classes (Under development).

The accuracy of the estimate is important for the decisionmakers. They will want an accurate number for the cost of the project to be assured that there will not be overruns. But an accurate estimate requires information on a detailed level and the scope of work will not change. In addition to this, all uncertainties to the and systemic risks must be eliminated. We should think that the solution would be to overestimate the project. But an overestimated cost estimate may result in refusal of investment in the project, or if the project is approved for execution the project would then bind up funds that could be utilised on other projects.

In Apply, the goodness of the estimate is measured by the productivity. The productivity is given by calculating the estimated hours vs. used hours.

5.7.2   Contingency

Contingency is generally included in most estimates and is cost additions expected to be expended.

It is an amount added to an estimate **to allow for the uncertainty that experience shows will likely result in additional costs**.

Contingency can be seen as a "technical" correction to compensate for the effects of skewed (non-symmetric) distributions for each of the components in the estimate.

The Contingency must be added to find the Expected cost, which is the statistical mean value (centre of gravity of the probability distribution).

The contingency will typically cover:

- • Design development within the agreed design basis/scope of work
- • Estimate adjustments
- • Bias, omissions and errors
- • Minor adjustments to execution schedules/milestones
- • Normal variations in market prices
- • Other risks within the control of the Project.

Contingency usually **excludes**:

- Major scope changes such as changes in the end product specification, capacities, building sizes, and location of the asset or project

- Extraordinary events such as major strikes and natural disasters

- Management reserves; and

- Escalation and currency effects

We need to find a way to represent these unknowns, and use a risk register to guess what the possible unknown can be.

"The traditional approach to dealing with the uncertainties of the estimate (scope, materials, design details, etc.), particularly at the early stages of the project, has been to include a percentage for contingency either based on the estimator's judgment or determined by a guideline using the completion status of the design documents. These methods are subjective and either reflect one person's (or small group's) opinion or are based on guidelines that are not specific to the project. Even the determination of the percentage complete of the documents is an arbitrary judgment" (Wallwork 2013)

This praxis is also described in the Apply work instruction F-WI-014 Section 3.1.4.3.(APPLY) where it states:

> *"Instead of carrying out risk analysis on the Basis Estimates, it has been decided by Apply Sørco to calculate the contingency by using standard percentage rates of the Basis Estimate, considered to represent common practice in the oil and gas industry in cost estimates for different types of studies. "*

The predefined contingencies for each estimation classes have been used as a basis for contingency setting in Apply. See Table 6-1 Apply Cost Estimation Classes (Under development). And then the contingency factor has been adjusted after a maturity evaluation using the FEL index, see Figure 5-37 below:
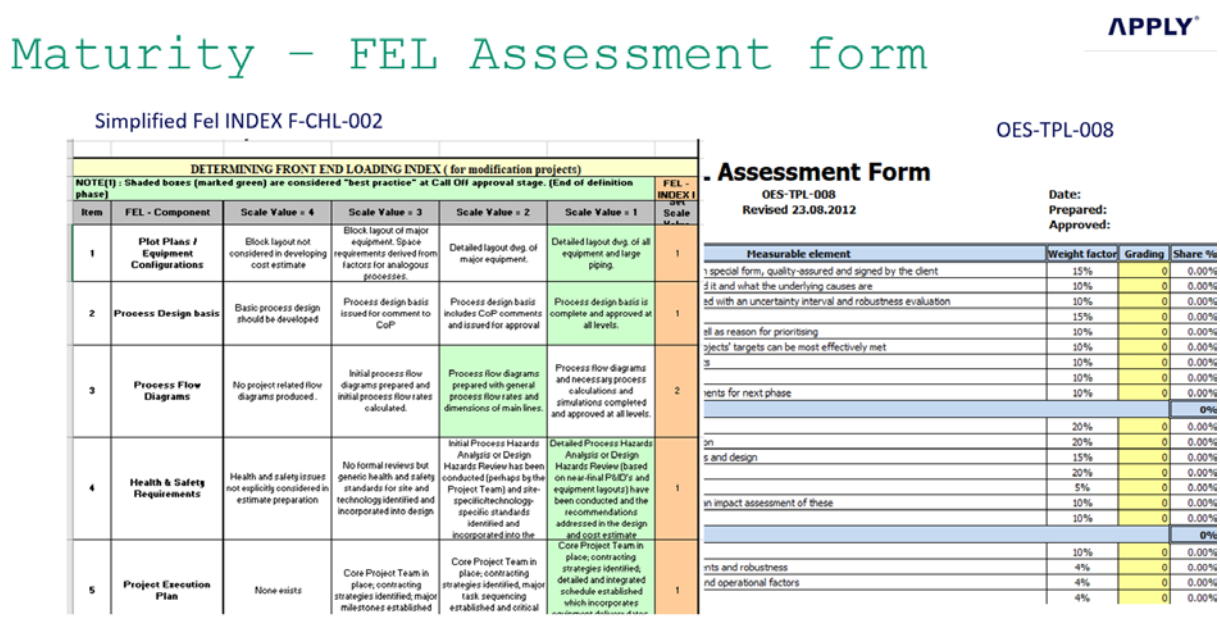
Figure 5-37 Maturity evaluation using the FEL INDEX form

The Figure 5-37 shows how the contingency decreases as a result of the development within the scope maturity:

Maturity development in Project Front End Loading
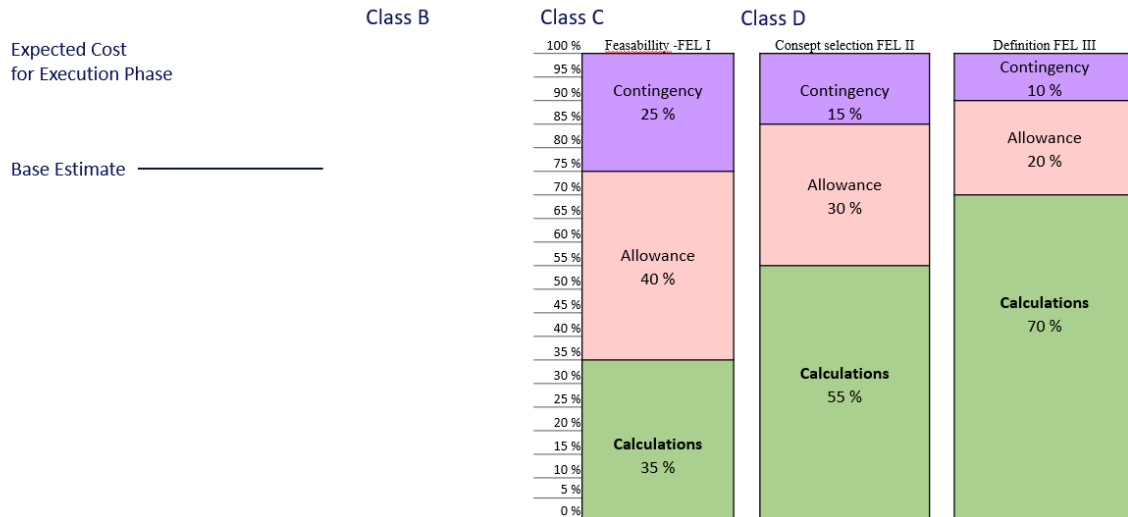
Figure 5-38 Maturity development in early phase projects (FEL 1-3)

Since there will be incompleteness in the drawings and design in the early study phases. Using the maturity level of the project to evaluate if the pre-set contingency is used may be effective. But, to determine a more appropriate, realistic and project specific contingency, the solution is to use a quantitative risk assessment by examine the risk elements of the estimate and determine their likelihood for occurrence and the range of values. A risk model providing the range of possible costs and their probabilities is made employing a Monte Carlo methodology in a risk assessment workshop. The required contingency can be calculated by subtracting estimated cost from the probabilistic cost at the clients desired confidence level (P-value). (Wallwork 2013).

