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Preface and Acknowledgement

This thesis has been performed in house Statoil for the Time and Cost Estimation group TCE. The thesis is a part of an overall initiative within time and cost estimation looking into learning curves in drilling and well operations mainly in Norway and on the Norwegian Continental Shelf (NCS). Statoil is the largest operator in this area, and this type of study has not been performed before.

The thesis is prepared for and advised from the University of Stavanger, Department for Industrial Asset Management, represented by Professor Jayantha Prasanna Liyanage Performance Measurement and Management; and the Department of Petroleum Technology, represented by Professor Bernt Sigve Aadnøy.
Thank you all for excellent advice & comments.

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My wife Tordis and our two girls

Anders H.K. Hellström
Stavanger, June 2010

Abstract and Management Summary

This thesis is performed for Statoil in Statoil premises in Stavanger. Statoil is a large offshore and subsea oil and gas operator in Norway, with increasing activity internationally, both offshore as well as on land. The thesis will look at Statoil's experience data, mainly in Norway, and compare these with established learning curve theory in the drilling and well business, in order to develop an updated method for learning curves in the time estimation process in the company. Time and cost estimation is tightly linked and this thesis' main contribution will be to the time aspect. The time and cost aspects of drilling and well operations have gained increased attention during recent years, with strongly escalating cost, and the thesis is a part of the initiative to improve the estimation process.

There is in the order of 100 wells drilled and completed each year in Norway, 70% of these by Statoil. Statoil is also involved in operations internationally, in example South America, Iraq, West Africa, Gulf of Mexico and Shale Gas in USA. The cost of these activities is considerable, hence the importance to maintain effectiveness, and even better; "to improve performance both short term and over time".

This report is based on data acquired from 97 drilling facilities and 3267 wells. Ideally the first wells should have a steep learning curve, towards the technical limit, where the minimum time usage is reached for the lifetime of the investment.

Earlier findings indicate that there are different opinions and understandings within Statoil of what learning curves are, as well as what they should be used for. The main application of learning curves is time estimation. To verify or improve the current learning curve used in drilling, Completion and Well Operations today, DBR data have been used for learning curve analysis. The analysis has been split into different rig types. A Learning Curve Analysis tool has been developed in Excel, where DBR data is imported and analyzed for the proposed new learning curve parameters and estimation process. The new learning curve parameters also include a delay parameter in addition to the standard Brett Millheim parameters.

Results indicate a poor level of learning measured by the Brett Millheim C_2 learning coefficient and alfa value. The alfa value tells how much additional time is added to the technical limit, in relative terms. There is also higher spread in the semi submersible results compared to the others rig types. The larger spread gives very high max values for the lowest efficiency wells. This is suggested to be an area of increased focus, both because of the performance numbers, but also because a very large portion of Statoil's wells are drilled with semi submersible's, and last because the rig rates usually are the highest for these rigs. And hence even small improvements can give large improvements.

Based on the results from the analysis and specific findings, some rigs were selected for a more in-depth analysis. Good examples with good field related learning have been found when using an old semi-submersible drilling rig for a series of comparable wells. A brand new rig drilling with its first wells is also presented.

Another question is also how improved and faster learning can add the most value to the company? This is a question with many different opinions, however high involvement, in Statoil today. This thesis would like to promote the "knowledge and value approach", meaning that increased understanding of time usage and learning processes can become a useful (and powerful) tool to visualize where on the learning curve a specific well are located, in order to be able and select reference wells more knowledgeable. And in operation, help to see in what direction the efficiency are going. It is suggested that the personnel

influencing the “underlying large cost drivers” such as method selection, procedures, etc. should have easy access to learning curve competency and information.

The potential upside from an increased focus on learning curves as a management and operation tool is considerable. The economical significance is in the in the order of being able to justify projects or not. Numbers like 25, 35 and even 50% and higher reduction in time usage is mentioned in literature, if you manage to raise the learning level towards a normal and excellent level.

It is suggested to:

- Improve the data quality in DBR for key parameters used in LCA analysis
- Include Learning curve analysis in the Drilling and Well Estimator (DWE)
- Perform Learning Curve Analysis (LCA) follow-up on completion and Well operations
- Continue and expand relationship with University of Stavanger (UiS) and Petroleum and Asset Management departments (Aadnøy and Liyanage)

Platforms where the drilling facilities have been upgraded to meet new HSE standards, etc. have been looked upon in order to see if possible to measure performance before and after with respect to learning. These upgrades usually takes place late in the field life, and the drilling targets before and after upgrade are very scattered as well as very few completely new wells drilled (one of the analysis criteria). Instead one finds a lot of different types of sidetrack’s and some extended reach wells making it difficult to compare directly before and after upgrade. It is suggested to go one step more into detail in the dataset in order to compare time for parts of the drilling process, similar to what has been done in the pilot study of this thesis.

It is also suggested to include the LCA analysis tool into the next version of the DWE estimator, where a natural framework is already built-in. An LCA analysis ability applied here will improve the understanding for what learning curves represent in practice, and what factors have an influence.

In the data made available there has been found for the existence of a “forgetting factor”. This is further described in this report. There has, also, been found support in the data to claim “learning delay” in some types of operations. The thesis work has included the following sub-processes:

- Literature study, to find out about and verify the industry standards.
- Set-up measurement parameters.
- Develop tools and procedures for data extraction from the drilling reporting database (DBR) and Learning Curve Analysis (LCA).
- Perform in depth analysis of 97 drilling facilities and 3267 (qualified) wells from the DBR data base system. A total of 5-10 000manual data steps have been performed
- Establish guidelines for dealing with uncertainties and finding the limitations in the dataset.
- Main focus has been startup of drilling facilities on fixed platforms, and the first (5) wells.
- Assessment of whether the current Statoil time estimation learning curve application model is OK, or if (the) industry standard give a better description
- Analysis of whether we see a learning curve at all. Can we better predict where and when we will see, and where we will not see a learning curve?
- Can project learning curves be estimated in advance?
- How we can improve learning speed has also developed as the work progressed, and maybe a separate thesis is needed to properly answer such challenges.

Conclude with several specific focus areas for future work, both internally, and together with an academically institution. As well as some findings, and indications that can be useful in the ongoing work within performance measurement and management towards an even more competitive Statoil in the future.

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1 Introduction

Estimation of time in drilling, completion and well operation is important as the basis for the budget process, as well as the evaluation of performance. Most of the cost involved in constructing a well is time dependant, i.e. rig rates, personnel rates, and equipment rental rates, are usually based upon day rates. Hence understanding the drivers for time usage is valuable information.

Drilling the first well with a new rig usually takes longer time, than making the same well with a rig that has been in operation for a period of time. When starting up new equipment and/or new organization, both in planning, as well as in practice on the rig. The same arguments are involved starting drilling on a new field with an old rig, however here the underlying drivers are more of geological character, and other area and field specific parameters.

The efficiency in making the second and third well should in theory be higher. Measured in time the time should be reduced.

The well construction time usage in Statoil is estimated using the Drilling and Well Estimator (DWE/BoreRisk). DWE is a probabilistic model using input reference well data, picked by the person running the estimation. Either from the Daglig Bore Rapport (DBR) database, or by input from other sources such as Rushmore reviews, manual input or other. DWE and the methodology around it have been proven to be able to produce predictable and reliable results in statistical terms. I.e. in 2009 it was predicted 99 wells, and resulted in 98 delivered wells, and in 2008 it was predicted 118 wells and resulted in 116 delivered wells.

However DWE is only made for estimation of one single well at a time, if you are going to estimate more then 1 well, you will need to do this partly by other means (as of now). Learning curves is not included as an automatic part of DWE today, but have to be handled separately as Project Specific Risk add-ons. As of now one cannot see where on the learning curve the selected reference wells are positioned in the sequence, nor can you model learning curves in you estimation process for multiple wells. But these options will be available soon, the rumors say ☺.

1.1 The history of Learning Curves

Below is a selection of the highlights from the history of learning curves, as found in the literature study performed.

1885 First Description of a Learning Curve made by the German Hermann Ebbinghaus, published in his book with original title “Uber das Gedächtnis Untersuchungen zur experimentellen Psychologie” published in 1885. Ebbinghaus did experiments on himself, memorizing different types of words, some without meaning, only letters in combination. Then memorizing these, and counting how much he did manage to remember correctly. His results showed that for each time he memorized a series of non-meaningful constructed “words” he was able to remember more and more correctly. This is the first time the term learning curve is used. Ebbinghaus (1964, pp.8-9) Here is an example of the results taken from the English version “Memory” that was published 1964.

“A poem is learned by heart and then not again repeated. We will suppose that after a half year it has been forgotten: no effort of recollection is able to call it back again into consciousness. At best only isolated fragments return. Suppose that the poem is again learned by heart. It then becomes evident that, although

to all appearances totally forgotten, it still in a certain sense exists and in a way to be effective. The second learning requires noticeably less time or a noticeably smaller number of repetitions than the first. It also requires less time or repetitions than would now be necessary to learn a similar poem of the same length."

…

"In the first place, it must be possible to define with some certainty the moment when the goal is reached – i.e., when the process of heart is completed. For if the process of learning by heart is sometimes carried past that moment and sometimes broken off before it, then part of the differences found under the varying circumstances would be incorrect to attribute it solely to inner differences in the series of ideas."

Ebbinghaus (1964, pp.8) says about forgetting:
"it is evident on the first glance and without further comparison that a strong displacement of the differences to the negative side has taken place. This fact is also expressed by the averages."

1934 More details are added to the description of the Learning Curve when
Arthur Bills (1934,pp.197)published his "General experimental psychology" about how to draw the learning curve from memory results data:

"Every individual curve is accurately drawn on cross section paper. The abscissa is then divided into the required number of equal parts and perpendiculars are erected at these points. The points on the curve where these perpendiculars intersect give the values which averaged with those of the other subjects to form the combined group curve."

Bills (1934,pp235) An example related to the role of order of appearance:

"Freedom from proactive interference favors the first item, and the last item is probably less subject to retroactive interference. It is also pointed out that the learner has longer to rehearse the first item before it reappears, but this could not explain the advantage of finality, nor the fact that the middle is the worst position. It is also probable that the advantage of association by place favors the first and last items, because of the prominence of their position."

1936 A mathematical Model is proposed to describe the Learning Curve.
Theodore Paul Wright proposed a mathematical model published in "Journal of Aeronautical Sciences" "Factors Affecting the Cost of Airplanes" Journal of the Aeronautical sciences 122-128 feb-1936
Suggest the learning curve to be,

$$Y_x = aX^{-b} \qquad (1.1)$$

where Y_x is the cumulative average direct labor, a the direct labor hours for the first unit produced, X the cumulative units produced and ^{b} the slope of the progress curve relationship plotted on log-log paper.

"In using the curve developed in this paper, it should be recognized that the factors derived are based on the assumption that no major changes will be introduced during construction."

Wright (1936,pp.124) states
"The improvement in proficiency of a workman with practice and particularly if time studies for economy of motions are made, is well known. This applies particularly in assembly operations but also holds for other types of work."

…

"In developing the curve which shows variation of labor cost with production quantity, it became evident that its form was of the type depicted by the formula F = N^x. This resolves into an expression for X as follows:

X=Log F/Log N Where F=a factor of cost variation proportional to the quantity N. The reciprocal of F then represents a direct percent variation of cost vs. quantity.
A curve may be plotted which shows directly the relationship between the two variables and when plotted on log-log paper, it becomes a straight line. "

1978 First attempt to implement Learning Curves in Oil & Gas well drilling was done by Ikoku (1978,pp.1)
"In oil and gas well drilling, the first well drilled in a new field usually takes the most time."
…
"During subsequent years, definitive studies of aircraft assembly showed the following pattern: the fourth plane required only 80 percent as much direct labor as the second; the eight plane, only 80 percent as the fourth; the 200th, only 80 percent as much as the 50th; and so on. Thus, the rate of learning to assemble aircraft was concluded to be 80 percent between doubled quantities."

1986 Ford Brett and Keith Millheim set the Standard for the O & G Well drilling Learning Curve. Brett (1986,pp.)
"Additions and modifications to the form learning curve relationships have been made over the years. But, all proposed relationship posits a decline in the cost or time to produce a unit with increases in the number of units produced."

Brett & Millheim's work has been extensively (used and) referred to until recent years, and is still used as close to an industry standard. (Often applied).

Brett and Millheim suggest the learning curve to be described as follows:

$$y_n = C_3 + C_1 * e^{(1-n)C_2} \qquad (1.2)$$

where y_n = Time to drill well n, C_1 = Learning Add On, n = order of well in drilling sequence, C_2 = Learning Coefficient and C_3 = Technical limit

1996 Bernt Sigve Aadnøy Analyzed a Norwegian drilling from a field development using length-normalization and broke out times and lengths per section. Hence you can have an equal total time per well situation, whichever the length of the well, and if we have one good and one bad section you will mask a lot of the good learning information that can assist the learning process for the next coming well under planning.

Aadnøy (1996,pp.222) says about rig time,
"Studying statistics, one will find that 10-20% of the rig time is spent handling unforeseen problems. This statistics has not been improved significantly the last 10 years. We have of course made some progress, but the wells have to some extent changed character. During the last 10 years long reach and horizontal wells have evolved into lengths never achieved before.

The industry is continuously changing. Presently there are trends towards deeper sub-sea wells, and new technology like slim-hole drilling is under development. Therefore, even if we make progress in one area, we will still be faced with new challenges, because the limits are always extended. An important way to improve is to learn from failures, therefore experience transfer is important.

The aforementioned problems are frequently of borehole stability type. Casing landing problems, stuck pipe, hole cleaning problems and cementing problems are often a result of borehole stability problems. These are difficult to handle, and it is fair to say that we do not yet possess the full understanding. My approach is to try to analyze all problems and to evaluate each well design in light of these."

Other sources also indicates the same non-productive time percentage, over longer periods than 10 years, in fact the indication is a continuous 20 % downtime as an international average through decades.

Aadnøy (1996,pp.Appendix A) about Time Analysis of field data from a six wells pre drilling period drilled in the period 1990-1993:

"The casing strings of the six wells were set at approximately the same depths, but the borehole inclinations were quite different, with reservoir sections drilled from 20 to nearly 60 degrees inclination. Obviously, the lengths of each section were different because of this. To make the data comparable, we therefore length normalized all data. That is we divided each time element with the hole length it represented. In this way we obtained data that were representative for all inclinations."

Jablanowski (2009,pp.6) says about the Brett Millheim model
"Brett and Millheim Model. Brett and Millheim (1986) propose an alternative learning curve specification in their influential paper on the subject. Their model is attractive because of its simplicity, and for the intuitive interpretation of the parameters." … "This model has gained wide acceptance and has been used extensively in practice (for examples, see Noraeger et al. (1987) and Zoller. Graulier and Paterson (2003). It is conceivable that more complex models could be specified. The incremental benefit of doing so however, is probably small. The Brett and Millheim (1986) model appears to be adequate for drilling applications"

What is a good learning curve? What is a sharp learning curve? What is a bad learning curve?

Brett Millheim divides the Learning Coefficient values into three categories, where A is the best, B is average and C Slowest Learning as follows:

A $1.0 < C_2$
B $0.5 < C_2 < 1.0$
C $C_2 < 0.5$

And found after having analyzed 294wells drilled in 18 different areas:
C_2 average of 0.54 with a median of 0.42.
Alfa average of 2.14 and a median of 2.04.

1.2 Current Learning Curve Model

The current Statoil Drilling & Well learning curve used for time estimation when starting new drilling rigs, either with new equipment, or with heavy upgraded rig. You add on time to Average Performance Statistics. Learning curve effects should be assessed in all phases of estimation and should address the following:

- New rig or new drilling contractor (typically 30% on well #1, 20% for well #2, and 10% for well #3).
- Modified/upgraded/restart of drilling facilities
- New geological area or lack of experience with the geology/formations
- Implementation of new technology

These topics should be addressed as part of the risk management process. Additional time to reflect such learning effects should be applied for the first 3 wells and added to the relevant activities.

To the first well add 30% to the time estimate based upon experience data times from relevant reference activities. On the second well add 20% to the time estimate, and on the third well add 10% to the time estimate. After the first 3 wells, the main part has been learnt, and the remainder add on will be smaller scale long term learning effects, that requires performance improvement over time, and continuous improvement

Statoil Estimation Drilling New rig Learning Curve as defined in the Statoil governing system APOS (Arbeids Prosess Orientert Styring).

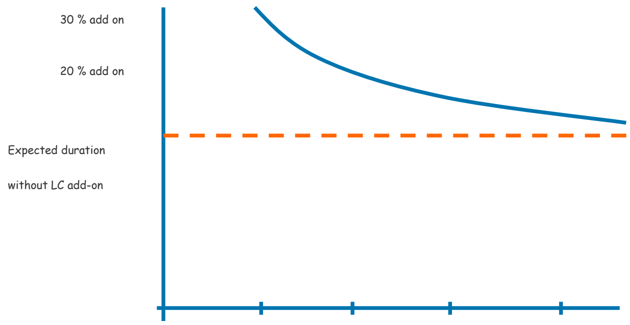

Figure 1-1 Current Learning Curve add-on as defined in APOS

The same model is used regardless the number of wells, and regardless on location, number of rigs etc.

1.3 Problem Description

According to the estimation process presently defined in APOS learning curves is handled as a manual add on of 30, 20 and 10 % on respectively the 1st, second an third well from a brand new platform drilling system or rig. This is where this thesis is focused. What is the actual experienced learning curve add-ons? Are there more precise experiences data that could assist in the estimation process? Could it be beneficial to look at different rig types separately? What are the hard facts from the experience data? In other words, “Is Statoil Drilling and Well a Learning organization?” and what can be done to become even more competitive?
Such basic research was not performed when the APOS process was defined, and therefore this thesis work has been initiated and performed in 2010.

1.4 Scope

The scope of the thesis is to find out what the Oil & Gas well drilling industry standard is, related to learning curves in time estimation. Then use this to build a model and analyze DBR based data to see if the current model is sufficiently precise for Statoil, both now and in the coming years. If it is possible to draw specific conclusions and recommendations for when to use learning curves this will be done, as well as how to use them in the estimation process. The input from this will be considered for use in updating the Statoil governing system (APOS). This will be described in bullet form below.

1) Find out what the industry Standard in Learning Curves is for Drilling and Well Learning curves.

2) Use this method and develop a spreadsheet package that makes it possible to analyze all DBR data for learning, and within the timeframe of this thesis.

3) Go through all data registered in DBR and analyze for learning from the startup of a new rig and onwards. Do this for all rig types and present the overall results, and comment on results. Try and conclude with whether Statoil is a fast learning organization, or at what level, based upon the results in this thesis.

4) Go in depth and try to find out if it is applicable with learning curves when using an old semisubmersible rig when drilling a new series of wells? Is there any data that would exemplify this in the DBR database?

5) Propose a new learning curve definition for APOS, type of learning curve, average parameter values, and a simple spreadsheet to assist in the estimation process for startup of a new rig.