It is therefore recommended that the Contingency is calculated in the Cost Risk Analysis for class C and D estimates and that the predefined standard values for contingency could be applied on simple projects.

In this thesis a proposal for a CRA analyses model using @Risk (Egeland 2019) has been developed. It is recommended that this model is further developed and that Apply buys a licence for @Risk since there currently is no availiable tool for Monte Carlo simulations other that for Schedule in Safran.
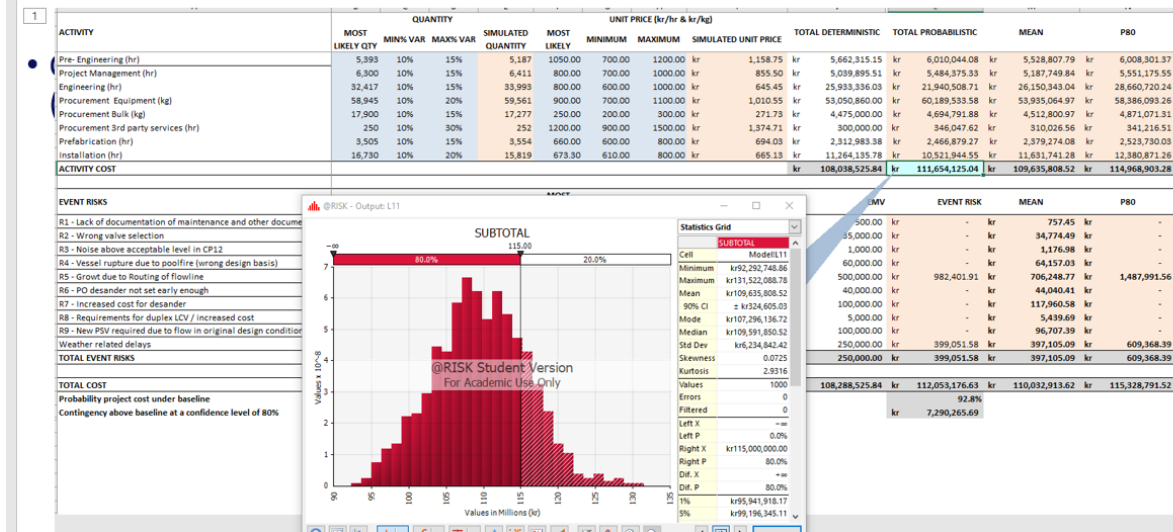
Figure 5-39 Proposed model for CRA using Monte Carlo Simulations @Risk (Egeland 2019)

CRA

Density curve

Cumulative probability or percentile

Regression coefficients tornado

Change in output means tornado
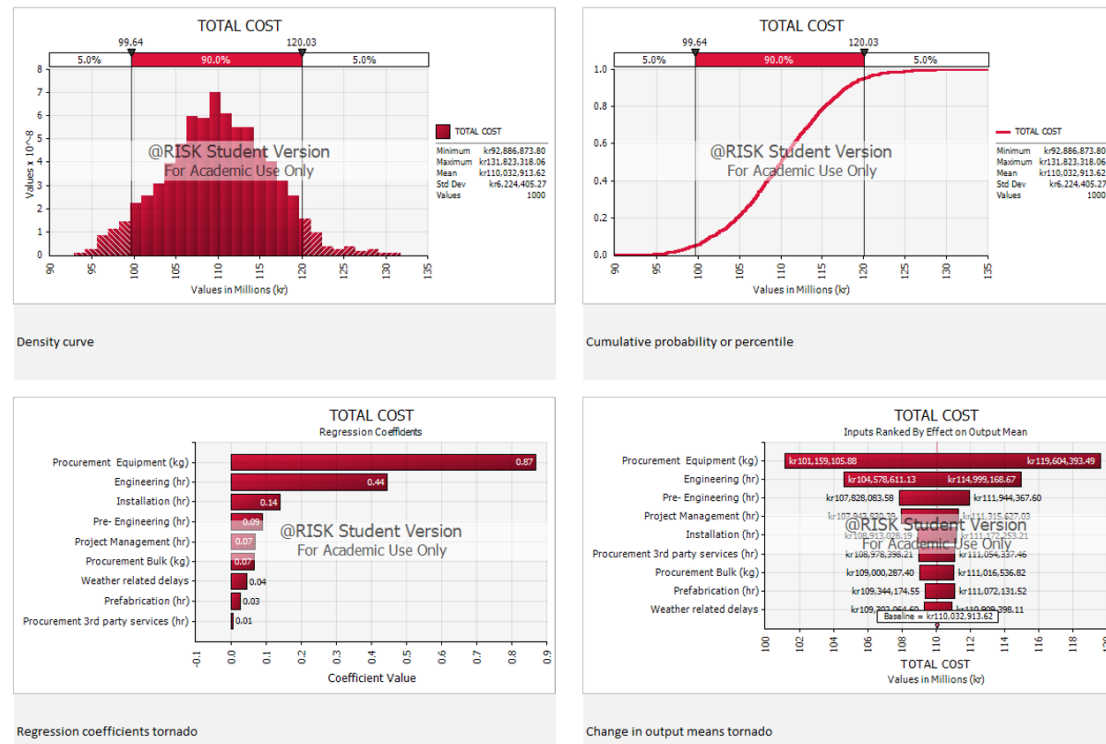
Figure 5-40 Output report from the CRA model (Egeland 2019)

5.7.3   Complexity Factors

In Apply, the only global complexity factor that is assed to the estimate is in class E estimates for jobcards. Here there is a factor to be used if the construction work is performed onshore or offshore.

It is recommended to do a complexity mapping for all estimation applications. The mapping should evaluate both global factors and discipline factors.

The global factors could be:

- location; onshore/offshore and where
- type of facility; rig/floater/fixed platform/etc
- age; new/old facility (availiable space, documentation, safety issues, etc.)
- schedule; on critical line/require shut down etc.
- etc.

The local factors are factors that affect the discipline construction work both direct and indirect, such as:
- Congestions
- Work at multiple levels
- Indoor/outdoor installation
- Turnaround work
- Tie-in complexity
- Work over production areas
- Work over sea
- Long distance to Support areas (Store/ lay-down area/workshops)
- Hot Work
- Etc.