2 Methodology

The work has been performed as a normal 8-16 hrs job for the main part of the thesis. A work plan and schedule was set up in the beginning with a total availability of 76 working days.
During the performance of the project weekly status meetings has been held. During the thesis work the development of Learning Curve Analysis (LCA) spreadsheet has been a large part of the work, as well as the summary of the LCA results, and presentation of those with histograms, overall comparison parameters etc. The main tools used and some developed are; Boxology (simplified flowchart of the thesis work scope), Action and decision log, LCA Spreadsheet and Procedure, Data extraction procedure from DBR, Filtration Procedure, Normalization format,

Work packages performed;

- Literature Study
- Pilot Project
- Perform Extraction of data from 97 rigs from DBR
- Perform sorting/data filtering/verification of 3267 wells
- Perform Analysis of 97 of rigs
- Gather / summarize LC Key Parameters
- Results presentation/look for common underlying aspects influencing LC parameters.
- Conclusions and recommendations for future action and implementation into APOS

Pilot studies have been performed to refine, test and verify working methods.

The choice of pilot project was based upon a request for a Learning Curve Analysis (LCA) on a 4 well drilling campaign made from an old Semi Submersible drilling rig. This LCA analysis became an excellent mind-breaker for starting to see the challenges related to comparing different wells. Into what detail level you should go, how to extract data, what data to use, starting the process of learning the difference between random effects, batch drilling, whole wells, sections and delay.

During the pilot project it was tested, in real life, how to, extract data from the DBR database, organizing the data in Excel for analyzes, manual visual LC interpretation in PowerPoint, and identification of how to proceed in order to be able to fulfill the full scope of this thesis.

The work involved several manual time-consuming steps which is OK for a one off thesis. However would be very time consuming and require a considerable amount of training, follow up, and still have results of various quality if done in a similar manner again. There are too many manual steps in order for a normal engineer to use in addition to the computerized routines. It is recommended later on in this thesis to build the learning curve aspects into the future DWE. That would remove a lot of the manual working steps, and it is believed to become a useful “Learning Curve Management Tool” in the estimation process. However, for this thesis the manual approach has been used.

Data have been extracted for all wells, registered in DBR for the particular rig, the LCA spreadsheet is built for the first 25 wells.

There has been set up a method for extracting data from DBR, How to QC these data, analyze and present results from this data.

A method was developed together with the DBR specialist for extraction of the data and organizing it more efficiently. As well as realizing that benchmarking data was more consistent and quality control for this purpose rather than other depths and times

During this work the time used and the progress of the actual work made us limit the scope from originally Drilling, Completion and Well Operations into only drilling operations with whole wells from start to finish This was chosen in order to achieve sufficient in-depth analysis of drilling data, and drilling was chosen since this is where the most reference data is available compared to the remainder two.

In order to gain oversight over the estimation process, and how learning curves are treated today the DWE course (Drilling and Well Estimator) was attended.

An EndNote course (proper referencing a thesis document) have also been attended, the database set up, which has been used for keeping track on references.

In the next section you will find a more elaborate description of three of the “project management tools” used in this thesis.

Boxology

To set the framework and the working process for the thesis a Boxology diagram have been developed. See Figure 2-1 below. The Boxology describes the main steps in the working process for the thesis, and gives a visual overall picture, what important steps that need to be taken, and what can be done as parallel activities. When having performed the content of all boxes, the thesis should be finished, and according to all stakeholders' expectations. The Boxology was initiated very early in the thesis, and adjusted and updated as the work has progressed. The intention is to describe the overall process, and how to solve the thesis challenge. The Boxology includes everything that needs separate actions, specific areas of competence, and specific activities (lines) in the Gant time planner.

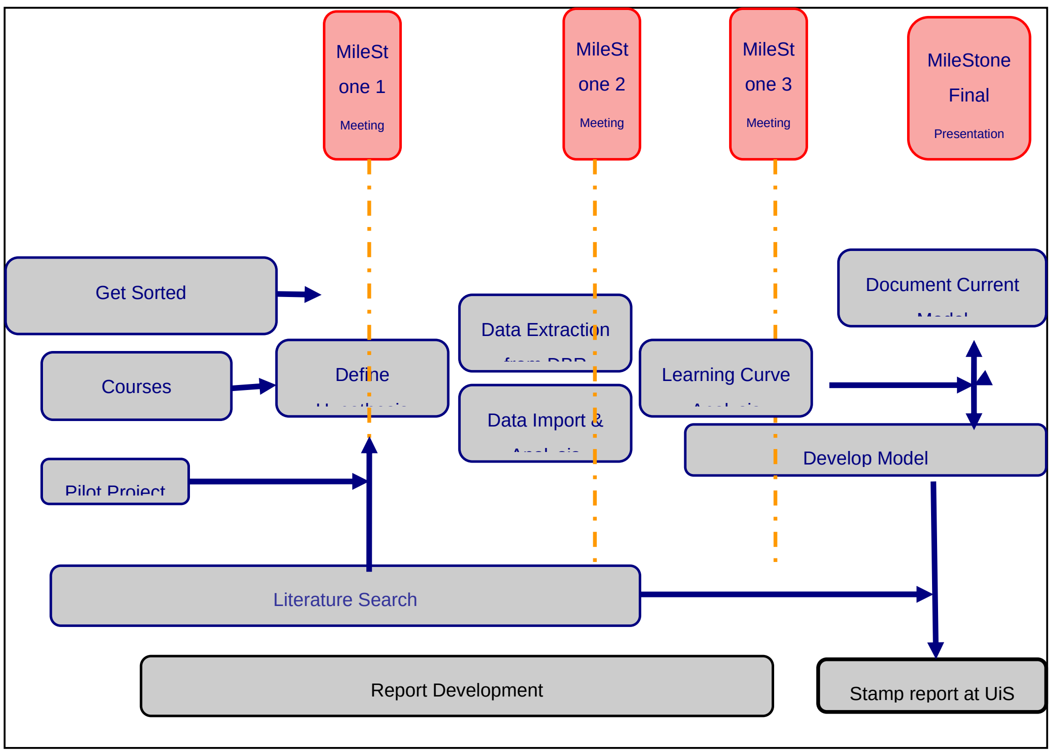

Figure 2-1 Boxology showing the overall thesis process from start, including milestones to delivery of report.

2.1 Time Planner to track progress

In order to track progress and follow up the performance as the project develops a Gant time planner was developed in the project management and scheduling software Safran Planner. See Figure 2-2. The plan is broken down based upon a Work Breakdown System (WBS), [reference: Boxology]. An overall example view is presented below. The time scale and which activities that relates to each other are depicted in this view. The schedule assists in overseeing the overall practical perspective, as well as keeping track of the weekly and monthly and overall progress, which was discussed at the weekly status meetings. The schedule was revised and updated with progress before each status meeting. All Boxology main items are included, broken down, in a more detailed Work Breakdown Structure (WBS).

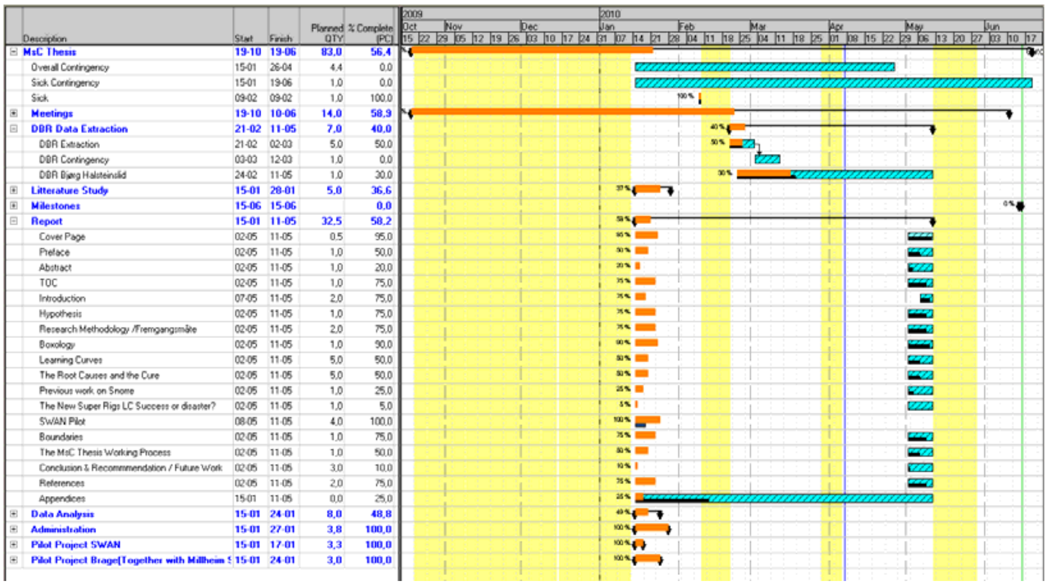

Figure 2-2, An example from the Gantt time planner that was used. Details showing Work Breakdown Structure and progress.

2.2 Action Log

In order to follow up all single practical large and small tasks that popped up along the road and ideas needed to set the Safran plan into practice; an action log was established. An example is presented in Figure 2-3. In the action log all working tasks are identified and logged as they appeared (meetings, mails, etc.), as well as who is responsible for taking action. The date of initiation was logged as well as date closed.

The log was filtered, such that it should be easy to see what action needs to be prioritized highest at any time. The initiation date is used in order to support the Safran time planner. The closure date helps to monitor the progress, when updating the progress in the Safran plan.

B	C	D	E	F	G
			Prio Høg	3	
	MsC Thesis Action Log Student Anders H.K. Hellström, Supervisor Hogne Kile, Advisor UiS Jayantha P. Liyanage		Prio Normal	2	
			Prio Lav	1	
N	Action to be taken	Responsible	Date Logged	Date Closed	Priori
92	Levere Draft Hardcopy av oppgaven til JP, målsetning om kommende fredag	Anders	09.apr.10		3
97	Legg inn Flyterigg navn manuellt for alle 52 flyteriggene.	Anders	13.apr.10		3
99	Kvalitetsikre at alle LCA arkene er sortert på start dato stigende!	Anders	13.apr.10		3
59	Send Mail te Helge Rosenlund, beskriv metode for uttrekk, og analyse, og kopier Knut. Denne gjør jeg ifm skifte fra Step I til II.	Anders	05.03.2010		2
13	Create Distribution List for Management Summary, Include Hanne Skaara Salvesen Will this on be restricted as well? How many years? Robert Zachary Evans	Anders	21.jan.10		2
17	Er lærekurver bedre behandlet i andre industrier/ Army? JP Liyanage?	JP	22.jan.10		2
20	Lage Kokebok for uttak av data fra DBR, samt Analyse av dataene etterpå. Torfinn Hellstrand, Bjørg Halsteinslid 99 24 21 67, Hvordan filtrere ut uvesentligheter? Enten Jostein eller andre hun har i bakhånd. Step I, Step II og Step III. Denne blir til under vegs som jeg finner riktig metode. rev 15-Mar-2010	Anders	25.jan.10		2
43	Pistle, H. and Thompson, W. H.: "Optimization-The Key to Reduced Well Costs,"Proc. Of the Sixth World Pet. Cong. (June 19-26, 1963) 343-357. Bestillt 1-Mar-2010, Legg inn i EndNOte	Anders	01.mar.10		2
60	Konsoloidere EndNote Kartotek	Anders	08.03.2010		2
68	Drivers for learning paper, Skrive e-mail til JP og be om status 13-apr-2010.	JP	15.mar.10		2
74	LC Estimator rev8 Avtale møte med Rob Evans og gå igjennom Rev8.	Anders/Rob	17.mar.10		2
7	Kalle inn UiS til presentasjon i Bergen 10nde Juni, avventer nærmere deadline	Anders	18.jan.10		2
88	QC Thorfinn Hellstrand Data Åsgard, Troll, Snøhvit??	Anders/Tthorfinn	29.mar.10		2
91	Avtale internt statusmøte i Bergen	Hogne	09.apr.10		2
93	Sjekke opp hvilke rigger som startet sin karriere i Statoil/Hydro/ Saga med nye rigger, Sjekke med Thorfinn Hellstrand.	Anders	09.apr.10		2
94	Ligger de første brønnene for disse riggene i DBR? Sjekke med Thorfinn Hellstrand	Anders	09.apr.10		2
95	Lage Åsgard samle felt, sjekke entry for hvilke felt som er inkludert.	Anders	09.apr.10		2
96	Når var Borgland og Bideford i sving etter Glasgow ombyggingen? Spør Thorfinn Hellstrand	Anders	09.apr.10		2
25	Aftenbladet artikkel om oppstartsproblemer ifm Aker Barents og Spitsbergen. Sjekk opp.	Anders	29.jan.10		1
26	Når skulle Aker Spitsbergen begynt å bore?	Hogne	29.jan.10		1
48	Få tak i litt mer informasjon om brønnane på Sincor, Jon Fikser, men busy. purr mandag 15nde mars! Putting sendt 15nde mars. Mottatt en god del. Purre når jeg går i vent. så er jeg lovet prioritet :)	Anders	01.mar.10		1

Figure 2-3 Example of action log sorted on open actions, who number, and what priority level.

2.3 Meetings

Kick off meetings were held in Bergen in 2009 and Stavanger in January 2010 with UiS and Statoil personnel.

Weekly status meetings have been held at Statoil, with the Statoil thesis advisor. Progress has been verified, and focus points have been defined until next meeting, and new action points logged.

Mid term status/guidance meetings were held at Statoil with representatives from UiS Petroleum and Asset Management departments, and different Statoil departments. In order to verify the LCA spreadsheet developed for analysis and the method for extraction of data, to presentation of results. Action points from this meeting have been followed up, and presented to stakeholders in separate meetings at Statoil, and at UiS departments before the large scale overall data extraction and analysis started.

Preliminary results status presentation has been held for involved Statoil departments in Bergen. Final results will also be presented in Bergen together with handing over the final report.

3 Theory

Learning Curve is one of the terms used to describe the development of performance while making the same thing over and over. Learning curves are within Performance Measurement and Management. Brett Millheim published in 1986 their work in making a Drilling Performance Curve. They state about learning curves:
Brett, et al. (1986,pp.2), *“Learning Curve Theory mathematically describes the ability of organizations and individuals to improve their performance over time.”*

Construction of new wells in series, are examples of where you can measure and look for a learning curve. If you choose to take action based upon the measurements you can say you are working with managing your learning curve. All actions and non actions can influence the learning curve, however the measurements should remain the same in order to monitor the development over time.

The Brett Millheim paper focuses on overall time used for constructing a well, while Aadnøy (1996) went more in detail. Aadnøy (1996) present a study of time usage in the beginning of drilling in a new field in Norway, where he show that it was beneficial to go one step further into detail, and split into sections, looking at each section individually as well. If you are in a situation where some sections are developing in opposite direction on the learning curve, this is easier to catch and see, if you have divided into sections already. Seen overall the wells could look as no learning or slow learning, while in real life there might be on or just a few sections with negative learning.

Starting a new series of well drilling can be:

1) Startup of a new build rig/platform
2) Old rig used on campaign for several wells in a sequence on a new field.
3) Old rig New Crew
4) Change in rules, regulations
5) Change in organization
6) Change in drilling targets
7) Change in Method selection

The first wells in a series, will have the largest changes related to learning. Hence it is important with high focus from the first well, and the coming wells. In this thesis, the focus has been the first wells in a series. Brett (1986,pp.6) indicate the importance of the first wells in a series; *“The drilling performance curve study indicates that maximum resources should be used on the first 3-5 wells to maximize the learning.”* The number of relevant wells is depending on the learning rate coefficient C2. If the C2 is zero, there will not be changes in the learning curve, however the nature of the DPR equation 1.2 is that the largest changes will happen during the first five wells. Later on in this report the Learning Curve Analysis spreadsheet will be presented, there the number has been set to 25 wells included in the LCA sheet for the overall analysis.

I have chosen to go ahead with the Brett Millheim equation, since I find:

1) this is the industry standard,
2) it is an intuitive method, and hence
3) relatively easy to communicate, and
4) relatively easy to exchange parameters for benchmarking

3.1 Time estimation in APOS

The Expected Time shall be determined based on statistical simulations, taking into account experience from relevant reference wells and a risk assessment of the activities.
The computer program Drilling and Well Estimator (DWE) should be used for this purpose. In DWE you select relevant reference well candidates, and DWE then use these to calculate an expected time, P10 and P90. The probability distribution used is log normal. The Expected value (mean) will differ from the P50value, and will typically be in the range between p50 and p70. See figure 3.1

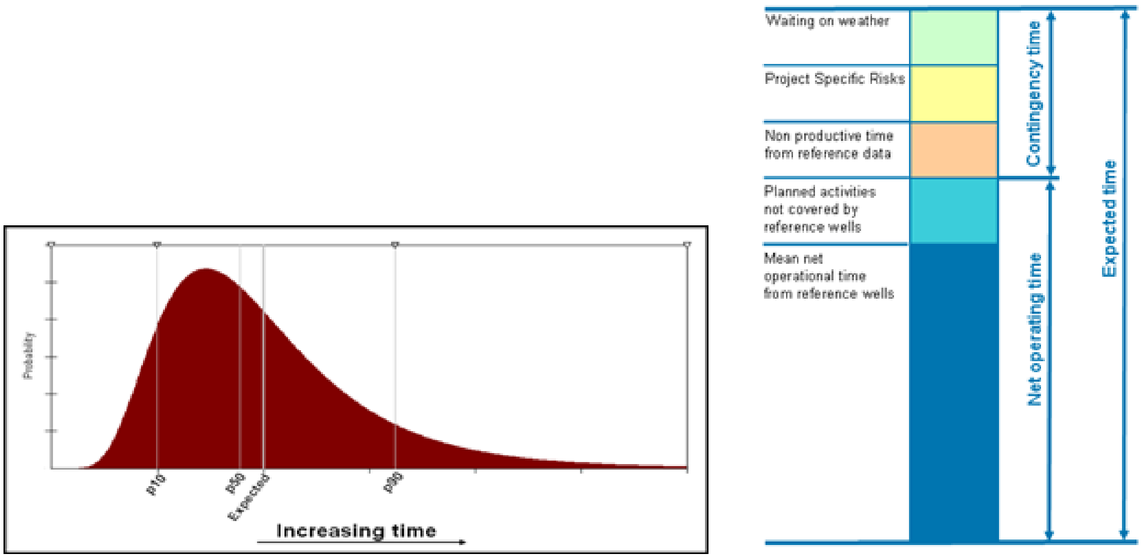

Figure 3-1 Probability Distribution Sample, illustrating the main principles and statistical relations in the time estimation model and shows a lognormal distribution where p10, p50, p90 and the Expected value has been marked. To the right is a schematic illustrating the time estimation elements.

If you are estimating wells for a:

1. new drilling facility
2. new contractor
3. Modified/upgraded/restart of drilling facilities
4. New geological area or lack of experience with the geology/formations
5. Implementation of new technology

3.2 The Brett Millheim Drilling Performance Curve (DPC)

The DPC curve is built up from a technical limit C_3, and then adding on a learning addition, that will vary with the amount of knowledge in the area, experience, and how well you are set up to drill in that particular area with the involved parties. All of these are reduced depending on how well the organization is setup up to learning from experiences along the way. There is also a relationship between the learning ad on, and the magnitude of the technical limit etc. This is called alfa. The involved parameters are presented below in detail, and see Figure 3.2 for reference.

C_3 Expected Minimum Time usage Technical Limit

Brett, et al. (1986,pp.3) *"The C_3 value measures what the drilling organization considers to be a "par" effort in the area. When an organization continually drills wells at its C_3 value it does not mean that more improvement is not possible. It does mean, however, that the organization has stopped learning from its experience."*

The C_3 can i.e. be based upon Technical limit or a DWE estimate. In this study the C_3 have been based upon the lowest value in the dataset minus 15%.

The DWE estimate is then important to reflect the long term expected value given the same major time driving factor selection. When making step changes etc. the C_3 will have to be changed.

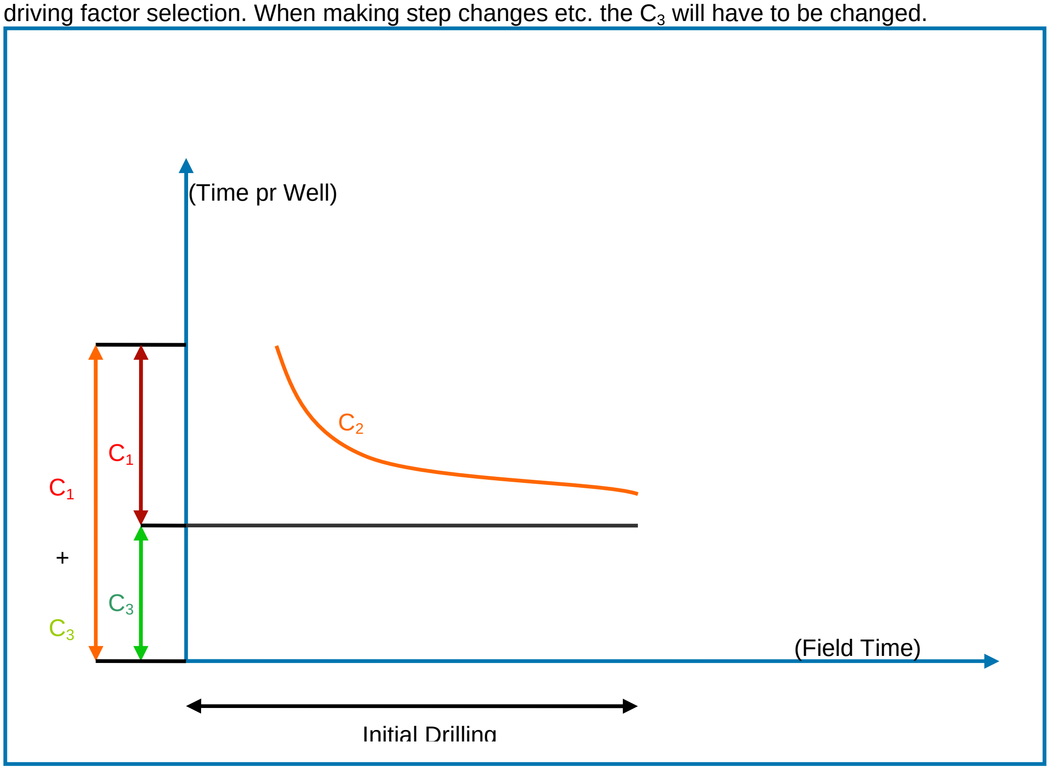

Figure 3-2 The Brett Millheim Learning Curve principal schematic

The Equation; Time = $C_3 + C_1 e^{(1-n)C_2}$

C_1 Learning Add On

The extra time used in excess of the technical limit. The learning add-on can be related to the C_3 level via the alfa factor which is presented later.

C_2 Learning Rate Coefficient

The C_2 value is part of the power of the exponent in the Brett Millheim equation. And is a measure for how fast a drilling performance is changing. The higher C_2 the faster the drilling times decline. In the study performed by Brett Millheim the average C_2 value was 0,34.

And they suggested an A, B and C rating of drilling operations as follows:

Excellent Performers:	$0.8 < C_2$
Good Performers:	$0.45<C_2<0.8$
Average Performers:	$0.25>C_2<0.45$
Poorer Performers:	$0.1<C_2<0.25$
	$C_2 < 0.1$, or Large Standard deviation, or no correlation,

The minimum learning coefficient you could expect should be positive, and in the order of 0.15, just by nature.

Brett, et al. (1986,pp.3) *"The C_2 value in a learning curve relationship (the exponential decay time constant) measures the speed and the effectiveness by which organizations learn to improve their drilling efforts. High values of C_2 mean that the organization can quickly adapt to the new drilling environment by learning from the experience of the first wells, and by producing new, effective drilling plans which address the specific drilling problems present in the new environment. High values of C_2 are produced by personnel and organizational when the following occur: an organizational structure has good communication between well planners and the field, there is good documentation and analysis of drilling problems, there is competent implementation of drilling plans. And there is a high level of preparedness. As such, the C_2 value is one collective measure of the overall effectiveness of a drilling organization."*

C_1+C_3 Expected time first well in a series

C_1+C_3 are the time it takes to drill the first well, and the point at where the learning curve start from.

Alfa Relative Part of Expected Total Time usage

Alfa = $C_1 / (C_1+C_3)$

The alfa parameter is tracked and published by in example Brett Millheim, and can be a useful relationship to follow. When you are starting to come closer to 1.0 there is not much add on for the learning curve, and you have a performance close to technical limit.

Brett, et al. *(1986,pp.3) "The value of alfa will vary with the difficulty of the area to drill, and with how prepared a drilling organization is to drill in the area."*

Delay Factor (D)

No delay D=1, 1 well delay D=2

When you have discovered and found a better way to work. It takes time to implement changes. I.e. it takes time to adjust and QC procedures. I take time to mobilize new and different types of equipment. It takes time to improve and fine-tune technology & tools and methods used. Offshore is longer lead times, subsea is even longer? Lead-times, land are shorter lead-times. In this thesis the D is part of the LCA analysis to see if there is any confidence into claiming a delay.

Brett, et al. (1986,pp.4), *"Also for the study, wells in a field which spudded at relatively the same time were considered to be a single well in a sequence, not two. This method of accounting for wells was adopted* *because drilling organizations have little opportunity to apply the experience gained from a well spudded only short before another."*

D_{New}	Delay before Learning Takes effect
F	Forgetting factor
C_1+C_3+F	Start Level including Forgetting

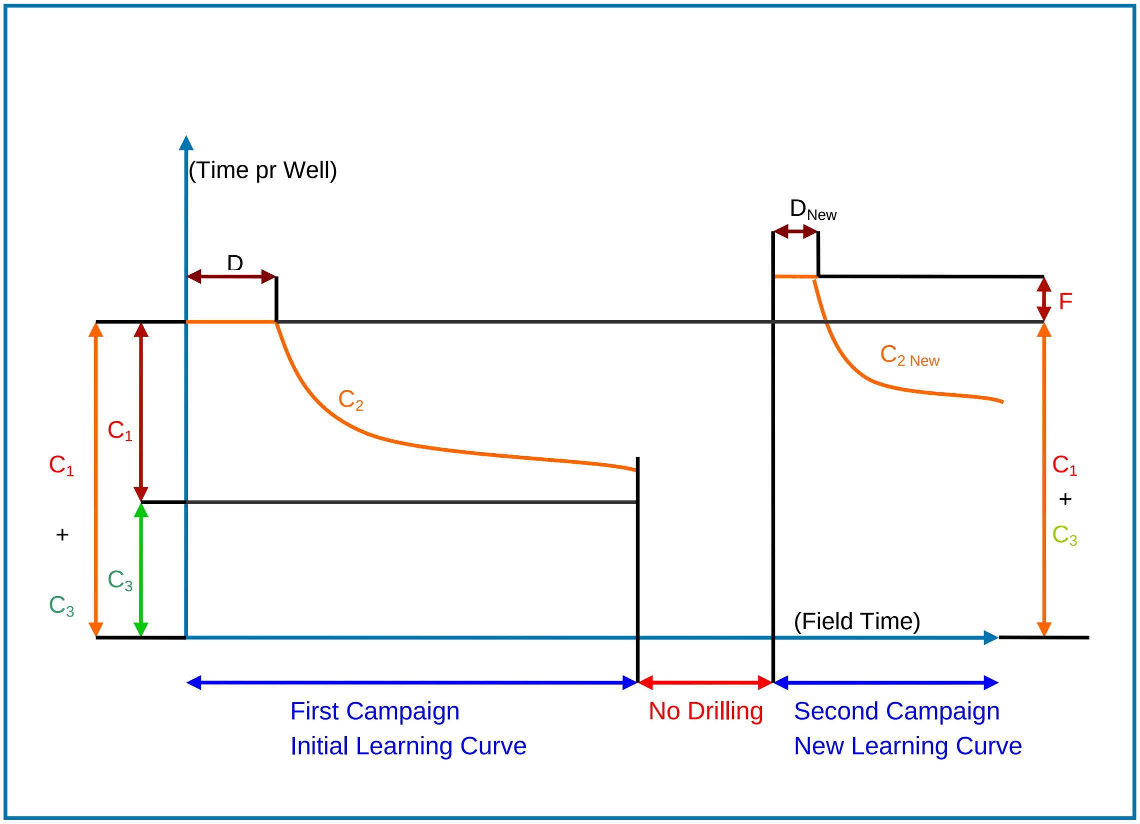

Figure 3-3 Suggested new learning curve model

Forgetting factor (F)

After having established a drilling organizations and operation, and you have put in the extra effort & managed to improve learning to a fair level, then demobilizing the operation for a period. Find out you need more wells, and mobilize again & start drilling. The drilling times come in longer then when you ended, and you wonder why? This is forgetting and the forgetting factor.

In this thesis it is looked for candidates where the forgetting factor can be seen. How much and in what way you should take forgetting into consideration, compensation.

Extended Reach Drilling

Drilling Extended Reach wells in a same field could be like drilling the same well over and over again down to a specific point, from where the only difference is the length of the horizontal section. In theory there would be a linear relationship if Cross plotting the Step Out time versus Step Out length.

A TD target further away will only add more length drilled, as long as using the same method, tools etc. Hence the expected time it takes to drill will be the same down to a certain point, for then varying with length of the additional step out. The liner and procedure for running the liner will be the same. Only difference will be longer tripping times from the longer horizontal. However the risk involved when working in a deeper well, will be higher. As represented in figure 3.4 below. The gap between the expected and the P90 estimate will become larger and larger however, and the potential downside of problems that arise will be larger.

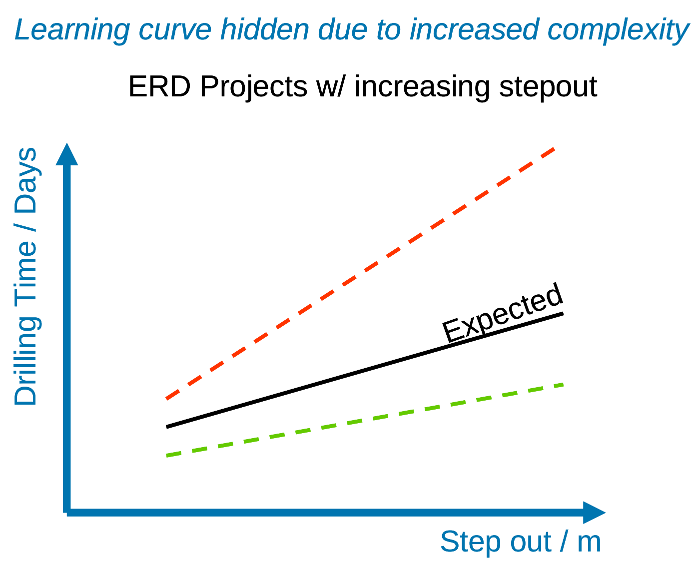

Figure 3-4 Plot exemplifying the expected time, P90 red line and P10 green line.

Normalization

In order to be able and compare wells with different lengths, length normalization has been performed. There are also other kinds of normalization that can be beneficial for clearing up the trends; however for this study length normalization has been used. To see the difference raw time data have also been presented in the LCA tool, however it is the normalized data that has been used. Both Aadnøy and Brett Millheim have mentioned normalization.

Aadnøy (1996,pp.210) *"The casing strings of the six wells were set at approximately the same depth, but the borehole inclinations were quite different, with reservoir sections drilled from 20 to nearly 60 degrees inclination. Obviously, the length of each section were different because of this. To make the data comparable, we therefore length normalized all data. That is we divided each time element with the hole length it represented. In this way we obtained data that were representative for all inclinations."*

Brett (1986,pp.4) *"Differences in the amount of directional work, extreme differences in geology*[17]*, or big differences in depth confused application of the model. Using performance measures such as "feet drilled per day", "cost per foot" or "rotating hours per well" rather than drilling times" could partially clear up the picture."*

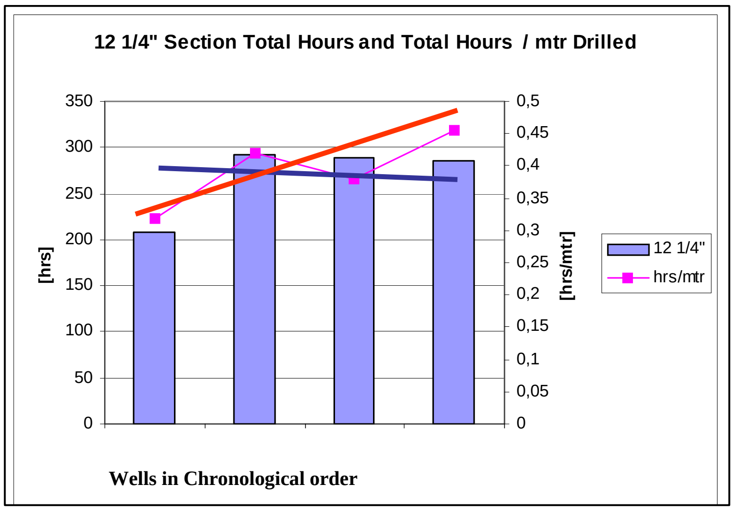

Figure 3-5 Example from pilot study, with declining time per section in blue columns, and normalized towards actual drilled length of section in pink.

How will this normalization affect the different DPC curve parameters?

C_1, will different since the time is per meter; instead of a total time used, and can not be compared directly without multiplying with the length again. If you would like to use hrs instead, you could select a typical depth, and multiply all the normalized hrs/mtr data with the same depth. In that way you have performed the normalization, but present a time value.

C_2, is important to tell about the rate of learning, and it would be would be great, to be able and compare with the industry standard Brett Millheim C_2 values.

Since the C_2 value only reflects the curve changes, and not the absolute position of the equations. The C_2 values will be the same, and hence comparable. This is shown later on in the report under LCA verification.

C_3, the technical limit or optimum value will see the same effect as for the C_1, and will need a length in order to be able and compare the total well time with Brett Millheim etc.

Rushmore Reviews Benchmark Data

Rushmore reviews have become the industry standard database for sharing drilling, completion and cost experience. The sharing of information is based upon, the input your company put in. If you have put in data for a specific year, and for a specific country, then you will have access to the other data available for that country. The amount of wells registered in Rushmore for completion, are not as high as for drilling, however it is an increasing trend for all categories. The overall number of wells that are reported in Rushmore is presented graphically in Figure 3-7 Historical number of wells in Rushmore by region below. You can see the exponential increase in total amount of data, and when the different regions around the world have started to use and report in Rushmore. The total number of wells registered with drilling data, is estimated to pass 40 000 wells in 2010.

An example of what data can be collected from the Rushmore reviews is presented in Figure 3-6. There you see a plot based upon data from Rushmore reviews, the data has been normalized, and analyzed for DPC parameters. The time it takes to drill the last well is practically cut in half of what it started out at. You could also compare your company's performance towards the other competitors in an area you are established.

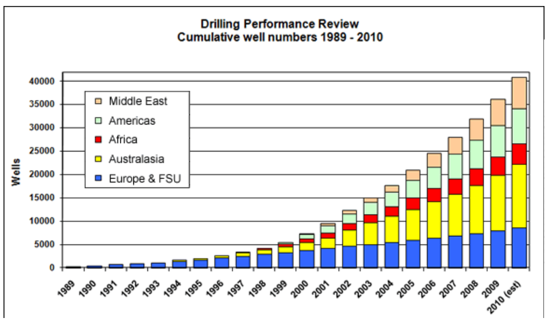

Figure 3-7 Historical number of wells in Rushmore by region (Plot from Rushmore Reviews)

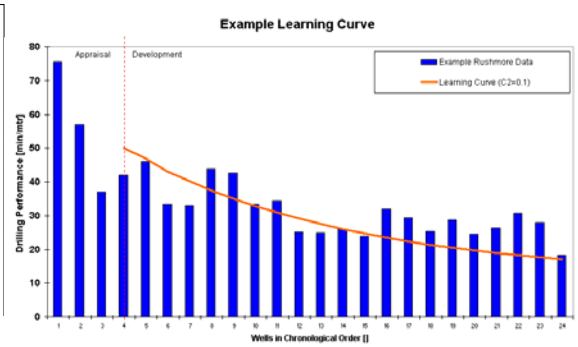

Figure 3-6 Example of a learning curve based upon data normalized towards length, presented in chronological order. Appraisal and then development phase. (Data from Rushmore Reviews)

Rushmore data can also be very useful where you do not have direct experience and insight to the data from competitors or partners in the country or basin where you are evaluating to go in. Figure 3-6 shows an example of a field development with three appraisal wells and a series of development wells. The learning curve appears to extend back into the Appraisal drilling, implying a good transfer of knowledge from Appraisal to Development drilling. This is unusual & probably coincidental. The curve is normally upset by a break in the drilling program post appraisal, the use of new rigs at the start of development, and directional development wells c.f. vertical appraisal. The learning curve in this example seams to extend back into the appraisal phase. This is considered unusual, however an excellent example of learning (curves). Normally you see higher time usage on the first development well, followed by 1 or two wells scattered around the same times as the first appraisals. You may from now on call this the Delay Effect (D).

3.3 Economic Value of your Learning Curve

The economic effect of learning curves plays a big role on the total time usage and associated cost for the whole series of wells to be drilled. This is exemplified as drilling a 16 well series in Figure 3-8 below, where the pink line represents an industry average learning, the yellow line represents bad learning. The area in between colored in light green represents a downside of approximately 1800million USD. The area in light blue represents a full learning effect on the second well down to the technical limit. This is the maximum theoretical upside, here with a value of 680million USD. The conclusion from this example is that learning play a big role in the outcome of the cost of the series of the wells, and the effect of not learning has a very large downside, compared to a limited upside if you manage to increase the learning above average. However if you are able and transfer the experience gained in this project onto one or several other projects, rigs, campaigns working in parallel you will get a larger effect.