Complexity factors

APPLY

Global factors
Onshore /Offshore
Type of Facility
New / Old Facility
Location
Schedule

Where and when the complexity factors should be added to the estimate should be further evaluated

Discipline factors	Impact on
Congestions	Direct work
Work on multi levels	Direct work
Indoor / outdoor installation	Direct work
Turnaround work	Direct work
Tie-in complexity	Direct work
Work over production areas	Direct work
Work over sea	Direct work
Long distance to Support areas	Indirect work
Hot work	Indirect work

Figure 5-41 Proposal to complexity factors for construction work to be evaluated

Currently there is no tool for mapping of complexity in Apply. Below is a proposal of a complexity mapping tool in excel. This worksheet will require a set of pre-defined complexity factors. These factors must be based on Apply's historical experience data / productivity for similar work. Currently Apply's experience data can be found in the FERM database, but only for the Equinor projects.

It is recommended to set up a strategy complexity mapping and identify want should be measured and where it should be stored. Once there is a set of defined complexity factors, the complexity mapping could be useful both for benchmarking and for better prediction estimates.

The excel tool shown in Figure 5-7 should be further developed.

Figure 5-42 Proposal of a complexity mapping template

5.7.4 Recommendations

- Develop tool for **Complexity mapping** and guidelines for implementing the complexity factors

- Implement @Risk in the Apply toolbox for CRA (Cost risk Analyses) and further develop the proposed CRA model for Apply

    - For CRA in Tenders

    - For CRA in Studies

- Develop a process for CRA with guidelines and WI

5.8   Big Data Collection / value-added data integration

The Independent Project Analysis (IPA)(Greg Ray 2019) found in a research among their clients that digitalization tools are burdensome for projects organizations to implement. In the early phase projects (Studies), value-added data integration successes are uncommon even though the new data-technology is creating value in others project's lifecycle.

In order to be able to predict future cost for a project, historical engineering data of quantities, weight and process capacities is essential. IPA(Greg Ray 2019) recommends that for capital projects data capturing should include detailed cost and schedule information, in addition to the engineering data, and basic project information such as location and other complexity factors. The complexity factors and quantification of risk and contingency requires experience.

The identification and quantification of risk and contingency is requiring experience and skills. Organizations that have retained historical cost records can leverage the experience embedded in the data. However, this provides that the data for similar work is organized and that there is consistent work and cost structures. The probabilistic range of possible costs that may incur in a future project, can then be used for calculation of the contingency.(Poskie 2013)

If the project data is organized and collected systematically, it can used for benchmarking and to create unit prices and trends for future costs. But one of the main challenges is to organize the cost structures and collect the data in a standardized way. The NORSOK Z-014/ISO 19008: 2016(NORSOK 2012, ISO 2018) was developed to ensure standardisation of such data.

The volume of information generated in the projects are large. And, in order to leveraging project data to feed decision making, there is a need for digitalization[2]. Appreciating the difficulty of capturing information on projects, identifying what data are important, how to organize it, and how to extract insights from it, the right people with the skills to do this is also required (Greg Ray 2019)

Note: Data collection from different sources other than determined by a public approved or other recognized body can be flawed as it can be manipulated.(Sandberg 2019) Such data should be evaluated carefully before use.

The possibilities within the digitalisation of data is however promising. Analyses of the digitalized project data can give better predictions for the future than earlier, given that data will be shared across systems, departments and companies. But, if the data integration is not assessed properly, the company may risk its future competitiveness. (Greg Ray 2019)

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[2] Greg Ray, L. W. (2019). "Capital Projects Struggle to Implement Digitalization." IPA Newsletter **11**(Issue 2).
        «The definition of digitalization varies but is generally ascribed to the process of using digital technology to transform the way we do business"

Estimation in Apply

5.8.1 How is the data collected in Apply?

Apply has a process for Manage Lessons Learned
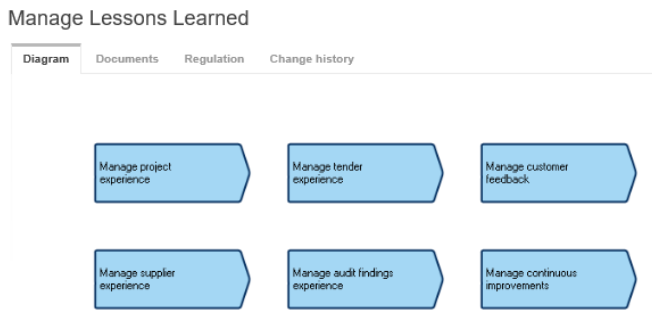
Figure 5-43 Process for Manage lessons learned

Under the process "Complete Project", the projects shall plan and complete close out actions according to internal requirements. The purpose is to ensure that the project is closed under the necessary management and control. (ref. COMPLY)

Figure 5-44 Complete project

Estimation in Apply

In the "Close Project" process for modifications– the activity "Generate productivity and estimate experience data" requires
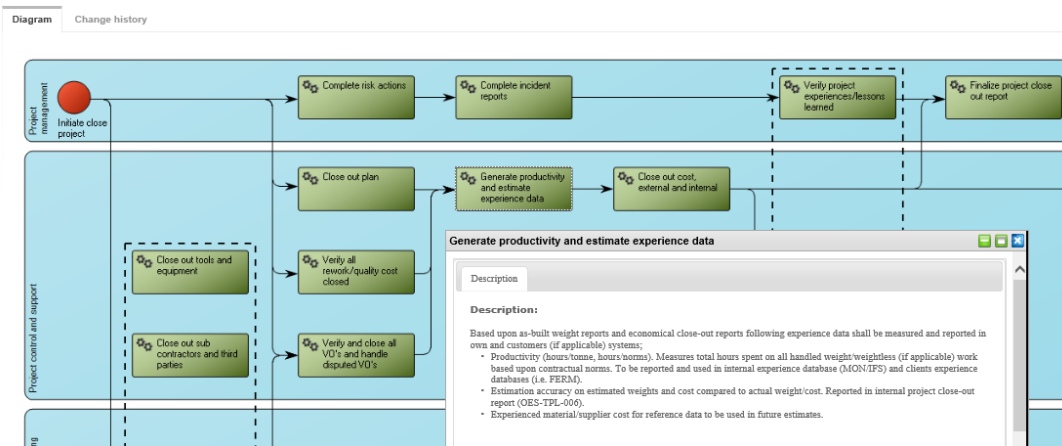
Figure 5-45 Close project - Generate productivity and estimate experience data

The Equinor V&M contract has requirement for reporting handled weight and spent man-hours from the MON database to the Client's FERM database. However, the process does not give instructions for other contract of how to retaine historical cost records in order to add value for future projects.

Below is a map of the Data Infrastructure in Apply. There is today a missing a project data collection flow from close out and lessons learned and into the estimation templates.
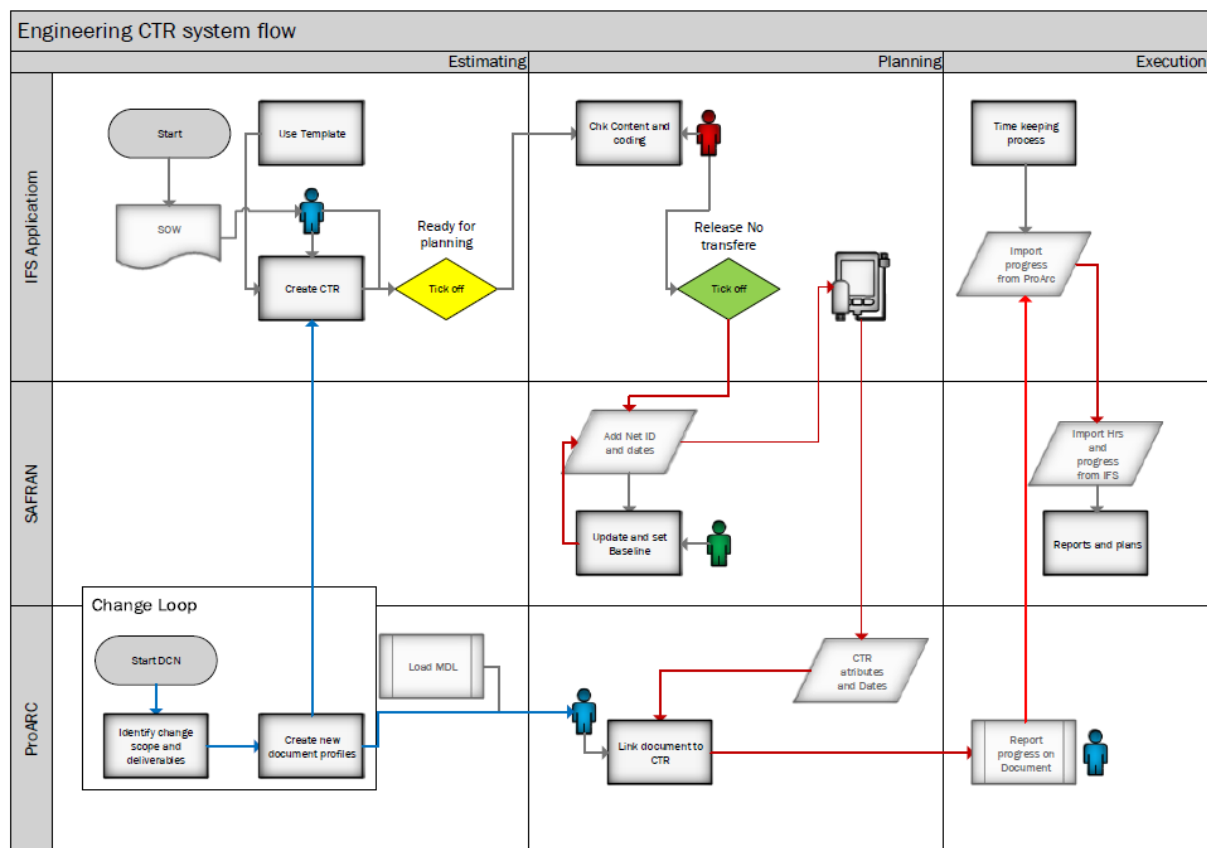
Figure 5-46 Apply Data Infrastructure - Activity Information Flow(Apply)

Estimation in Apply

In Apply there is some difference in the data infrastructure between the contracts. The figure above shows the flow of data from Estimation via Plan to Execution. The data infrastructure is semiautomated with some automatic transfer in addition to human interphases and manual operations.

The different contract does also have different requirements for manhour and weight reporting and estimation. The estimation is based on the Norms and manhour rates in the different contracts. Direct work is compensated in accordance to the norm given in the contract. The setup will vary from contract to contract and must be carefully evaluated in each case to ensure correct reporting.

All purchases done in the Apply purchase system is registered in the IFS database. The procedure is shown in COMPLY under Manage Supply Chain and is described in work instruction 5630-SC-WI-0006 Sourcing – Prepare Purchase Part Data.(Apply)

However, the in the Purchase parts database the PO line items do not contain any coding as per NORSOK Z-014/ISO 19008:2016.

In the procedures there is no instruction of data collection for estimation purpose. If historical data is wanted, the search must be done manually with search in the description field.

Except for the instruction in the process for "Close Project" of preparing a project close-out report and generate productivity and estimate experience data, there is no clear strategy of which project data should be collected. There is no database other than the internal MON database for weight reports, and the external database FERM (that is used for the Equinor contracts only) that us used to show the productivity.

5.9 Estimation basis

The basis for estimation is defined in the set of rates, norm and MUR.

Apply have a Rate-Norm-MUR distribution agreed with Apply's vendors fabrication of piping and structures or modules of when pricing a tender. The risk and need for adjustments will then be evaluated from tender to tender to avoid cost escalation due to uncertainties in the estimate.

5.9.1 Rates

Calculations and setting of manhours rates to be used for studies or tenders for are obtained from the Apply Finance controller and the Resource & Technical department for each study or tender. So is also the data for currency exchange rates, inflation rates and other cost data. The rates include payroll, payroll burdens, engineering support. They do not include office space/computing/etc., travel or any other project cost categories, any contingency or any margins. The base salary used for calculation the rates is provided from HR department. Rates are updated in conjunction with each salary adjustment, when contract formats at the time being changes or for other reasons deemed necessary for an update. The split between staff and agency personnel is to be obtained from the Resource & Technical department, which could be based on market quotations, experience numbers from projects or future prognosis.

5.9.2 Norms

In Apply there is different norm sets used for calculation the engineering man-hours and for calculation of all the direct work hours that can be identified from the given scope of work

Weight based Man-hour Norms (man-hour/ton) shall by multiplication with the weight and relevant discipline factors be used for calculation of all the direct work hours, including prefabrication, installation/mounting, removal, testing and mechanical completion of work executed onshore or offshore. Once a contract has been signed, the Norms and manhour rates is valid. Norms given in man-hours /tons is based on a historical norm set but is also adjusted to fit the contract end client requirement before contract signing

The Man-hour Norms/discipline factors shall include the following: (Equinor GL0329)

- *"The **Execution of work described in the estimating manual F-WI-019** in an offshore/onshore environment. Cautious work conditions caused by operative systems and platform/plant operation, hot work etc. are elements of an offshore/onshore environment.*

- ***Work preparation, dependencies** concerning fabrication sequence, other trades, other priorities and safety which is under control by the contractor.*

- ***Loss of productivity caused by Operator** that will emerge on daily basis given the nature of the work, the close conditions of work with Operator and dependency on Operator, location of the platform/plant or the platforms/plants operative condition."*

The Engineering Labour Norms is the Man-hours per document/ tag (man-hour/unit) and is used for estimation of the CTR activities in the execution phase for the engineering disciplines using the number of documents given in Master Document list (MDL) and the number of Tag's from the Master Equipment List and MTO.

Estimation in Apply

The norms man-hour/ton for prefabrication and construction used in Apply are benchmarked against the FERM database.

5.10 WBS and CTR structure

The Work Brake-down Structure (**WBS)** consists of Work Elements and Work Functions.