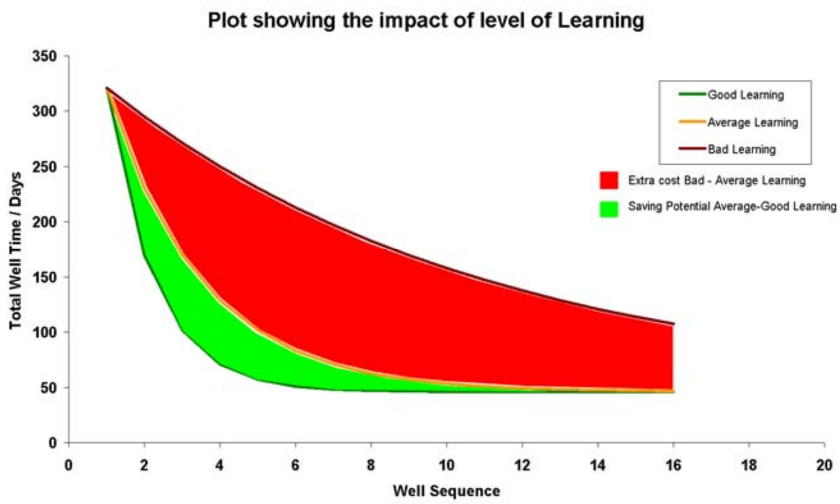

Figure 3-8 Plot exemplifying the economical up and downside of good learning in green, and bad learning in red.

Another example, however here by a series of 30wells drilled by one rig, and with learning coefficients C_2=0(zero learning), with C_2=0,15(Poor performer) and with C_2=0,35(Average performer).

The days per well plot and cumulative number of days to drill the whole series is presented in Figure 3-9. The overall difference in total days to drill series is in the range of:

1500days Zero Learning (685days & 84% add on towards the Average Performer)

925 days Poor Performer (110days & 14% add on towards the Average Performer)

815 days Average Performer

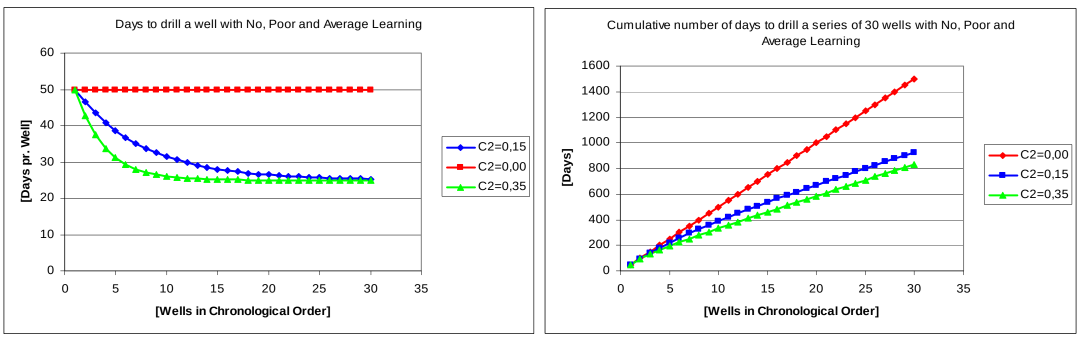

Figure 3-9 Left plot showing days to drill each well from 1-30. Right hand plot showing the cumulative number of days it takes to drill the whole series of 30 wells.

Step Change

Making a more efficient method selection, implementing new technology or other, can cause step changes. Initiating a new start point for the learning curve,

In theoretical terms what happens is that you reduce the technical limit, and increases you potential for learning. See figure Figure 3-10 for a schematic illustrating this.

Brett (1986,pp.5) *"Once the drilling performance stabilize (C_3) there is further opportunity to effect more reduction in time and cost. Figure 11 shows an example of a performance curve where new technology was applied late in the development of the field. A new drilling performance curve reduced the C_3 level from 2347days to 125 days affecting a savings of 12,5MM (assuming a $20K/day spread cost). Ideally, as soon as the drilling performance curve flattens out, future drilling is ready for applying some type of new technology and for operational approach."*

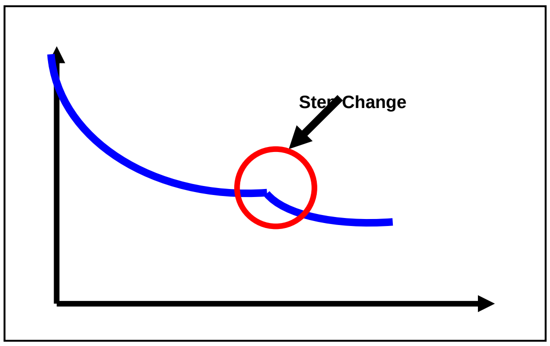

Figure 3-10 Schematic exemplifiying a perfrormance step change.

Examples of step changes could be.

- New faster type of drilling technology
- New procedure allowing more parallel activities(ex. Dual derrick)
- New Cementing practice and technology allowing half the time from circulating until able to drill.

When upgrading a drilling facility, you should see a new starting level, depending on if the upgrade have speeded up the process, or slowed down.

Single Rig vs. Multiple Rigs

There are different parameters influencing the learning curves in a field development using a single rig, compared to a field development using multiple rigs. C_2 values will only be directly comparable when they are analyzed on a well by well basis per rig. Or averaging the wells drilled at the same time and using average numbers to a set of rigs. If this is not the case, then one will have to treat the C_2 value different from other sources C_2 values.

Experience transfer between rigs/operations

Depending on same or different rig providers, and operator involvement. Multi rig analysis.

Multi rig scenarios, Multi Teams, Magnitude of LC.

Hareland, et al.(2007,pp.2-4) *"The software uses nearby offset well drilling data and records to calculate the different formations drillability on a meter by meter or less basis. This is done by taking the meter by meter* *drilling data for each offset bit run in conjunction with the offset field reported bit wear, pore pressure and lithology composition. Through different bit type inverted ROP models the drillability or Apparent Rock Strength Log (ARSL) is predicted using an iterative process in the simulator. "*

…

"2. The drilling learning curve is improved both in terms of better pacesetteters and in term of more consistent results.

3. The improvements in drilling performance depend on how mature the drilling in a field or area is. Results indicate that the reduction in drilling time of as much as 39 percent is possible but on the average about 15-20 percent Is seen."

…

"5. If pore pressure or rock strengths are off it can be seen directly when analyzing the ARSL real time. The actual ARSL can then be used to estimate bit wear in the hole real time and then to optimize the parameters for further drilling while the bit is still in the hole"

Some of the parameters are:

Brett (1986,pp.5), *"To obtain a high rate of learning (C_2) requires an organization must learn and capture experience and technology in such a way that it can be rapidly transferred to other operational personnel. This implies a central organizational personnel. This implies a central organization structured like the Critical Drilling Facility19 in Tulsa or many of the drilling organizations used to develop platforms in the North Sea (Note: our analysis showed more high level drilling performance in the North Sea than another geographical area). Drilling teams linked by high level communications, using state-of-the-art technology consistently showed a higher level of performance."*

…

"there should be a central group of drilling experts in any organization that drills a significant number of exploration and exploitation wells"

Aadnøy (1996,pp.222) about logging experiences and using the in the coming planning and operation
"Before closing this discussion on borehole stability, it should be observed that if the average time to drill each well is 60days, unforeseen borehole stability problems accounts for 15% of the time consumption. This percentage has not seen a dramatic improvement the last decade, and for future wells, which will be even more ambiguous, borehole stability is going to become an even more important issue."

Aadnøy about the well construction process, ""

Aadnøy (2009,pp.13) *in the new Advanced Drilling and Well Technology SPE suggest how to best use advanced technologies in the overall advanced well design divided into 4 main parts*

"
1. *Concept options to be generated*
2. *A robust business case for the preferred choice*
3. *Z sound deployment framework*
4. *Excellence in project management"*

An example from a land operation where Statoil is involved today:

For 6-8 months ago one well was drilled in 40-45days. Then a training program was implemented, with specific focus on drilling practice. Resulting in a more consistent performance averaging in the order of 25days per well, +/- 40% decrease.

The limits of Technology Changes

From the beginning of modern oil well drilling until today there has been many challenges along the path. Examples of areas that needed special care and development of technology; HPHT, Increased water depth, Increased inclination degrees, increased length of step outs, horizontal drilling technology.

Aadnøy (1996,pp.220)

"The industry is continuously changing. Presently there are trends towards deeper sub-sea wells, and new technology like slim-hole drilling is under development. Therefore, even if we make progress in one area, we will still be faced with new challenges, because the limits are always extended. An important way to improve is to learn from failures, therefore experience transfer is important.

The aforementioned problems are frequently of borehole stability type. Casing landing problem, stuck pipe, hole cleaning problems and cementing problems are often a result of borehole stability problems. There are difficult to handle, and it is fair to say that we do not yet possess the full understanding. My approach is to try to analyse all problems and to evaluate each well design in light of these."

All these and many more have been developed along the road of oil well drilling technology development. As a more in depth example I have looked more in the "Worldwide progression of water depth capabilities for offshore drilling & production" a plot made by Mustang Engineering (Houston updated…)"

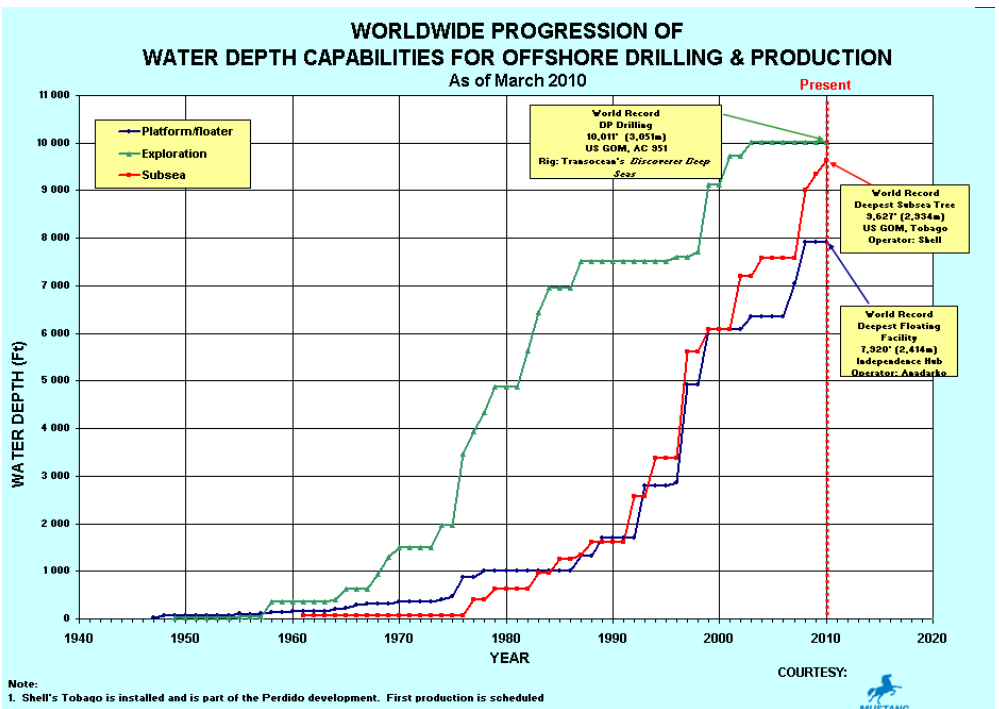

Figure 3-11 Depth versus time plot of exploration depths and production depths worldwide. With courtesy of Mustang Engineering.

Drilling Engineering

In Norway there was 247wells drilled in 2009, and 99 of these by Statoil. In Canada it was 20 000wells drilled in 2009. The Norwegian part of number of wells delivered on a global basis is limited. The Norwegian way is too expensive for the rest of the world. We need to learn and show a little more respect to the others, and learn more from them!?(This is according to people in the business the comment you hear from people that have been working in other countries than in Norway.

Ahlmedi (2009) Competence Engineering Preparation and Planning (KEPP) was used in order to explain why it could be that technically more difficult wells was drilled in a more predictable way than other simpler wells. Hence advanced, difficult, new technology implementation, HP, HT, HPHT, environmentally sensitive areas etc. can be performed safely and in a predictable manor, if the KEPP input is sufficient.

Houston – Rio They do Engineering work upfront of each well. The same way as we did in Norway in the 70-80s.
In Canada there is a 4 year degree in reservoir engineering and a single course in drilling.

One well planning
How much time is put into planning and follows up of operation?
What is the budget/economics involved for a well? 40mill nok – 1bill nok

Competence
Using the best available competency first in the planning and startup of the drilling campaign in order to gain full benefit of the learning curve.

Culture
Example with 82 different companies involved in one well, planned and coordinated by one engineer. Average number of suppliers in a drilling and completion operation on the NCS is in the range of 28. Maximum number of suppliers, is not known, however a number between 50 and 100 has been experienced. Petter Osmundsen)

What about the working schedule of 2weeks offshore and 4weeks off time, at home with the family? Is this the ideal scheduler with regards to Learning Curves?

Norway has invested a lot in high end technology, an have driven the Subsea development, as well as the Subsea to Shore (S2S) development.

Are there Cultural differences with regards to the learning process?Staffing density, number of personnel, compared to number of wells produced?

Engineering
Is this something that you do with your left hand?
If the engineer can influence the outcome of the cost by 5% the cost implication would be between 2mill nok - 50mill nok, let say one engineer plan 4 wells a year the total cost influence would be between 8mill nok – 200 mill nok.

Over Engineering
Focusing to much on reaching the side goals, so that you risk loosing sufficient focus on the primary objective to the well. I.e. Focusing more on logistics and high Rate of Penetration (ROP) paying less attention to actually reaching the target pay zone in the best way. There and then the high ROP etc looks very good, however when the well comes into production, and maybe end up with a lower recovery, compared to if the well placement had been spot on. The economy in this is usually very favorable for meeting the pay zone spot on. Even though it might result in slightly more time usage.
Could this be explained by a culture of “Over Cautiousness”? Where a lot of attention and time is spent on extraordinary non industry standard extra add on. Over engineering, but on the wrong things.

Planning
How many personnel hours should you put into one well?

Optimization
Do we take advantage of the computer technology in the optimization and sensitivity analysis with regards to time usage and drilling efficiency? Using analytically advanced IT tools in order to optimize the planning

and selection process. Performing exactly the same process every time. Khosravanian (2009) in Iran have worked together with Aadnøy, and based upon Aadnøys principles Aadnøy (1996) there has been set up and run a computerized cross analysis on several parameters and optimize towards cost. Examples on input parameters are casing depths, cement cost, mud cost, casing cost etc.

Khosravian (2009) *"In this study, to optimize casing point selection under geological uncertainty, we observed that:*

** Using multiple scenarios in the RSH field provides better decisions to determine the best casing setting points in wells, with predicted savings of 2.4% to 15.2%*

** The casing point planning (CPS problem) extension to the uncertainty environment is a good tool to determine casing setting depths of wells.*

** The more data available, the smaller the uncertainty and the better the resulting decisions."*

A lot of focus on logistics/Long lead time items, and focus on downtime, instead of planning for the right scenarios.

Has the trend moved towards a more operational culture, which actually does not make use of today's computer power, and following powerful analysis tools that are, or can be developed?

Incentives

Incentive Theory/points

Osmundsen (2009,pp.20-21) discuss the incentive formats, and how these could influence the drilling efficiency measured in mtr/day. *"The authorities and the industry have a common interest in reversing the negative trend in drilling efficiency on the NCS. Should this reduction result in the loss of resources which might otherwise have been recovered profitably, it would also be a matter of concern from a socioeconomic perspective. However, rapid drilling is not always compatible with good reservoir utilization and efficient information gathering, so a trade-off must be made here. Section-based drilling incentives, where work in the actual reservoir can be treated specially, sem suitable for making such a trade-off. Strong speed incentives can then be provided for pure transport stages, followed by detail control when drilling in the actual reservoir. The interests of oil companies with a fairly long planning horizon will partly coincide with those of the government where reservoir utilization is concerned. However, conditions could clearly arise – through pressure on liquidity, for instance, or on reaching specific indicators – where the authorities ought to keep a close watch on reservoir utilization."*

Incentives, do the service and rig company get a too high percentage of the total income regardless how the well construction efficiency develops, (learning curve). If the percentage cut is to high on the overall safe rate, maybe there needs to be a stronger disciplinary incentive towards increasing efficiency, and not only avoiding downtime?

The service companies still based a lot on ray rates. Is a lot of the well planning made by the service providers? If so what incentives do they base their choices upon? The Incentives for the service provider is very different from the owner or operator incentive. Max revenue and contribution within limited amount of time and contract period.

Risk Analysis / Management

What is the largest risk involved? Sensitivity Analysis Find out which parameters that is most sensitive to changes, in order to see where you risk decreasing your learning curve.

The influence of different perspectives.

There is different stages, and situation that you estimate time usage, and measure the time usage for evaluation of performance. Different types of learning curves. After rig upgrade etc.

From the engineers standpoint

You could see arguments like:

"I am clearly showing a learning curve is included, which covers both the start up risks and costs, as well as the performance improvement we expect." or "I can stop all those irritating questions from the project manager"

From the Managers standpoint

I only have on box so I will just use the plateau rate, and ignore the rest – its closer to the number I first thought of anyway" or "I will be promoted long before the first phase of execution is over budget and delayed."

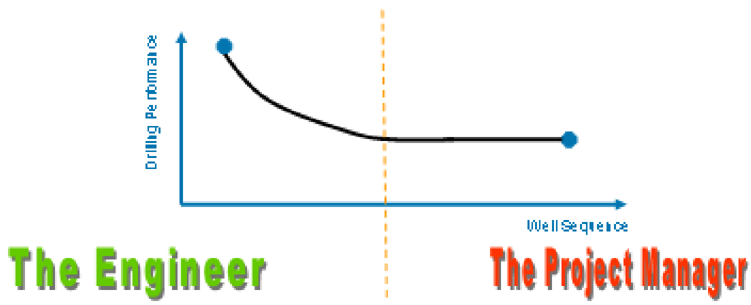

Figure 3-12 Illustration of the learning curve versus time, and focus are for an engineer, and a manager.

Brett, et al. (1986,pp.5) *"Another ramification of the drilling performance model is the shorter the drilling program in a particular area the more impact there is on the overall economics of the drilling program by reducing C_1 and having as high a C_2 as possible down as low to C_3 is possible."*

Breaking down the well construction process into smaller activities, you can see a more differentiated picture. This was exemplified in the pilot study; see further chapter 4 and it is possible to have some positive learning activities in the same well as where you have negative learning experiences. These will of coarse on a well level work against each other, and "mask" the results. Making it more difficult or impossible to bring on the necessary performance measures in order to steer and take benefit of this learning into the larger picture for the other rigs in the same organization.