Work Elements are the tangible (or intangible) "packages" into which the work is to be divided and are unique to each project.

Work Functions are the "things that are done" to work elements, and are common to almost every project, such that by "summing" across work elements, all projects can be compared at the cumulative work function level.

Principles for building the WBS into an estimate:

- An appropriately structured WBS will make compilation or collection of costs quick and easy.

- The WBS structure is often provided by the client as a basis for the client reporting.

- The names chosen for the elements and functions should be restricted to eight characters. The Work Function names are generic and recognise the functional "split" used by the majority of the Industry.

An Apply standard WBS structure is stored in the planning system Safran Project. See also procedure *F-PR-017*.

Figure 5-47 Example of WBS structure

In the Apply processes and procedures for estimation the COR codes for phase and personal resources are used as basis for the CTR (Cost, Time and Resource) numbering. This is described in the procedure F-PR-017 (Apply 2015). This procedure is based on the NORSOK Z-014 that is superseded by ISO 19008:2018 Standard cost coding system for oil and gas production and processing facilities (ISO 2018) . The CTR number comprises of 10 characters, see figure below:(Apply 2015)
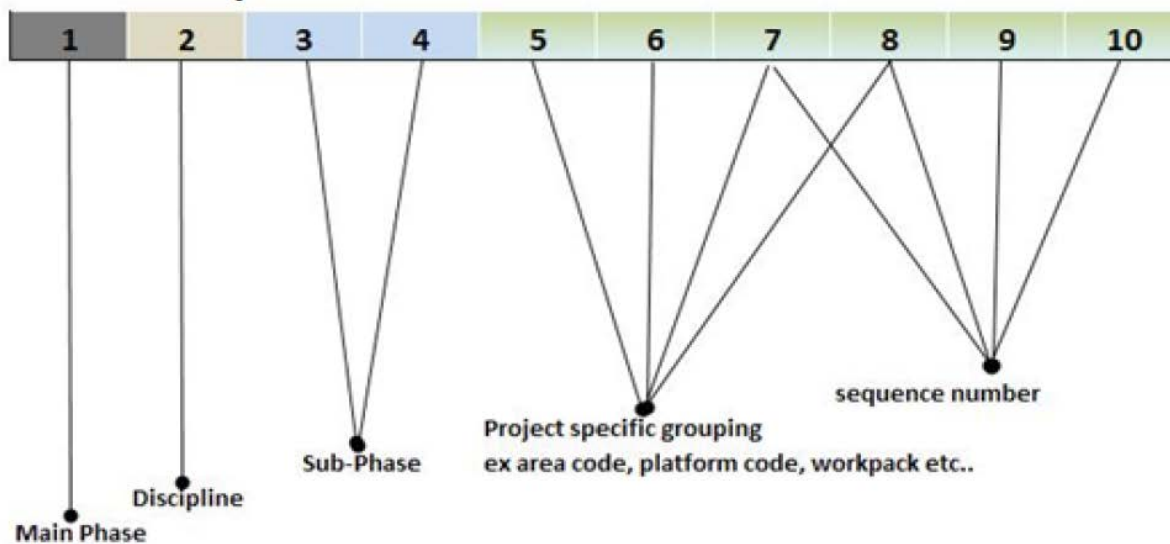
Figure 5-48 Apply CTR coding structure outlined (ref. Fig 01 in F-PR-017 page 3)

Main Phase: Organization Breakdown Structure (**OBS**) as required by NORSOK Z-014 is outlining the main stages and areas of responsibility of a Project, i.e. K for Engineering, C for Construction etc.

Discipline coding singular letter is as referred to as COR in NORSOK Z-014, i.e L for Piping discipline.

Sub Phase is a simplified version of NORSOK Z-14 (**SAB**) – standard activity breakdown. The sub-phase code is adjusted to incorporate Apply's own specific requirements. The code explains the type of work being executed and is a sub-category of the main phase code. For example, the Main Phase (OBS) K-Engineering can be split into several sub phases for Pre-Engineering, Studies, Detailed Engineering etc. Likewise, C construction can be split to show difference between regular offshore installation, or offshore installation work being executed during a shutdown.

The remainder of the CTR code is **Project specific** Grouping and describes for example: Platform code - Module – System - Part system - Installation pack -Building Block Etc.

Sequence Number: This number serves as the unique identifier for the CTR and is maintained in the IFS at Apply.

The complete list of CTR codes is listed in section 5 of the F-PR-017.(Apply 2015)

CTR codes

Organization Phases (OBS)

Code	Description
A	Contract Milestones
B	Project Milestones
C	Mobilisation
H	Management& Administration
I	Expenses
J	Procurement Milestones
K	Engineering
L	Fabrication
M	Transport & Marine
N	Onshore Construction
O	At shore Construction
P	Inshore Construction
Q	Offshore Construction
R	Commissioning
S	Subsidiary-internal cost
X	General

Discipline (COR) — Applies to all Phases

Code	Description
A	Management & Admin
B	Procurement
C	Architectural & Civil
D	Drilling
E	Electrical
F	Automation
G	Geoscience
H	HVAC
J	Instrument
K	Surface Treatment
L	Piping
M	Material Technology
N	Structural
O	Operation and maintenance
P	Process
Q	MC/Commissioning
R	Mechanical
S	Health, safety and environment (HSE)
T	Telecommunication
U	Subsea
V	Vendors , ATS and 3.de parties
W	Weight
X	Insulation
Y	Pipelines
Z	Multidiscipline
	Deviation to NORSOK Z-014

Sub Phase (SAB)

Applies only to Phase H

Code	Description
00	Milestone
01	Project Manager
02	Project Control
03	Engineering Manager
04	Procurement
05	Construction Manager
06	Commissioning Manager
07	Document Control
08	Economy / Accounting
09	Planning
10	Cost Control
11	HES project safety
12	IT/IM services
13	Change Control
14	Work Preparation / Method
15	External Services
16	HSEQ
17	Secretary
18	Quality Control Work
19	Quality Assurance Manager

Applies only to phase K

Code	Description
20	Study
21	Pre Engineering
22	Detailed Engineering
23	Fabrication Engineering
24	Job card Preparation
25	Follow on Engineering
26	As-built
27	Indirect Engineering
28	IM Application Administration

Applies only to phase J

Code	Description
30	Company Provided Equipment
31	Contractor Provided Equipment
32	Surplus Equipment
33	Company Provided Bulks
34	Contractor Provided Bulks
35	Surplus Bulks
36	Spares
37	Consumables
38	Services
39	Hired Equipment

Code	Description	
41	Mobilization	Phase L thru X
42	Civil Works	Phase L thru X
43	Prefabrication	Phase L
44	Assembly	Phase L
45	Stripping / Dismantling	Phase M thru X
46	Construction	Phase M thru X
47	Installation	Phase M thru X
47a	Pre Shut-down Installation	Phase M thru X
48	Modifications	Phase M thru X
49	Shutdown	Phase M thru X
50	Mechanical Completion	Phase M thru X
51	Commissioning	Phase M thru X
52	Assistance to Client	Phase M thru X
53	Vendor Assistance	Phase M thru X
54	Demobilization	Phase M thru X
55	Testing of pipelines	Phase L thru X
56	Testing of Cables	Phase L thru X
57	Nitrogen-Helium leak testing	Phase L thru X
58	Loop testing	Phase L thru X
61	Preservation	Phase L thru X
62	Third Party	Phase L thru X
MA	Offshore Supervision	Phase M thru X
MB	Quality Control	Phase L thru X
MC	Scaffolding	Phase M thru X
MD	Cleaning	Phase M thru X
ME	Transport	Phase L thru X
MF	Rigging	Phase M thru X
MG	Material Control	Phase L thru X
MH	Fire Guards	Phase L thru X
MK	Safety	Phase L thru X
ML	Dimensional Control	Phase L thru X
MM	Weight Control	Phase L thru X
MN	Temporary Construction Services	Phase M thru X
MP	Storage	Phase M thru X
MZ	Other Indirect	Phase M thru X
NA	Non-Working Hours (Lunch)	Phase M thru X
NB	Non-Working Hours (Safety Drills)	Phase M thru X
NC	Non-Working Hours (Standby)	Phase M thru X
ND	Non-Working Hours (Waiting on Client)	Phase M thru X
NE	Non-Working Hours (Waiting on Others)	Phase M thru X
NF	Non-Working Hours (Waiting on Weather)	Phase M thru X

Applies only to Phase I

Code	Description
80	Travel Expenses reimbursable
81	Travel Expenses non reimbursable
82	IT Support Expenses (non-hours)
83	Miscellaneous cost reimbursable
84	Miscellaneous cost non-reimbursable
85	Misc other cost reimb. to JV
86	Social and welfare cost
87	Courses - reimbursable
88	Courses - non-reimbursable
89	Accruals
90	Overhead miscellaneous procurement
91	Overhead cost reimb.

Figure 5-49 CTR cosdes in Apply. Note: the green COR codes deviated from NORSOK Z-014

5.11 Benchmarking

In Apply the data collection has mainly been driven by the client's requirements. For the Apply's Equinor V&M contract and earlier for the COPSAS V&M contract, weight and manhours is reported into the FERM database.

The FERM database collects experience data from execution of modification projects form oil and gas projects for the Oil and Gas Companies to form basis for benchmarking.
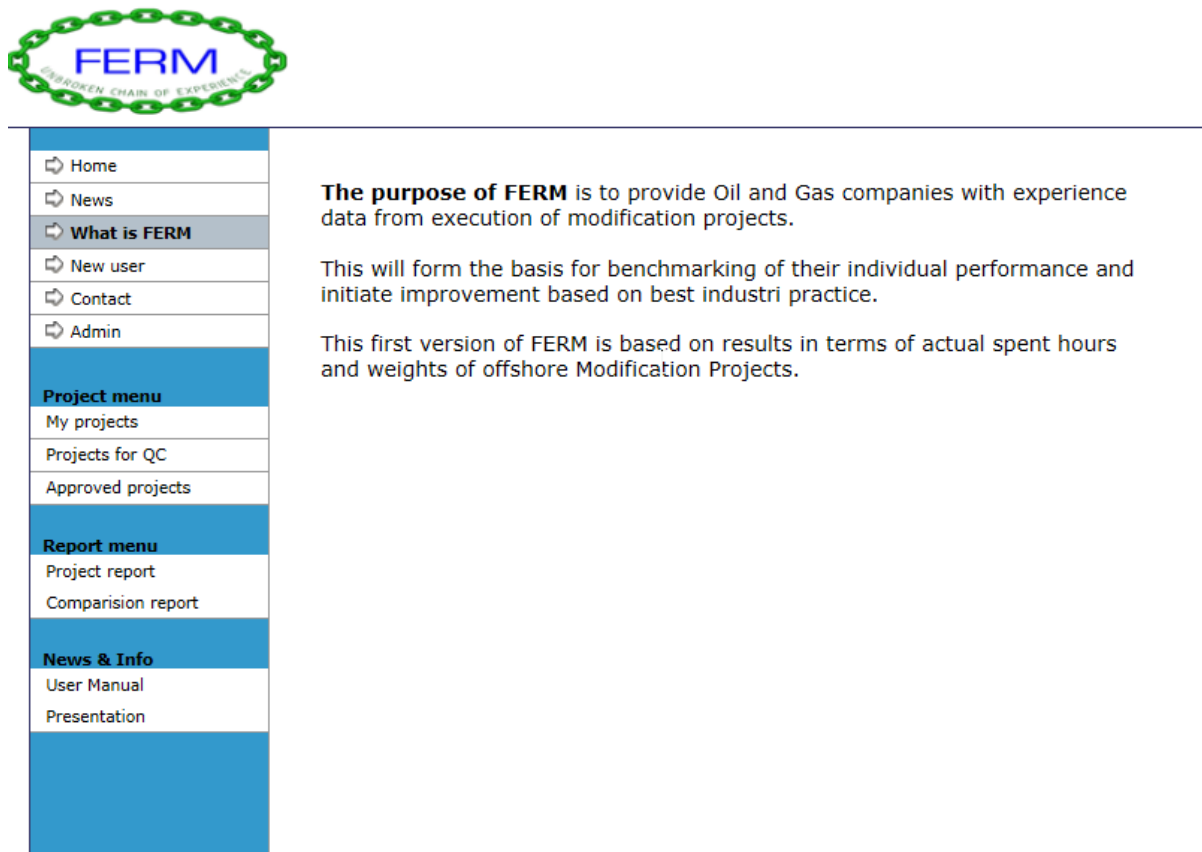

Figure 5-50 FERM database

In the process for Close Project, the activity "Generate productivity and estimate experience data it is described how this experience data shall be handled. (Apply 2019)

The input to the database is based upon as-built weight reports and economical close-out reports. Experience data is measured (weight, lengths) and reported in own and customers (if applicable) systems;

•   Productivity (hours/tonne, hours/norms). Measures total hours spent on all handled weight/weightless (if applicable) work based upon contractual norms. To be reported and used in internal experience database (MON/IFS) and clients experience databases (i.e. FERM).

•   Estimation accuracy on estimated weights and cost compared to actual weight/cost. Reported in internal project close-out report (OES-TPL-006).

•   Experienced material/supplier cost for reference data to be used in future estimates.

Estimation in Apply

The input is categorized within project type and area. The similar projects can be compared in a comparison report.

Figure 5-51 Project Comparison Report

The report shows actual man hours used in total and per activity level and discipline.