Andersen et al. (2009,pp.14) Online detail measurement of tripping times etc. can according to *"Optimizing a number of identified KPIs for the drilling operation has shown that there is a potential saving of between 8-15% of the total well construction time by using this approach"*

Aadnøy (1996,pp.15), Report about implementing the median line principle in the selection process of mud weight. *"Common borehole problems are discussed and evaluated in a rock mechanics context. The result is the 'median line principle', which simply says that the mud weight should be kept close to the in-situ stress field in the surrounding rock mass. In this way the borehole problems are minimized since a minimum of disturbance is introduced ion the borehole wall.*

The mud weight methodology was applied in the three last wells in a field study of six wells. The enclosed field study of six wells. The enclosed field study shows a considerable reduction in tight hole conditions, which is considered a good indicator of the general condition of the hole," The macro level will see the overall trends and changes that occur. I.e. it was implemented new regulations in 1992-93 in Norway bringing in automated pipe handling systems etc. in order to move the drilling personnel away from falling items, and potentially very dangerous working conditions.(monkey board, Kelly, man riding etc.)

The history changes, Aadnøy (1996,pp.222) *“Studying statistics, one will find that 10-20% of the rig time is spent handling unforeseen problems. This statistics has not improved significantly the last 10 years. We have of course made some progress, but the wells have to some extent changed character. During the last 10 years long reach and horizontal wells have evolved into lengths never achieved before.”*

Andersen, et al. (2009,pp.14) about Automated Drilling Performance Measurement of Crews and Drilling Equipment *“Optimizing a number of identified KPIs for the drilling operations has shown that there is a potential saving of between 8-15% of the total well construction time by using this approach.”*

Integrated Operations
OLF (2006) about the potential for NCS in using integrated operations; *“The result of the project is a likely, but conservative potential gain from Integrated Operations for the Norwegian Shelf expressed as present value (NPV). In addition, the potential gain has been estimated in percentage in regard to the total value of the reserves on the Shelf. The project has also estimated the implementation costs, and a sensitivity analysis has been made for various oil price developments.*

2. Definition of Integrated Operations *Norwegian Parliament White Paper No. 38 – on the petroleum activities - defines Integrated Operations as being:*
”The use of information technology to change work processes to reach better decisions, remote-control equipment and processes, and to move functions and personnel onshore”
Several of the companies which operate, have participating interests or otherwise have activity on the Norwegian Shelf use other and closely related terms. Some of these are:

• *Reduced drilling costs:*
– *Fewer sidetracks with more accurate drilling*
– *Real-time optimization of path and drilling process*
– *Reduced need for sending out specialists and service personnel”*

From where is the operation run from? Communication is important in order to gain and share knowledge in the rig organization as well as between rigs. There is a large upside on this, as described in the OLF (2006) Experience Transfer can be quicker when there is several operations run from the same office. However with the development of information and communication solutions implemented during recent years, the placement is believed to play a less important role than before.
Measure and make available the Learning Curve results continuous. Actively work with understanding of the drivers, in order to manage your learning curve. Manage in a sense of allocating the right resources at the right time for the right projects. Implementing new technology as early as possible in the right projects in order to gain full benefit of the upside.
However experience transfer does not come automatically, and without effort. In order to get benefit, from other experiences, these need to be actively taken into consideration, and implemented. The faster the implementation the higher C_2 value in the resulting learning curve. And the more Step Changes can be evaluated and implemented. Of course it should be mentioned that there is a risk involved in implementing changes, however this is also one of the keys to success.

Limitations in engineering capacity. The size of learnt experiences, and changes that should be evaluated is limited in to the spare capacity available in the operations engineering staff, or depending on a close interaction between the engineering and other supporting functions.
However the closer you can do the implementation to the actual ongoing operation the tighter and more rapid implementation can be seen.
Statoil have international operations, and are increasing presence internationally. Geographical Placement of operations of Statoil fields today. Which rigs are run from where?

Figure 3-13Global map with purple dots representing Statoil presence in conuntries.

3.4 Integrating learning curves in time estimates

Jablanowski (2009,pp.4) about probabilistic learning, *"If there is a large uncertainty in one or more estimates of the learning equation's parameters, then parameter C_2, then it can be defined in the simulation as a random variable. For example, assume that C_2 is normally distributed with a mean equal to 0,5 and a standard deviation equal to 0,1. A new set of learning factors can be computed and applied to each of the simulated campaigns (holding the other parameters constant at their previous values)"*

How to use experience learning curve data for estimation

Use the DWE estimation, alfa value expected and standard deviation, C_2 mean with standard deviation. Utilize the results from this report for estimation of rig type specific C_2 and alfa values with associated uncertainty.

Use DWE for estimating the C_3 value.

The C_1 value adds on can be found from the DWE estimate, and the experienced alfa numbers via the relationship below:

$C_1 = C_3 * \alpha / (1-\alpha)$ Eq. 3.1

C_3 = DWE Estimate based upon a realistic set of reference wells

=> $C_1 = DWE * \alpha / (1-\alpha)$ Eq. 3.2

n = number of the well you are estimating in a sequence, and C_2 the learning curve factor with associated uncertainty. The Statoil version of Brett Millheim would then look like:

Expected time of well n = $DWE * e^{(1-n)*C_2}$

DWE LCA Assistant

Calculates your Learning Curve

DWE Net Operating Time (C3+C1) first well	75		
Technical Limit (C3)	30	days	from DWE
Type of Drilling Facility	1	[1-5]	From list to the right
a mean	2,5		
a st dev	1		
c2 mean	0,2		
c2 st dev	0,2		
C1	45		

		C2	C2 St.Dev.	alfa	Alfa StDev
1	Fixed Rig	0,2	0,2	2,5	1
2	Semi Sub.	0,3	0,6	2,6	1,6
3	Landrig	-0,23	0,51	1,11	0
4	Drillship	0,7	0,9	2,4	1,1
5	Jackup	-0,1	0,8	1,4	0,6

Well No. [n]	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
C3	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
C1	45	37	30	25	20	17	14	11	9	7	6	5	4	3	3
% Add On to DWE	150 %	123 %	101 %	82 %	67 %	55 %	45 %	37 %	30 %	25 %	20 %	17 %	14 %	11 %	9 %

16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
2	2	2	1	1	1	1	1	0	0	0	0	0	0	0
7 %	6 %	5 %	4 %	3 %	3 %	2 %	2 %	2 %	1 %	1 %	1 %	1 %	1 %	0 %

rev. 11-Jun-2010 by AH

Figure 3-14 Screen shot from the DWE learning Curve assistant. Developed a tool for analysing DBR data, for input to DWE.

The related uncertainties will have to be used or at least considered. And the results have to be correlated towards common sense. It has not been time for verification of this theoretical discussion and derived relationship. Monte Carlo Simulation would need to be performed in order to be able and capture and predict the uncertainties as well as possible.

And a sensitivity analysis towards the different input parameters is recommended.

Jablanowski (2009,pp.6) about Integrating Learning Curves in Probabilistic Well Construction Estimates in their Conclusion and Recommendation;

"A general method and specific procedures for integrating learning curves in probabilistic estimates has been provided. Results of this type of analysis provide engineers and decision-makers a refined representation of uncertainty, and can improve capital investment valuation and decision-making. It is argued that for implementation of these methods to be successful, they should remain simple in structure, easy to use, and transparent regarding the assumptions. Based on this research, the authors offer two major recommendations:

Use Several Methods. *The engineer should openly acknowledge his or her ignorance regarding specification of the inputs to the probabilistic analysis and how learning will progress over time. AA realistic goal for this type of analysis is to establish an overall potential range of outcomes and fixating on one set of assumptions or scenarios is not realistic.*

Transparency. *Do not use black boxes. If the analysis is done in one off-the-shelf spreadsheet software, the results will be easier to communicate with all of the stakeholders: drilling colleagues, drilling managers, asset team members and managers, partners, and regulators. Transparency helps to build joint ownership of the estimate, and communicates the uncertainty (and the sources of uncertainty) in the estimate."*

4 Pilot Project

Within a Statoil project it was requested a learning curve analysis for the drilling and completion of a specific four well campaign drilled with an old semi submersible drilling rig. This analysis was performed and used as a pilot project for the thesis. In the analysis the following parameters was looked upon:

- Total time used
- Temporary P&A & Running Riser
- Drilling time
- Completion time

The data used was Non Rushmore Data, hence potentially some errors with regards to lengths. Completion was included, and normalization was tested and gave partly contradictory results compared to per well total

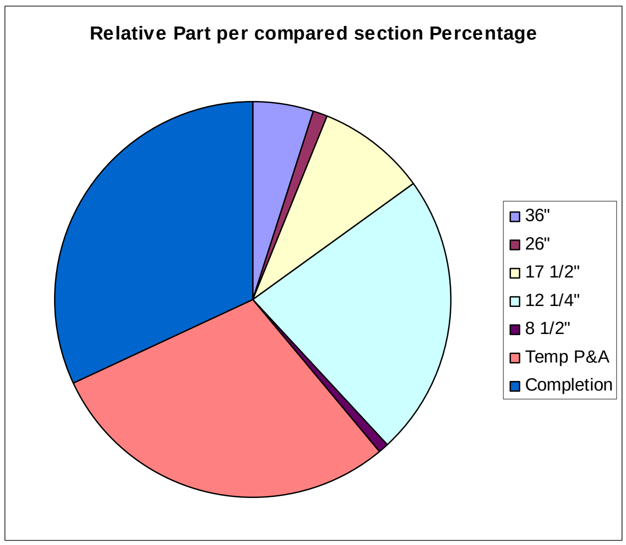

Figure 4-1 Section time usage relative to total time.

time comparison. This pre study for a limited size operation is performed, with the aim at finding something about learning curves. Overall relative time comparison of the different main sections from DBR is presented in Figure 4-1.

An overall time per well comparison would be the most natural approach to start, however in this case that will not give any meaning. The reason is that the wells are partly batch drilled (one section drilled in three of the wells directly, but in different order) in order to gain time & cost savings for the project. Therefore the times used have been taken out by section, and is presented chronologically. The relative parts of each section to the overall have been calculated. Four wells is considered low in statistical terms, and hence it will be limited how strong the results will be from this analysis alone. Interesting to see that almost 1/3 of the time used is related to Temporary P&A, 1/3 is Completion and only 1/3 is Drilling.

Table 4-1 Showing the positive and negative learning curves on section level.

Section	Percentage	Learning Curve
Completion	32	☹
Temp P&A	29	☹
12 1/4"	23	☹
17 1/2"	9	☺
36"	5	☹
26"	1	☺
8 1/2"	1	☹

Quality has not been included in the comparison; complexity has not been included in this comparison. Time of year has not been corrected for in this comparison.

And it is a manual Visual Trend check that has been performed. "First Impression Analysis"

Level of Detail

The level of detail in the pilot project was down to the sections. For the overall LCA analysis it will not be possible to go that detailed into the data. However this will be suggested for implementation into DWE.

Conclusion

- As we often see, learning does not come automatically by just doing the same thing over and over, not even when we do it many times.
- As this very brief assessment also shows we have been able to indicate positive learning for 1/3 of the performed operations in the four wells, and negative learning for the other 2/3, i.e. a mixed picture with regards to learning.
- A highly preliminary hypothesis is that there seems to be a need for "focused" and aggressive learning and improvement drive and specific learning and improvement related activities if we want positive learning (curve) results.

Table 4-2 Showing the overall percentage of positive and negative learning in the pilot project.

	Time	
Positive Learning	10 %	☺
Negative Learning	90 %	☹

5 Development of Software

Learning Curve Analysis (LCA)

Below is a brief description of the DBR database presented, and then the data extracted from DBR, filtering to only keep whole wells. In order to solve the core question in this thesis “Is Statoil Drilling and Well a Learning Organization” by industry standard means. It was early in the pilot project realized that we needed a tool that could assist in simplifying the work involved in the analysis per rig, operations. The process and the tools developed had to be as streamlined as possible, however using as much standard programs, and routines as possible. At one point this was near giving up, excel in favor of Matlab for Curve fitting, however when finally the Matlab demo license were up and running, the actual problem was solved in excel by splitting the calculations into several parts, and running in the order of 2000 lines with different values and results. Ended up with a combination of Macro Programming, and the built in solver goal seek functionality. And, of course, a lot of if statements to remove negative values etc.

5.1 DBR

Today holds data from approximately 4500wells.

Started in late 80’s logging mandatory drilling operation parameters, sending to the authorities. During the years from the beginning, and until now, there has been many upgrades, modifications etc built into DBR, and some relevant highlights are:

1) 1998 Changed coding system to change from drilling to completion coding consistently with Rushmore reporting,
2) Include Saga data from Hydro
3) Include Hydro data

The parameters used from DBR

Well Name & Number (sum_level1)

The well name and number is used for quality control purposes. In example to identify mother bore and

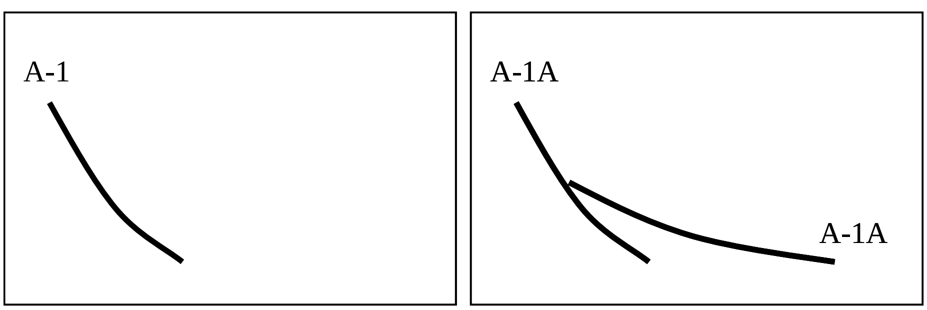

Figure 5-1Illustration of the numbering system for main wellbore and sidetrack.

laterals. See illustration below.

Non Productive Time (NPT), or Downtime (d)

Includes only the downtime D from DBR

Does not include Quality time (Q in DBR)

Does not include Waiting Time (W in DBR)

Does not include Waiting on Weather time (WOW in DBR)

Used for reducing the total time to a productive time, actually used for making the hole.

Total Time (tot_days)

Total time is used,, Waiting on weather is kept outside of this because of incentives. Mother Nature does not issue credit notes, however rig and service providers do. Therefore WOW is kept out, and the downtime per service provider is in.

Drilled Length (tot_length) Depths

The actual length drilled, hence starting from seabed and all the way to the planned target. This means excluding technical sidetracks etc. drilled only to be left as time consuming, in order to reach the target. See illustration below for a example on this. The Drilled length is used for normalization, and Quality Control.

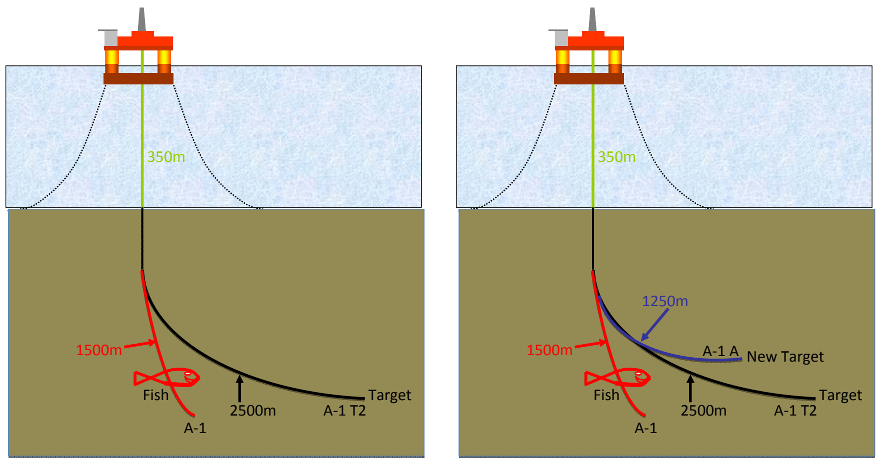

Figure 5-2Illustrating the different length's that are involved when leaving a fish in the hole, and sidetracking taround. And in addition towards a new target.

start_time

Start of first drilling code

end_time

End of last drilling code.

Technical Limit

The least time used ever. Broken down into specific sections (Main Section), and combined into an overall technical limit time.

As time goes by, Technical limit should go down.

Data Extraction from DBR

Data have been pulled out of the DBR system, which is the documenting system for gathering and storing data associated to drilling activities performed.

A total of over 4500wells are registered here as of today.

The history of the database has changed over the years, and following takeovers Saga and Hydro wells from their equivalent systems have been merged into the Statoil DBR system.

In DBR the Data Analysis function have been used as follows:

1) Reports

2) Analyze reports menu
3) Operations / Time distribution
4) Well history and section listing
5) Operation period
6) Select wellbores
7) Do not Exclude ion track wellbores
8) Do not Exclude maintenance wellbores
9) Find and select all the wellbores you need. I.e. Transocean Wildcat all wells.
10) Select section D_BMARK
11) Select All drilling activity codes
12) Select rig
13) Run report
14) Choose location, file name, and xls file- Save

Quality Control of DBR extracted data

Aim to remove incomparable wells based upon length below 1000mtr, and productive length that reached the initial target. (Rushmore definition)

Remove incomparable wells

Should ideally have counted as well order step in learning curve plot, in order to fit Learning Curve better in LCA analysis.

This has not been taken into account in the LCA 9.3

This will cause, somewhat more humps, instead of more smooth learning curves.

The trend will be the same, and the impact is nicer to have. Will not severely influence the conclusion however it might be recommended for implementation later on.

Open the extraction file in Excel and perform the following steps:

1) Select all
2) Double click and auto adjust column width
3) Data Choose Auto filter
    a. Sort “tot_length” ascending
    b. remove lines with lengths below 1000m
    c. Sort “sum_level1” ascending
    d. Identify identical well names and “remove new wellbores from the same mother bore” by manual identification if possible.
    e. If there is doubt Crosscheck with Compass well directional database and see what line that represents the full mother bore, and what lines are sidetracks and are to be removed.
    f. Sort “end_time” ascending
    g. Save with sorted in filename.

5.2 Limitations in DBR Data Quality

The basic units Learning Curve analysis is depending on is time, length, chronological order, and a way to find out weather the actual well name is representative and comparable for your sake. In this report only complete wells have been sorted out, hence left sidetracks and multi laterals out, only the main wellbore for multilaterals.

Have found and checked up the following errors in DBR:

On an exploration well it was found to be several errors. The on well was registered with two different well names, one name during drilling and one name during Permanent Plug & Abandonment (P&A).
There were also double up with reports during the P&A operation, and a simplified “Dummy Reporting” using a simplified detail level.

Errors like the one above is typical for moving data from one database to the other using the automatic “computer Programmers” approach. Of course the QC job has to some extent been too limited, and not giving adequate detail confidence as would be adequate for this thesis. The number of wells, where the example above is valid is mostly older exploration wells from the Norsk Hydro system “Bore”. The DBR data quality for the more recent years has been improved, and is increased to include more aspects.

An additional simplification that is a “known” QC limitation it shows from the same “Bore” system is lack of coding after the last drilled hole section. Instead keeping the last drilling code, resulting in inconsistent and wrong efficiency parameters in DBR. As well as the depths of each drilled section is inaccurate, compared to actually drilled and verified well trajectories.

The same QC limitations as described here above might also be valid for production wells; however that has not been looked into the same systematical way as above. However it is used as a inaccuracy in the conclusions, and a recommendation to implement QC in the recommendation part. With regards to using these data for time estimation in DWE, the overall results of the DWE estimation is very accurate in an overall perspective. Hence the recommended work is believed to increase the precision further, and increase the knowledge about time usage, learning curves, Performance Benchmarking towards Rushmore and others etc.

Example of to long length in DBR resulting in erroneous data point.

							hrs. Out 23:30 hrs. RFT samples, Filtra
8 1/2"		05.09.1989 00:00	05.09.1989 00:30	0,5	0	ELOD	Rigged up to run the SHDT-log.
8 1/2"		05.09.1989 00:30	05.09.1989 05:00	4,5	0	ELOD	Detected a conductor failure in the logging c
8 1/2"		05.09.1989 05:00	05.09.1989 06:00	1	0	ELWU	Ran log no.5: CST. In 06:15 hrs. Out 10:30 hrs
8 1/2"		05.09.1989 06:00	05.09.1989 10:30	4,5	0	ELWU	Ran log no.5: CST. In 06:15 hrs. Out 10:30 hrs
8 1/2"		05.09.1989 10:30	05.09.1989 15:30	5	2651	CARU	Ran in the hole for wipertrip. Scraped the 9 5/8
8 1/2"		05.09.1989 15:30	05.09.1989 16:00	0,5	3200	CARU	Continued running in the hole for wiper trip. Hit depth. Changed the logging cable.
8 1/2"		05.09.1989 16:00	05.09.1989 19:00	3	3200	CARU	Circulated the hole clean. Pumped a highvisco
8 1/2"		05.09.1989 19:00	05.09.1989 23:00	4	0	CARU	Pulled out of the hole. Took torque readings the liner running string to 2 1/2".
8 1/2"		05.09.1989 23:00	06.09.1989 00:00	1	0	ELWU	Rigged up logging equipment to run log no.6:
8 1/2"		06.09.1989 00:00	06.09.1989 05:30	5,5	3000	ELWU	Ran log no.6: SHDT. Hit a bridge at 3000 m stabilizer and reran the log. Were still unable t
~~8 1/2"~~	**COMPL_LINER**	**06.09.1989 05:30**	06.09.1989 06:00	0,5	0	CSSU	Made up the cement kelly.
~~8 1/2"~~	**COMPL_LINER**	06.09.1989 06:00	06.09.1989 06:30	0,5	0	CSSU	Made up the cement kelly.
~~8 1/2"~~	**COMPL_LINER**	06.09.1989 06:30	06.09.1989 19:00	13	2994	CARU	Rigged up and ran the 7" liner to 2994 m.
~~8 1/2"~~	**COMPL_LINER**	06.09.1989 19:00	06.09.1989 19:30	0,5	2999	CARU	Circulated and rotated the liner througha tight s equivalent to the 7" liner weight.
~~8 1/2"~~	**COMPL_LINER**	06.09.1989 19:30	06.09.1989 22:30	3	2999	TEOD	Circulated through the liner. Observed asudder
~~8 1/2"~~	**COMPL_LINER**	06.09.1989 22:30	06.09.1989 23:30	1	2999	TEOD	Dropped the liner setting ball. Circulated increase.

The history of Statoil DBR starts in the 80’s as a database writing the daily report sent to the authorities. (Norwegian Petroleum Directorate (NPD) at that time.

Norsk Hydro bought Saga Petroleum, and converted their data into the BORE database.

Norsk Hydro was bought by Statoil and a conversion was made from Bore to DBR. This example has been imported from Bore to DBR. As you can see the coding for running and setting the liner is coded as a part of the drilling 8 ½" section. This was the preferred way before Rushmore, however when starting to report to Rushmore this became the start of the completion section of making well.

5.3 Learning Curve Analyses

Have developed a spreadsheet for finding the Brett & Millheim DPC parameters from rig startup,. In detail this means finding the C_3, C_2 and the C_1 values.

The curve fitting and the estimation of C_1, C_2 and C_3 by Brett Millheim saw performed using a statistical software SAS with a least square method. In my code I use the same, however in excel and manually written code forcing the learning curve on the line, and not aside.

For future work it is recommended to take a step up using a more advanced software or code simulating/testing out different delays, C_1, C_3 and C_2 values. The excel method is very manual, many steps that must be QCed manually, and takes some assumptions that would easily be solved using a higher level software.

Trend Analysis, Curve fitting of C_2

Ahlmedi (2009,pp.)
Develop an Analysis Spreadsheet with functions for:
Sectionizing, taking out section data from every well, and organizing together
Cutting off in time (start stop)
Cut off in high or low values (Filtering out Extremes)
Normalizing data with regards to section length
Plotting each section
Plotting total Drilling
Total completion
Total downtime Non Productive Time (NPT)

Comparison of Brett Millheim C_2 values, and LCA 9.3 C_2 Values
How to evaluate different C_2 values, and compare with other sources? Like Brett Millheim?

Have performed an analysis based upon Brett Millheim days per well and normalized min/mtr with the following input parameters and results:

Table 5-1 Input parameters for comparison of Brett Millheim and LCA 9.3

Well No.	d	tot_days	tot_length
1	0,1	30	2500
2	0,1	25	2500
3	0,1	20	2500
4	0,1	15	2500
5	0,1	10	2500
6	0,1	7,5	2500
7	0,1	5	2500
8	0,1	5	2500

Used a 10% decrease on the estimate for the C3 value.

Table 5-2 Showing results from Comparison of Brett Millheim and LCA 9.3. Same C2 value, and C1 and C3 only differing by their units.

	[Days/Well]	[min/mtr]
C1	25,500	14,688
C2	0,347	0,347
C3	4,496	2,590

Conclude that the C_1 and C_3 values are different values, however with the correct units for each of the inputs.

However the C_2 value is the same. This is good new, because that means that the two C_2 values are comparable between the two, and compared to the already published work by i.e. Brett Millheim. Hence the results from this report regarding rate of learning and C_2 values can be directly compared to the other published work from the O & G industry.

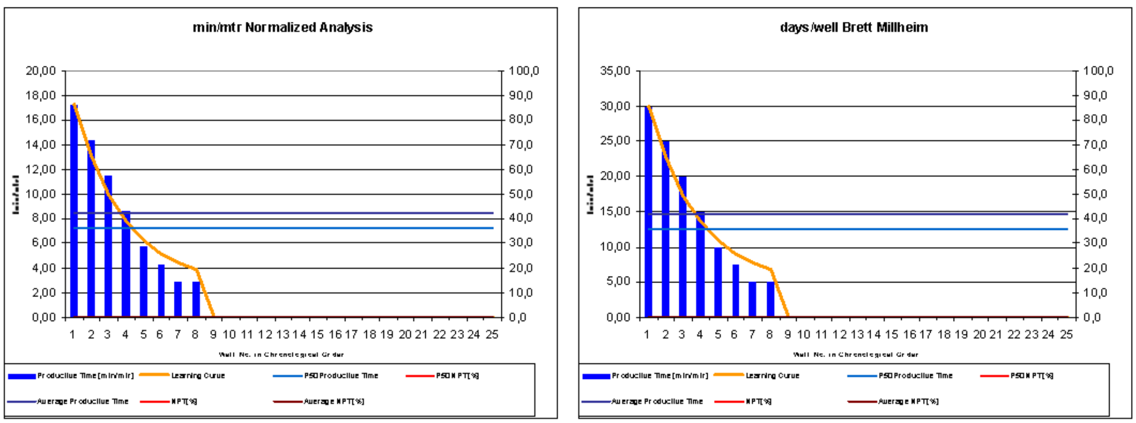

Figure 5-3 Showing the learning curves generated with Brett Millheim to the left, and LCA 9.3 to the right.different units on the tiem scale, however the same exponential curve.

Create and QC Learning Curve Analysis spreadsheet.

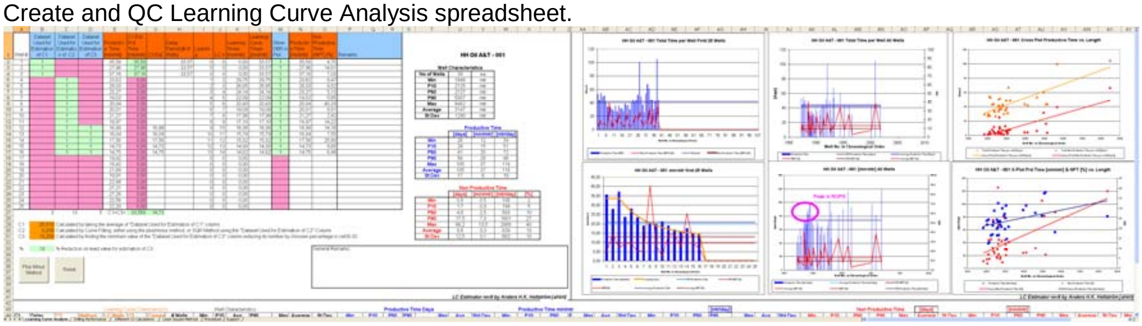

Figure 5-4 Showing the LCA analysis spreadsheet user interface, with analysis plots asssitng in the interpretation.

Curve fitting

The steps in curve fitting is illustrated by the plots below. In Figure 5-5 normalized minute per meter data is plotted in the blue columns. The red line is the downtime.

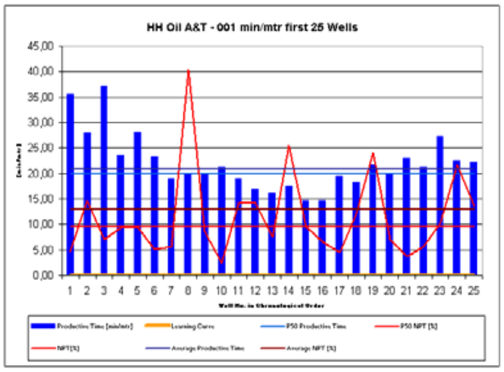

Figure 5-5 Plot showing normalized, sorted DBR data . For time in blue columns the unit min/mtr is used.

In the next step you select which wells should be used for calculating the average starting position. In the example below in Figure 5-6 the first three wells have been selected, and the learning curve start point has been plotted.

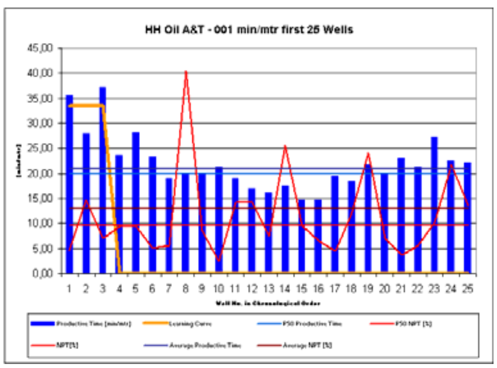

Figure 5-6 The learning curve is plotted in orange, here teh first three wells have been choosen for a start level.

In Figure 5-7 the last step has been performed by choosing to calculate the learning curve for wells number 4-17. The Spreadsheet then runs a macro, and tests many different values in order to settle for the value giving the best curve fitting based upon the Least Square Method.

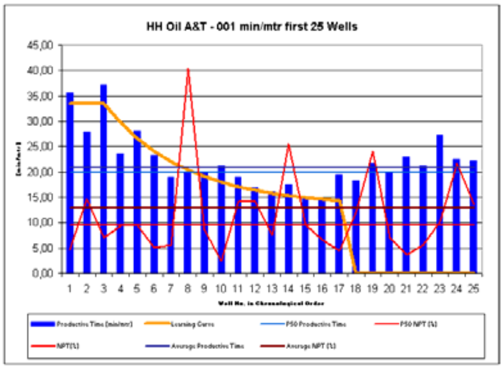

Figure 5-7 Have continued the learning curve by adding the DPC curve from well no. 4 and onwaards.

After having performed the curve fitting, you copy the key parameters from the LCA spreadsheet, and into a summary spreadsheet. In this sheet all key parameters for all rigs are gathered. This is also the place to look for overall learning.

Gathering of Key parameters for comparison

Copy key parameters into a rig summary spreadsheet. Comparing key parameters from all Platforms, semi Submersibles, Drill ships, Jackup's and Land rigs.

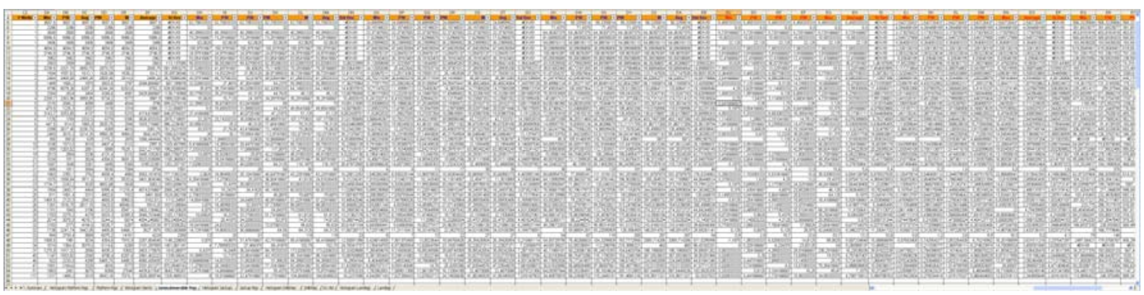

Figure 5-8 Summary spreadsheet where all key learning curve parameters are gathered.

The statistical data per is presented as in table and plots in figure 5-9 below.

Fixed Platform Drilling Rigs								
Statistical Parameter	C1	Delay	C2	LC Wells	C3	# Wells	C1+C3	Alfa
Unit	[min/mtr]	[ea]	[min/mtr]	[ea]	[min/mtr]	[ea]	[min/mtr]	[dim. less]
st dev.	7,7	1,1	0,14	4,8	3,2	13,2	9,3	1,0
Average	11,0	2,1	0,13	8,6	8,1	23,1	19,1	2,5
Median	8,3	2,0	0,12	8,0	7,5	19,0	17,1	2,5
Min	1,7	1,0	-0,19	3,0	3,9	1,0	7,3	1,3
P10	3,6	1,0	-0,03	4,0	4,2	9,6	10,6	1,4
P50	8,3	2,0	0,12	8,0	7,5	19,0	17,1	2,5
P90	20,3	4,0	0,30	14,0	12,1	39,8	33,6	3,9
Max	31,6	4,0	0,33	22,0	13,3	47,0	44,3	4,8

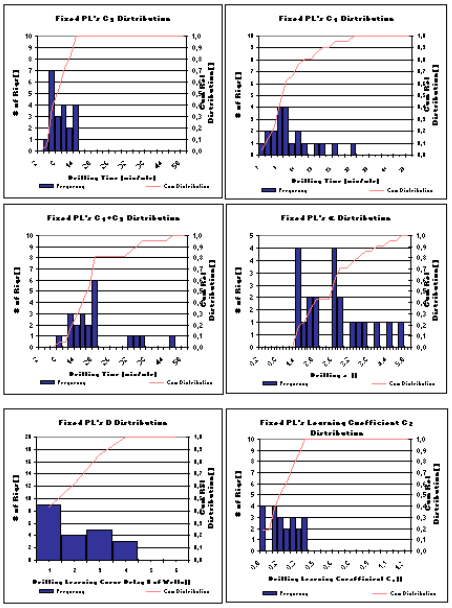

Figure 5-9 Histogram Example with summary of learning curve parameters on top. One sheet like this is prepared fo each type of drilling rig. (5ea) see Appendix A for reference.

All results per DPC parameter has been gathered and presented in tables like below in Figure 5-10. These are presented and commented in the chapter Results and Analysis.

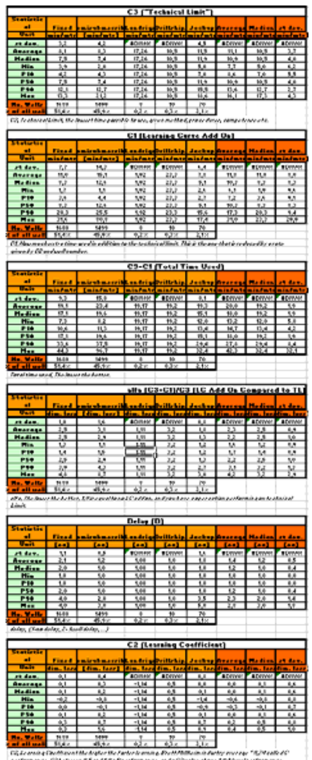

Figure 5-10 A summary table per learning curve parameter where it is easy to compare the different rig types, and evaluate how Statoil is doing compared between the rig types. Full tables are presented and commented in the Results and analysis chapter later on.

5.4 Data Extraction and Analysis Summary Table

Summary of data extracted and analyzed. As well as the number of annual data steps. In short a number of 3267 wells have passed the QC process and have been evaluated for learning curves. Split onto 97 rigs.

A total of 5500 manual computer steps have been performed to overcome the data amount. This is time-consuming, and potential for errors is considerable.

Drilling Facility Category	DBR Extraction [Rigs]	Sorting Wells per rig [Wells]	Import data to LCA Spreadsheet [rigs]	Perform LCA Analysis [rigs]	Import LCA Key Parameters into summary sheet [rigs]	Perform Statistical Comparison [1 per Drilling Facility Category]
Fixed Platform Driling rigs	25	1680	25	25	25	1
Semi Submersible Drilling rigs	48	1499	48	48	48	1
Drill Ships	5	10	5	5	5	1
Jackup Drilling rigs	14	70	14	14	14	1
Landrigs	5	8	5	5	5	1
Summ Steps	97	3267	97	97	97	5
Steps	3660					
Add On, 50% due to bug fixing, fine tuning procedures etc.	1830					
Grand Total Steps	5490	DBR extract, DBR Filtered, LCA,				

Figure 5-11 Summarizing the number of data steps that have been processed manually during this thesis.

6 Results and Discussion

Results from the Overall Analysis, and In Depth Analysis are presented below. First for each parameter in the learning curve model and then main findings are commented in more general terms
For learning curve model reference see Figure 3-3.

6.1 New drilling facilities

All wells registered in DBR have been evaluated, and based on that dataset, and the extraction, filtering and analysis procedure described earlier in the report the following results have evolved, sorted per defined Learning Curve parameter. The full data summary set, with histograms are found in appendix A.