Apply's CTR structure should match to the NORSOK Z-014 (NORSOK 2012) in order to report correctly. Presently this is not the case and the input data to the FERM database need to be manually adjusted to fit into the FERM database.
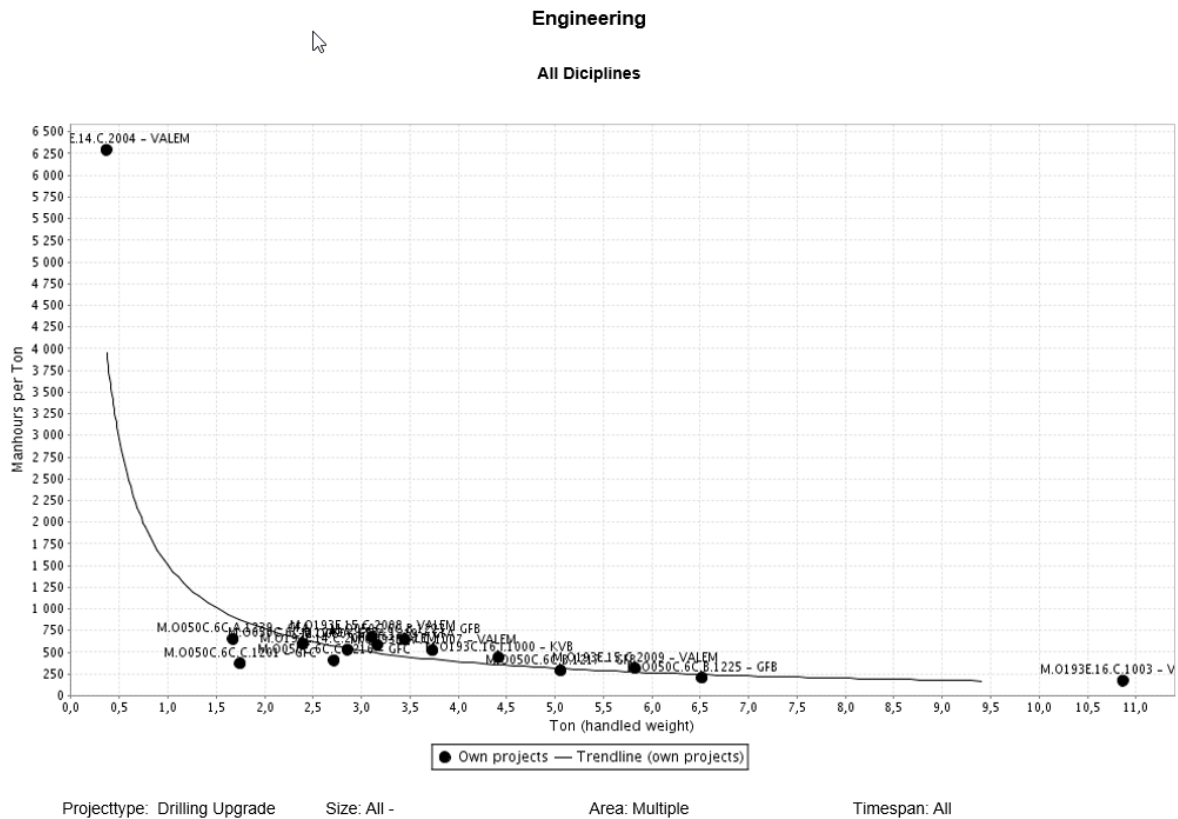
Trend curves can then be plotted:

Figure 5-52 Example of manhour/weight curves from FERM

The FERM database shows us only the V&M historical data and should be carefully evaluated when used for other type of projects like EPCI projects. For benchmarking purposes there should be an evaluation of different project characteristics and an evaluation of the standard deviation.

Sandberg (Sandberg 2019) shows how the no of criteria can affect the estimation result and the deviation for a field development project. Other comparing criteria should be evaluated for modification and for type of projects.

The criteria for comparing modification projects could be:

Characteristic	Total handled weight tons	Investment (average) mill NOK	Standard Deviation mill NOK
Project type			
System			
Equipment type			
Capacity			
Material			
Complexity			

The collection of historical data can then be used to derive Apply's own scaling factors for top down estimation.

Estimation in Apply

5.11.1 How can the historical data be used in Apply's estimation?

Historical data is used to benchmark the norms and rates. It should also be used for deriving Apply's own factors to enable top down estimation. Below is example of factors for top down estimation that should be derived in Apply. Without historical data a set of Apply factors cannot be derived, and the company will depend on factors derived from other sources.

Factors to convert delivered equipment into Fixed - Capital Investment Cost

Details	Lang factor (Bauman) ref Perry table 9- Fluid processing	Comments	Apply factor assumed	(NOK) Cost	(NOK/hr) Norm	(%) Persentage of total	(kg/hr) Norm	(kg) Weight
Equipment delivered	1		1	100		24.3		100
Installed	0.27-0.47		0.47	47		11.4		47
Piping	0.66-1.2		0.66	66		16.1		66
Structural steel fondations	0-0.13		0.13	13		3.2		13
Electrical	0.09-0.11		0.11	11		2.7		11
Instruments						0.0		
Batterylimits building and services	0.18-0.34	NA	0			0.0		
Excavation and site prep	0.1	Structural site prep	0.1	10		2.4		10
Auxiliaries	0.7	Safety equipment etc	0.7	7		1.7		7
Total physical plant	3.5		3.17	317		77.1		317
Field expence	0.41		0			0.0		
Engineering	0.33		0.33	33		8.0		33
Direct plant costs	4.24		3.5	350		85.2		350
Overhead	0.21		0.21	21		5.1		21
Contingency	0.42		0.4	40		9.7		40
Cfc Total fixed capital investment Lang factor	4.87		4.11	411		100.0		411

Guthrie Factors for individual items

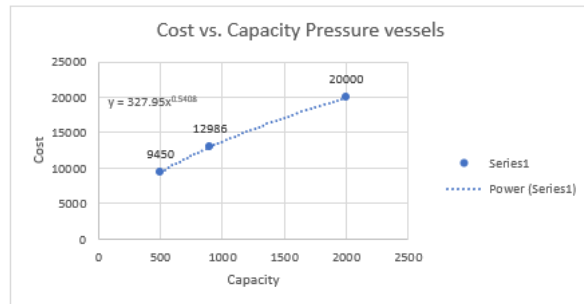|	Exhangers		Vessels							Apply		
Details	Shell and tube	Apply	Vertical	Appy vertical	Horisontal	Apply Horizonta	Pump and driver	Apply Pump and driver	Comressor and driver	Apply Compressor & driver	Tanks	Apply Tamks
FOB Equipment	1.00	1.00	1.00	1.00	1.00	1.00	1.00		1.00		1.00	
Piping	0.46		0.61		0.42		0.30		0.21			
Concrete	0.05	0.00	0.10	0.00	0.06	0.00	0.04		0.12		0.00	
Steel	0.03		0.08		0.00							
Instruments	0.10		0.12		0.06		0.03		0.08			
Electrical	0.02		0.05		0.05		0.31		0.16			
Insulation	0.05		0.08		0.05		0.01		0.03			
Paint			0.01		0.01		0.01		0.01			
Total Materials = M	1.71	1.00	2.05	1.00	1.65	1.00	1.70		1.61		1.20	
Erection and setting L	0.63		0.95		0.59		0.70		0.58		0.13	
X, excluding site prep and auxilia	2.34	1.00	3.00	1.00	2.24	1.00	2.40		2.19		1.33	
Freight and insurance,taxes home office, construction	0.05		0.08		0.08		0.08		0.08		0.08	
Overhead or field expence	0.95		1.12		0.92		0.97		0.97			
Total module factor	3.34	1.00	4.20	1.00	3.24	1.00	3.45		3.24		1.41	