Table 6-1 Learning curve parameter C_3 - "Technical Limit"

C3 ("Technical Limit")								
Statistical Parameter	Fixed	Semisubmersible	Landrigs	Drillships	Jackup	Average	Median	st dev.
Unit	[min/mtr]	[min/mtr]	[min/mtr]	[min/mtr]	[min/mtr]	[min/mtr]	[min/mtr]	[min/mtr]
st dev.	3,2	4,2	#DIV/0!	#DIV/0!	4,5	#DIV/0!	#DIV/0!	#DIV/0!
Average	8,1	8,3	17,26	10,5	11,5	11,1	10,5	3,7
Median	7,5	7,4	17,26	10,5	11,9	10,9	10,5	4,0
Min	3,9	2,0	17,26	10,5	5,0	7,7	5,0	6,2
P10	4,2	4,3	17,26	10,5	7,0	8,6	7,0	5,5
P50	7,5	7,4	17,26	10,5	11,9	10,9	10,5	4,0
P90	12,1	12,7	17,26	10,5	15,5	13,6	12,7	2,7
Max	13,3	21,2	17,26	10,5	18,6	16,1	17,3	4,3
No. Wells	1680	1499	8	10	70			
% of all wells	51,4 %	45,9 %	0,2 %	0,3 %	2,1 %			
C3, Technical Limit, the lowest time possible to use, given method, procedures, competence etc.								

Table: Operational performance for C3 based on datasets of various types rigs

(Technical limit is defined in APOS as: The technical limit is the best possible time required for each individual operation based on actual experience.

The lowest values are found for the fixed drilling rigs, with a average of 8.1 and a median of 7.5 min/mtr, and a standard deviation of 3.2. The maximum value is 21.2 for the semisubmersible rig type.
The largest standard deviation is found for Jackups with 4.5, then followed by semisubmersibles with 4.2, and fixed with 3.2. Land rigs have in the range of double the average of the second longest type average. Indicating there is something very different with the land wells registered in DBR compared to the wells drilled with other rig types.

Very limited drillship data, which means that the there is insufficient data for land and drillship operations. In the comments to the results it will be focus on the three main rig types used in the historical data. Hence Fixed, Jackup and Semi Submersible rigs.

The max values of semisubmersibles are also in the order of two times larger then for the wells drilled by other rig types. Which means the downside is large, if the well has a lot of time-consuming.

Table 6-2 Learning curve parameter C_1 - Learning Curve Add On

C1 (Learning Curve Add On)								
Statistical Parameter	Fixed	Semisubmersible	Landrigs	Drillships	Jackup	Average	Median	st dev.
Unit	[min/mtr]	[min/mtr]	[min/mtr]	[min/mtr]	[min/mtr]	[min/mtr]	[min/mtr]	[min/mtr]
st dev.	7,7	14,3	#DIV/0!	#DIV/0!	6,4	#DIV/0!	#DIV/0!	#DIV/0!
Average	11,0	15,1	1,92	23,3	7,8	11,8	11,0	8,0
Median	8,3	12,6	1,92	23,3	5,1	10,3	8,3	8,3
Min	1,7	1,1	1,92	23,3	2,6	6,1	1,9	9,6
P10	3,6	4,4	1,92	23,3	2,7	7,2	3,6	9,1
P50	8,3	12,6	1,92	23,3	5,1	10,3	8,3	8,3
P90	20,3	25,5	1,92	23,3	15,6	17,3	20,3	9,4
Max	31,6	80,8	1,92	23,3	17,4	31,0	23,3	29,9
No. Wells	1680	1499	8	10	70			
% of all wells	51,4 %	45,9 %	0,2 %	0,3 %	2,1 %			
C1, How much extra time used in addition to the technical limit. This is the one that is reduced by a rate given by C2 and well number.								

The C1 learning add on has the lowest average for the jackups.

Drill ships have a median higher then the average, whilst the other rig types have a lower median than average indicating an opposite skewness of the distribution. It is hard to see logical explanation to explain or support this behavior, other than random effects related to the very limited dataset for drill ships.

Table 6-3 Learning curve parameters C_3 + C_1 = Total Time Used

C3+C1 (Total Time Used)								
Statistical Parameter	Fixed	Semisubmersible	Landrigs	Drillships	Jackup	Average	Median	st dev.
Unit	[min/mtr]	[min/mtr]	[min/mtr]	[min/mtr]	[min/mtr]	[min/mtr]	[min/mtr]	[min/mtr]
st dev.	9,3	15,8	#DIV/0!	#DIV/0!	8,1	#DIV/0!	#DIV/0!	#DIV/0!
Average	19,1	23,4	19,17	19,2	19,3	20,0	19,2	1,9
Median	17,1	19,6	19,17	19,2	15,1	18,0	19,2	1,9
Min	7,3	8,2	19,17	19,2	12,0	13,2	12,0	5,8
P10	10,6	11,3	19,17	19,2	13,4	14,7	13,4	4,2
P50	17,1	19,6	19,17	19,2	15,1	18,0	19,2	1,9
P90	33,6	37,5	19,17	19,2	29,4	27,8	29,4	8,4
Max	44,3	96,7	19,17	19,2	32,4	42,3	32,4	32,1
No. Wells	1680	1499	8	10	70			
% of all wells	51,4 %	45,9 %	0,2 %	0,3 %	2,1 %			
Total time used, The lower the better.								

All medians are below the average supporting a skewed distribution where you do not have very short values, however some very long ones. Which means that you will need to this behavior is identical to the theory used in the estimation model DWE uses.

The total time maximum values are comparable for fixed platforms and jackups, and almost half the equivalent timing for land rigs and drill ships. The lowest maximum value is for jackups, indicating a lower number of wells in the dataset and indicating that the longest total times not has happened yet. However for the semisubmersible has an average of 23.4 and a standard deviation of 15.8.

Standard deviation of ~20 in relation to C_1 plus C_3 is less per unit than C_1 and C_3 separately. Hence this could be helpful in reducing the spread and quality control the assumptions during estimation of learning.

Table 6-4 Learning curve parameter Alfa (C2+C1) / C3 - Learning Curve Add On compared to Technical limit time

alfa (C3+C1)/C3 (LC Add On Compared to TL)								
Statistical Parameter	Fixed	Semisubmersible	Landrigs	Drillships	Jackup	Average	Median	st dev.
Unit	[dim. less]	[dim. less]	[dim. less]	[dim. less]	[dim. less]	[dim. less]	[dim. less]	[dim. less]
st dev.	1,0	1,6	#DIV/0!	#DIV/0!	0,8	#DIV/0!	#DIV/0!	#DIV/0!
Average	2,5	3,1	1,11	3,2	1,8	2,3	2,5	0,9
Median	2,5	2,9	1,11	3,2	1,3	2,2	2,5	1,0
Min	1,3	1,1	1,11	3,2	1,2	1,6	1,2	0,9
P10	1,4	1,5	1,11	3,2	1,2	1,7	1,4	0,9
P50	2,5	2,9	1,11	3,2	1,3	2,2	2,5	1,0
P90	3,9	4,3	1,11	3,2	2,7	3,1	3,2	1,3
Max	4,8	8,7	1,11	3,2	3,0	4,2	3,2	2,9
No. Wells	1680	1499	8	10	70			
% of all wells	51,4 %	45,9 %	0,2 %	0,3 %	2,1 %			

alfa, The lower towards 1.0 the better. Alfa = 1.0 is equal to no LC add on, and you have a operation performing on technical Limit.

The mimimum alfa is found for jackups with a factor 1.8.

Also the median for fixed are equal to the average, and the standard deviation is 1,0, which is very good compared to the other rig types

Table 6-5 Learning delay - Number of wells delay, D=2 means 1 well delay. 3 gives 2 wells delay.

Delay (D)								
Statistical Parameter	Fixed	Semisubmersible	Landrigs	Drillships	Jackup	Average	Median	st dev.
Unit	[ea]	[ea]	[ea]	[ea]	[ea]	[ea]	[ea]	[ea]
st dev.	1,1	0,5	#DIV/0!	#DIV/0!	1,6	#DIV/0!	#DIV/0!	#DIV/0!
Average	2,1	1,2	1,00	1,0	1,8	1,4	1,2	0,5
Median	2,0	1,0	1,00	1,0	1,0	1,2	1,0	0,4
Min	1,0	1,0	1,00	1,0	1,0	1,0	1,0	0,0
P10	1,0	1,0	1,00	1,0	1,0	1,0	1,0	0,0
P50	2,0	1,0	1,00	1,0	1,0	1,2	1,0	0,4
P90	4,0	2,0	1,00	1,0	3,5	2,3	2,0	1,4
Max	4,0	3,0	1,00	1,0	5,0	2,8	3,0	1,8
No. Wells	1680	1499	8	10	70			
% of all wells	51,4 %	45,9 %	0,2 %	0,3 %	2,1 %			

delay, (1=no delay, 2= 1well delay, ...)

No or little delay is supported by the datasets except for the fixed rigs, where 1 well delay is suggested. The maximum seen for a semi is 4 and for a jack up is 5 – slow learning.

Table 6-6 Learning curve parameter Learning Coefficient C_2

C2 (Learning Coefficient)								
Statistical Parameter	Fixed	Semisubmersible	Landrigs	Drillships	Jackup	Average	Median	st dev.
Unit	[dim. less]	[dim. less]	[dim. less]	[dim. less]	[dim. less]	[dim. less]	[dim. less]	[dim. less]
st dev.	0,1	0,4	#DIV/0!	#DIV/0!	0,8	#DIV/0!	#DIV/0!	#DIV/0!
Average	0,1	0,3	-1,14	0,5	0,0	0,0	0,1	0,6
Median	0,1	0,2	-1,14	0,5	0,1	0,0	0,1	0,6
Min	-0,2	-0,8	-1,14	0,5	-1,4	-0,6	-0,8	0,8
P10	0,0	-0,1	-1,14	0,5	-0,9	-0,3	-0,1	0,7
P50	0,1	0,2	-1,14	0,5	0,1	0,0	0,1	0,6
P90	0,3	0,7	-1,14	0,5	0,7	0,2	0,5	0,8
Max	0,3	1,6	-1,14	0,5	0,9	0,4	0,5	1,0
No. Wells	1680	1499	8	10	70			
% of all wells	51,4 %	45,9 %	0,2 %	0,3 %	2,1 %			
C2, Learning Coefficient the higher the faster learning. Brett Millheim industry average ~ 0.34 called C performance, C2 between 0.5 and 1.0 a B performance, and a C2 value above 1.0 A level performance								

The highest learning coefficient seen in this study is 1.6, and the lowest is -1,14
2,7 is categorized as a class A. The average and the median values of the learning coefficient are all below 0,5 in the Statoil datasets except for drill ships. However both land rigs and jackups come out with negative learning coefficients.

In general

Jackup rigs represents 2.1% of the data, and Jackups have the best average alfa value in the order of 1.8, as well as the lowest standard deviation with 0.8 This is an indication that there is a lot of good effort put into KEPP (Knowledge Experience Planning and Preparation) that actually show in the dataset.

This indicates probably good planning and preparation, using the earlier learning and experience and being able to implement this on fixed installations, which is important. However since a large proportion of the wells drilled in Statoil are subsea wells, drilled by semisubmersibles, there is a large upside in addressing increased learning. Both regards to the higher rig rates, and also to earlier production with faster and more predictable operations.

Brett Millheim states: “The value of alfa will vary with the difficulty of the area to drill, and with how prepared a drilling organization is to drilling the area.” In Statoil this is also described by the Well Complexity Index (WCI), where again the planning and preparations factor (KEPP - Knowledge Experience Planning and Preparation) is important for the execution of same.
However the learning process in which you would like to become even better is still in the lowest category suggested by Brett Millheim – slow learning.

There are also several examples, where there is negative learning, and the time usage increase normalized for length. This is of course negative, and the lost value of this project performance is large.

The highest added value for increased learning efforts should be put into increasing KEPP for semi submersible operations. 45,9% of the dataset is wells drilled with semisubmersibles, and the rig rates for these are among the highest. So here is a large amount of money potentially to be saved, as well as an increased utilization of resources, and increase in efficiency.
The dataset is inconclusive for the rigs with only one or two wells.(Drillship and Land rig)

6.2 In Depth Analysis

Results from the in depth analysis are presented below. The example shown is drilled with an old semisubmersible drilling rig. Used on a relatively new campaign that lasted for 14 wells. It is very interesting to see that it is possible to see a that clear learning operation. Hence it is possible to learn, even with an old rig. In the

Below in Figure 12 Plot showing an old semisubmersible drilling rigs performance over wells in chronological order.

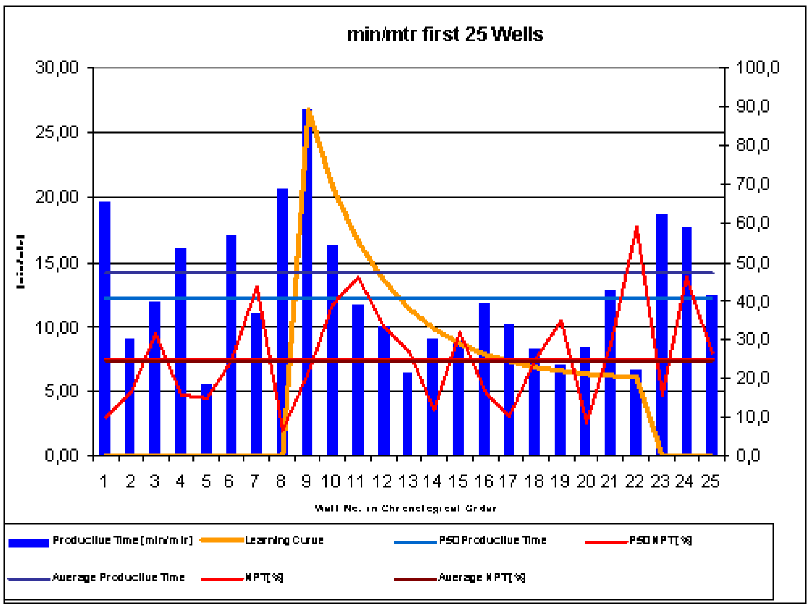

Figure 12 Plot showing an old semisubmersible drilling rigs performance over wells in chronological order.

6.3 The Learning Curve Forgetting Factor

The learning curve forgetting can be measured only when you are going into operation another time after have in had demobilization, and remobilize after a longer while. Parts of organization and equipment have been changes out, and it will not be obvious that everything will beast before. Theoretically It would be tempting to continue the learning curve where you let go, however in practice available data show differently. One example on this is presented below. The data does not come from the DBR database, but have been made available from one of Statoil interesting parties…

Example: Land based Heavy Oil Field Drilling

In the below plot the initial production drilling is illustrated in a blue line as the weighted average line. The drilling operation was shut down in the end of the blue line, and a period of waiting was initiated. After a pause of about 2-3 years the drilling was resumed, and the total drilling time per well is illustrated with the red line in the plot. The wells are ordered in chronological order from first well and onwards.

Technical data of the actual field

Below is presented the results from the drilling of two phases in the same heavy oilfield, with:

- Same well design in Phase 1 and 2
- One drilling rig used through phase, however different between Phase 1 and 2
- Land based, Heavy oil field development
- phase 1 over 200 wells plotted with a blue line
- phase 2 over 40 wells plotted with a red line
- 2-3 years between phase 1 and 2.
- New rig and new crew both on the rig and in the planning and running of the operation.

Typical Well Data:

Types of artificial lift PCP / ESP
Average field water cut 35 %
Average field GOR 250 scf/stb
Average well / field 650 bpd / 190 TBPD production
Completion types Slotted liner
Average PCP 75 ° inclination
Number of producers 321 horizontal wells
Oil viscosity (@ resv 2000 – 2500 cp conditions)
API gravity 8.5
Reservoir permeability 15 – 20 darcy
Reservoir porosity 30%
Heavy oil since Dec 2000
Production

Initial Campaign (Blue line in plot)

As one can see, the initial campaign started at levels of about 14 days of drilling per well, for then declining rapidly down to about 8-9 days/well in about 20 wells. From this point onwards the decline slows down until a final level of around 5,2 days per well is reached after about 180 wells.

New Campaign (Red Line in Plot)

The new campaigns started off with a brand new land rig, and new organization, the first wells coming in at about 18 days /well which is 3 days (20%) over the first well drilled initially over 220 wells ago! You should think that you were able and bring on the learning from the past operation; however the history tells the opposite. New rig new operation resulted in a significant increase, compared with the initial period.

However the rate of learning is comparable between the two, an after about 40 wells you are down to a level of about 9,5 days per well.

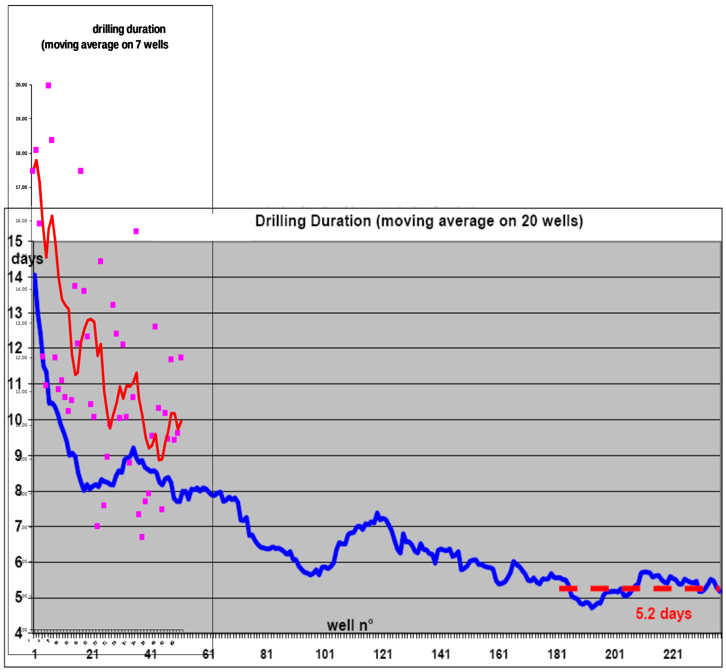

Figure 6-2 Plot showing the time per well in the first and the secon drilling campaing overlapping eachother. Blue line is first campaign, and red line is second campaign.

Startup after major upgrade

No candidate wells that passed the QC etc. in this thesis. Have suggested tools included in DWE for easily being able to check for this kind of performance.

20 fixed installations with their own drilling facility, have performed a upgrade of a duration of 3months or more.

Rig upgrades with a duration of at least 3months. The year after the installation name is the year the rig was taken into operation.

Platform Rig #	First in Operation	Upgrade finished
1	1978	2007
2	1982	2010
3	1985	2008
4	1986	2000
5	1987	2000
6	1988	2001
7	1988	-
8	1989	-
9	1993	-
10	1993	-
11	1993	-
12	1991	-
13	1995	2008 + 2009
14	1997	-
15	1999	2008
16	1999	2006
17	2000	2009
18	2001	-
19	2003	2008
20	2003	-

Table 6-7 List of Platforms with drilling rig that have done upgrade of the drilling facilities of a duration of at least 3 months.

The New Super rigs

Indications from partly drilled first wells are total time values in the range of … however since this is the first, and there has been considerable amounts of downtime. This should only be used as a first preliminary indication that statistically can be a “one off “event.

The percentage distribution of what rig type drilled the wells in historical data does only tell about the history. There is a change going on towards more and more side tracks, longer wells towards extended targets etc. It is also a trend towards more international activities, both as a partner, and more important for this thesis, as an operator. The internationalization includes heavy oil (bitumen), Ultra Deep Water, and shallow land based drilling after shale gas, in example on the Marcellus field in north east USA.