From Guthrie chem eng 76, 114-124 (march 24, 1969) Based on FOB equipment cost = 100 (CS)

Figure 5-53 Apply's Lang factors and Guthrie factors to be derived from historical data, ref. model OOM(Egeland 2019)

CAPACITY SCALING -Size n method

PROJECT	AAA
OPTION	A
Estimation date	dd.mmm.yyyy

Element	PRESSURE VESSELS/TANKS	
INPUT		
	Capacity	Cost
2	2000	20000
1	500	9450
Required capacity	900	
Data source/date		
OUTPUT		
Exponent n	0.54	
Cost at required capacity	12986	

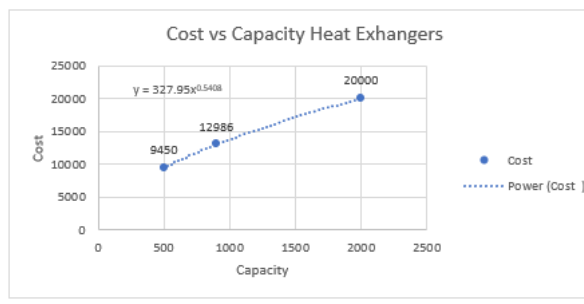| Element	HEAT EXCHANGERS	
INPUT		
	Capacity	Cost
2	2000	20000
1	500	9450
Required capacity	900	
Data source/date		
OUTPUT		
Exponent n	0.54	
Cost at required capacity	12986	

Figure 5-54 Apply's n factor for capacity and cost scaling ref. model OOM (Egeland 2019)

6   Findings and Recommendations

Element	Findings	Recommendations
Estimation Method	• Missing Overall guideline for cost estimation • CTR structure does not comply with NORSOK Z-014	• Make Overall guideline for cost estimation • Evaluate change of CTR Structure or better compliance with the defined CTR structure
Processes	• The process for manage Estimation to reflect the 3 applications: Tender, Studies and Execution • The processes is missing some with correct information, links and related documents	• Update the processes
Documents	• Missing documents – see document list	• Create the missing documents
Factors	• Tools or Complexity mapping and implementation is missing • Missing process and tools for CRA • Benchmarking should be improved by developing a inhouse model and collecting historical data (Lessons learned)	• Develop tool for Complexity mapping • Collecting / washing historical data • Develop tool and process for CRA
Tools	• Estimation is done in excel sheets – should be in a database • Inhouse estimation tools for study phases should be further developed • Buy Questor and @Risk	• Evaluate a database for estimation • Evaluate to Buy Questor • Evaluate to Buy @Risk • Further develop inhouse estimation tools for early phase projects

For process updates:

The process for Manage Estimates is proposed to be updated to reflect the 3 applications and the process for Prepare Estimate should be updated as shown below:
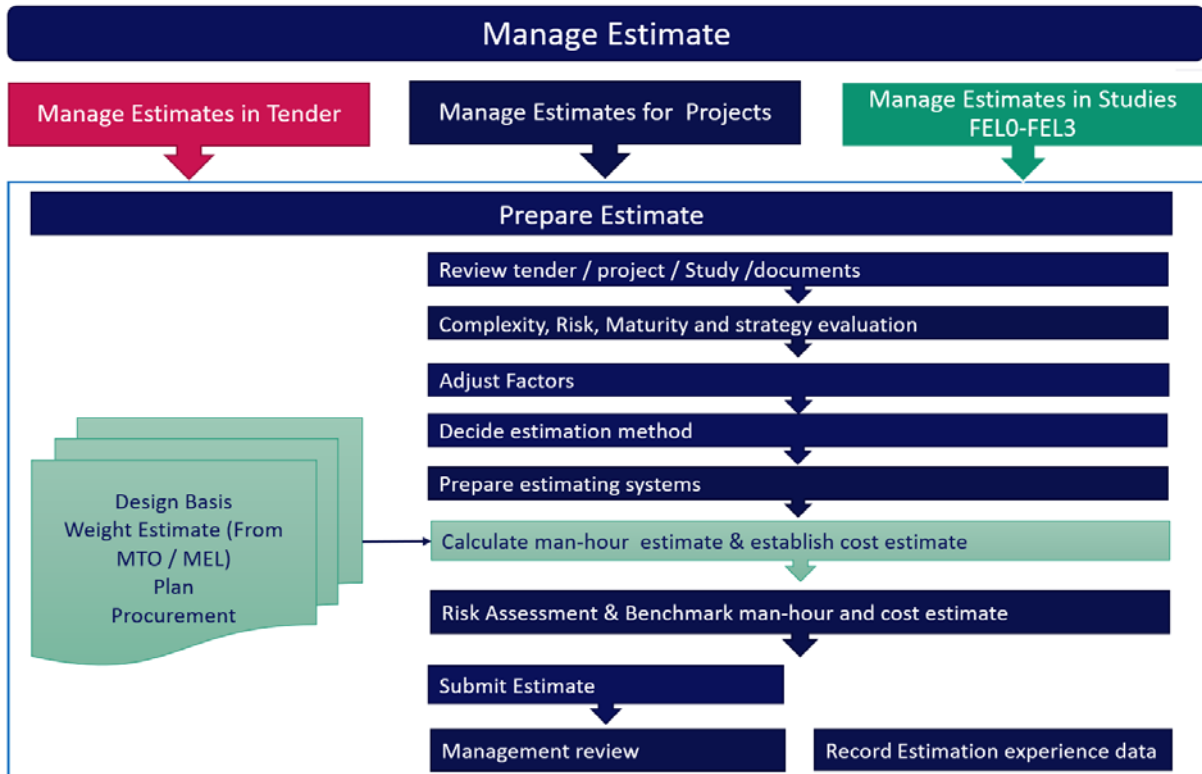
7   Conclusions

As Apply does not have a clear strategy for handling of experience data, it can be concluded that Apply's current data capabilities do not leverage the potential of transferring, exchanging, and storing the project data using digital technologies.

As recommended by Ray (Greg Ray 2019):

Apply should prepare a strategy for handling value-added data, analysing Apply's requirement for capturing information on projects, determine what data are important and how to organize it standardized way in a and store it and how to extract insights from it. This information will provide insights to improve the estimation and the project outcomes as it will maximize the value of its data.

The processes and supporting documents have an improvement potential and is now under revision.

The Complexity mapping

To fulfil the requirements for quantitative risk assessment CRA for class C and D estimates there is a need for a procedure and tools to run Monte Carlo Simulations.

And, in order to increase the competitiveness, the estimation tools required for early phase studies should be bought and further develop the inhouse- tools.

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9   Attachments

File	Description	Comments
Master presentation 28juni	Management presentation of the master thesis	
	OOM Scaling model	Can be provided upon request
	CRA model using @Risk	Can be provided upon request
	Apply internal documents	Can be provided upon request
	Equinor internal documents	Can be provided upon request