7 Discussion Boundaries and Challenges

1) Find out what the industry Standard in Learning Curves is for Drilling and Well Learning curves. The standard is Brett Millheim

2) Use this method and develop a spreadsheet package that makes it possible to analyze all DBR data for learning, and within the timeframe of this thesis. OK this is done

3) Go through all data registered in DBR and analyze for learning from the startup of a new rig and onwards. Do this for all rig types and present the overall results, and comment on results. Try and conclude with whether Statoil is a fast learning organization, or at what level, based upon the results in this thesis. Done
4) Go in depth and try to find out if it is applicable with learning curves when using an old semisubmersible rig when drilling a new series of wells? Is there any data that would exemplify this in the DBR database? Done

5) Propose a new learning curve definition for APOS, type of learning curve, average parameter values, and a simple spreadsheet to assist in the estimation process for startup of a new rig. Done

Did not deliver completion analysis, however the method developed through this thesis can be used for that as well.

Discovered holes in the dataset, discovered inconsistent data, discovered misleading data in the DBR database. Mostly in historical data, and some systematic, as well. Have described one type of systematic error. Have described accurate action points in order to achieve the goal 100%, however have not had the necessary time and resources to fulfill the whole scope. The main reason for this is the lack of consistency in the dataset, and the manual QC process in order to see if a well can be included or not in the analysis.
There have been analyzed 97 different drilling operations and a total of 3267wells that passed the QC process, and that are included in the analysis. Why has it been chosen to remove some and include some things, wells, operations, type of operations? Have chosen not to include contracted rigs after upgrade.
Drilling and Completion main focus, Well operations was initially included however prioritized away. Except for some general conclusions regarding a Class B Vessel with regards to learning curves.

Have found that there is potential to improve efficiency and to reduce time spent per well. There are differences in the learning curve parameters between the different rig types. These have been compared for, and are the answer to the scope step I.

Have performed an in depth analysis for learning both the very common scenario when renting in an old semisubmersible drilling rig.. This is very interesting, and the rig day rates for semi submersibles are considerably larger than for rigs on fixed platforms. This is the most cost driving rig type in the study. Very interesting to discover that it is possible to get a learning curve, and that the initial well on a new subsea field development comes in high, however the learning is good.

The status meetings set in the beginning of the thesis have been actively used.

What are the challenges identified
My background is very limited in the parts of the thesis that have taken the most time.
Some of the parts that have taken very much of the time available is:

1) Experienced along the analysis that there is some examples of operations where the beginning of the wells have been predrilled in a batch. In order to sort in a better way the sorting has to be done by end date. This was of course discovered after having been through the complete analysis. And had to redo. There are several examples of situations like this. Also where excel programming is possible to resolve needs, however the time needed to solve the nice to have, and potentially hour saving improved efficiency and QC. Has to be turned down because of limited time available. And the thesis overall progress have to be prioritized before the optimum overall solution for Statoil. Examples, Macro button for copying the whole summary line maintaining focus on the analysis document.
2) Link comment summary cell to the general remarks area further up.
3) Macro button to sort on start date and at the same time change the time scale in the time plots to the start date data set.
4) Macro button to sort on end date. With the same functionality as above.
5) Add on several more analysis parts further down on the analyses page in order to handle multi analysis parts. In example initial learning, step change and startup after major upgrade. As well as several campaigns with an already start up rig.
6) Hence you have to be able and choose what points in the dataset you would like to use for what part of the analysis.

Areas to be taken further into consideration/ Limited and Poor Data Quality
DBR QC of historical data (Especially they imported from Saga and Hydro.
Completion that pilot study indicates stands for at least 1/3rd of the hours spent. In that case also 1/3rd on Temporary P&A.

In a more detailed level in order to understand more of the underlying causes, and be able to improve decisions and choices for improving the efficiency. What are Statoil organization good at, and where is the holes that can be improved further? Historical development of performance would be very interesting to see.

Economical impact of learning After Major Rig Upgrades

2 years of drilling wells with 45days duration => 9wells/year * 2years = 18wells in an offshore environment

Completion 30-50% of rig time used per well.

Well operations representing apprx. 50% of the value creation per year in Norway within drilling and well Statoil. These Would be interesting to go more in detail on.

Completion represents between 1/3 and ½ of the well construction cost yearly.

After Major Upgrade
After a major upgrade where major modifications and upgrade was implemented, resulting in significantly reduced performance. However LC Analysis will not be possible at this point in Time.

The macro perspective of the DBR data have not been in the primary scope of this thesis, however it is hereby noted that it would be interesting to see if there is a correlation between the DBR data, the LCA method described, however scaled up to a macro perspective including all wells in DBR.

7.1 How to manage your Learning Curve?

This chapter was not defined as the core of this thesis, however it is believed that this is the core of the purpose of focusing on learning curves. This is where you would like to be. The “Tools for managing your Learning Curve”. Monitoring, continuously trying to understand more of the driving forces to the learning curve, and using this to manage your way ahead.

The engineering role has changed during the history of oil well drilling in Norway. Detail level, logistics focus and time consumption relative to engineering time. Service company responsibility.

What can you do to influence the learning curve? Does it give meaning to monitor and try to stare from a learning curve?
Can you see, or would you like to see potential negative Influence?
The Root Causes & the Cure / Potential Step Changes / Historical Step Changes
Governmental, Regulatory, HSE, Atomization, Oil prize etc. HSE drivers setting stronger regulations into the use of manual operation n the drill floor.
Efficiency DRIVERS
Competence & Continuous Knowledge Development /Improvement
Statoil, Saga, Hydro come from different set of cultures that have developed somewhat different types of fields, and portfolios. As well as the ownership structure. Statoil starting off as 100% owned by the state, today partly private owned.

Incentives Contracts Format Incentives
Framework conditions, Give the individuals that can influence the time and cost usage in both small and large level as powerful tools as possible in order to see the results from the actions they take. I.e. Method selection, contractor follow-up, and contingencies. Automatic comparison between DWE time estimate and actual DBR reported performance. Automatic LCA analysis built into DWE or other.

7.2 One rig doing all, or specialized rigs

For drilling and specialized rigs for completion vs. one rig doing both drilling and one rig completion?
Is it beneficial to use one rig for one type of operation, and another for a different type of operations?
In example, one for drilling, one for completion, and one for well intervention.

With regards to learning quickly it is thought to be favorable with one rig specializing in each of the disciplines.

Where do you start and towards what technical limit do you work towards?
With a rig specializing in one discipline, and a supporting organization around it, it is believed that the first well will start off at a lower(better) shorter than if the rig is doing all kinds of operations.

8 Conclusion and Recommendation

Conclusion

Current model is not always precise compared to the Statoil historical performance data in DBR. A more precise modeling is suggested to be:
The existing Learning Curve model in APOS is not sufficiently precise and relative for Statoil operations today and in the future.

Developing a new field: DWE used as is to give an estimate of C3,

Need to differentiate.
Have developed criteria's for when and what parameters to use.

1) DBR Data QC History, Futer looks OK. Lengths and times. Coding according to Rushmore.
2) Make LCA analysis available for the drilling, completion and well engineers. Where the influencing drivers can be identified and influenced.
3) Perform Learning Curve Analysis for Completion and Well Operations.

Recommendation

Change the Learning Curve to be the same in Statoil as the industry standard , Brett Millheim, Drilling Performance Curve (DPC). Use DPC when starting up new drilling rigs and measure with learning curve add ons,, based upon this thesis. APOS input assistant spreadsheet. Implement the new set of LC parameters into APOS?

Suggest to build in LCA part in DWE in order to include learning curves in the estimation process according to the below table.

Study the long term, tail improvements, in more detail, and do the same there. Develop more precise criteria's, and try at find root causes for continuous learning and follow up. Try and develop practical tools for the typical learning drilling completion and well operations organization. Ex. Balanced Drillers score card? Implement estimation of C-1 and C-3 values in DWE. And give a suggestion for C2 that will also be depending on the CEP put into the operation and type of operation etc.

Future Work

It is started preparations for a new thesis covering the long term PMM improvements, and all the aspects related to small improvements over time. Suggest tying LCA analysis spreadsheet directly without copying and pasting to the LCA analysis spreadsheets. This will improve the QC, and simplify the QC process. A lot of hours will be saved for future work. Continue Aadnøys detail approach and see how the production drilling developed. Develop a more objective and better analysis tool using a statistical software or SAS as Brett Millheim did.

1) Use the Experience in your organization to implement Step Changes (Courageous)
2) Focus on implementation and verification (and use Risk Management to assist)
3) Remember "The value of good people is high; the value of good people pulling together is higher" (Open)
4) Make the Learning Curve visible to the day to day people making the method selections etc that highly influence the learning curve.(Hands-on)
(5) Remember, "No Heroes, No Glory" – Make a Step Change and Manage Your Learning Curve Today ! ☺

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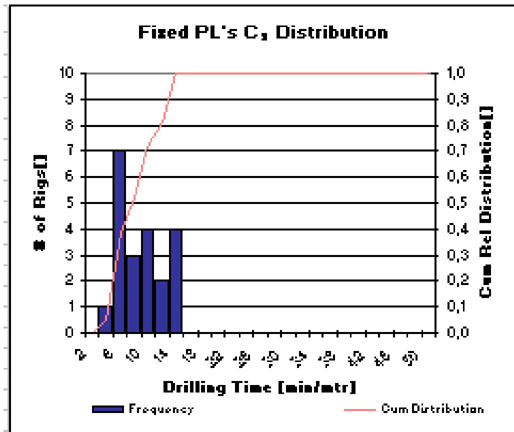
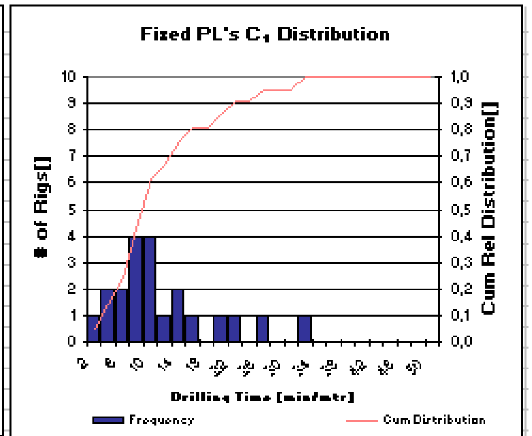
Appendix A (Results Step I)

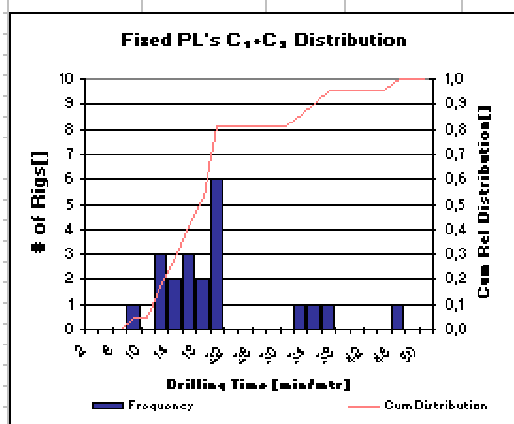
“Results from Learning Curve Analysis Step I are presented in the following Appendix A”

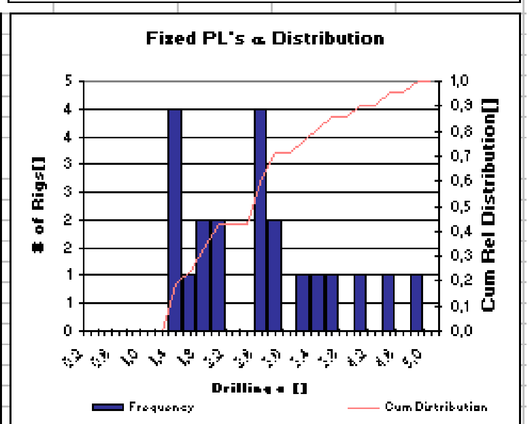
Fixed Rigs

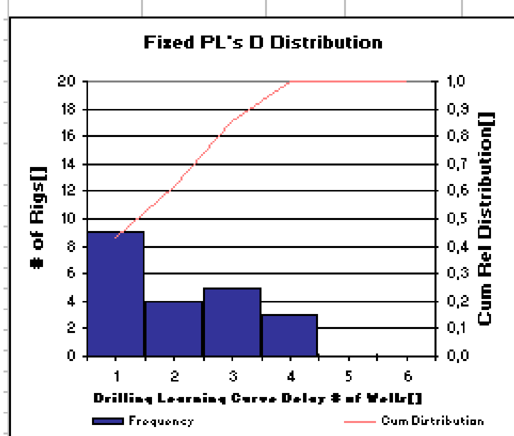
Fixed Platform Drilling Rigs								
Statistical Parameter	C1	Delay	C2	LC Wells	C3	# Wells	C1+C3	Alfa
Unit	[min/mtr]	[ea]	[min/mtr]	[ea]	[min/mtr]	[ea]	[min/mtr]	[dim. less]
st dev.	7,7	1,1	0,14	4,8	3,2	13,2	9,3	1,0
Average	11,0	2,1	0,13	8,6	8,1	23,1	19,1	2,5
Median	8,3	2,0	0,12	8,0	7,5	19,0	17,1	2,5
Min	1,7	1,0	-0,19	3,0	3,9	1,0	7,3	1,3
P10	3,6	1,0	-0,03	4,0	4,2	9,6	10,6	1,4
P50	8,3	2,0	0,12	8,0	7,5	19,0	17,1	2,5
P90	20,3	4,0	0,30	14,0	12,1	39,8	33,6	3,9
Max	31,6	4,0	0,33	22,0	13,3	47,0	44,3	4,8

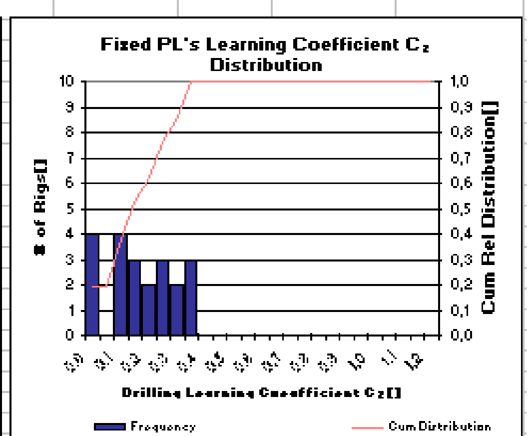






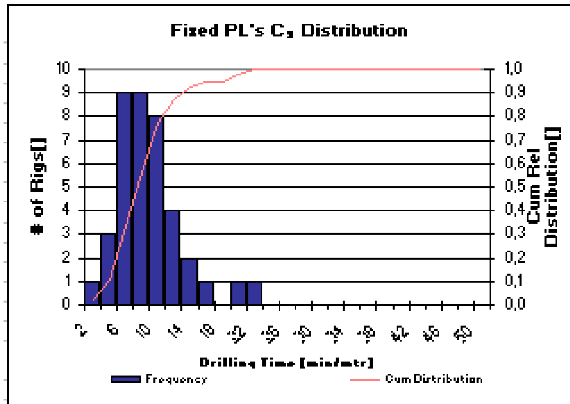


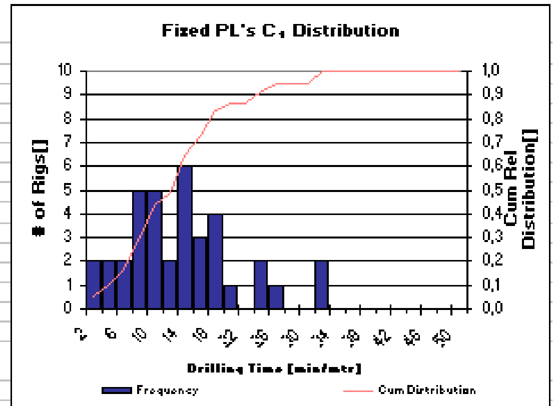


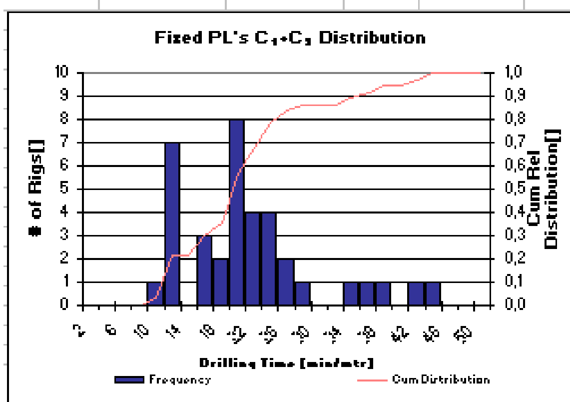


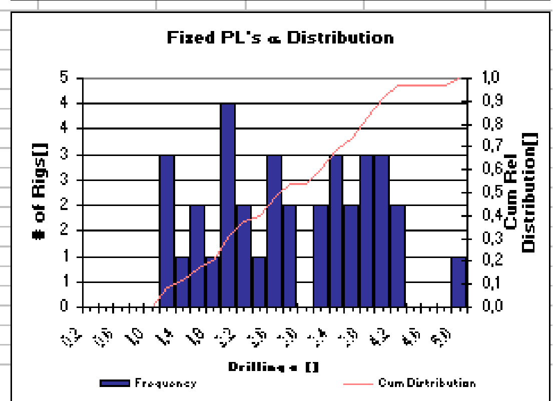
Semi Submersibles

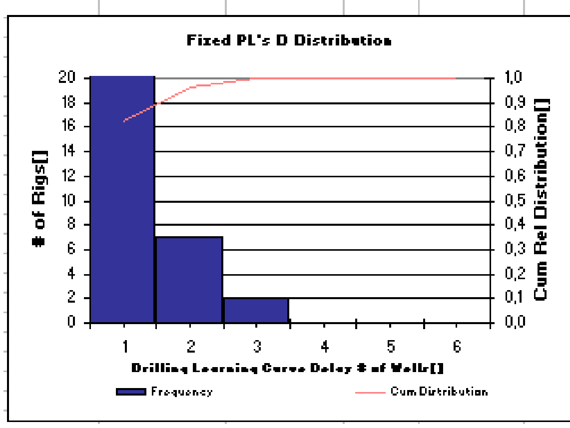
Semi submersible Drilling Rigs								
Statistical Parameter	C1	Delay	C2	LC Wells	C3	# Wells	C1+C3	Alfa
Unit	[min/mtr]	[ea]	[min/mtr]	[ea]	[min/mtr]	[ea]	[min/mtr]	[dim. less]
st dev.	14,3	0,5	0,44	6,1	4,2	20,3	15,8	1,6
Average	15,1	1,2	0,27	7,4	8,3	18,6	23,4	3,1
Median	12,6	1,0	0,24	5,0	7,4	17,0	19,6	2,9
Min	1,1	1,0	-0,83	2,0	2,0	1,0	8,2	1,1
P10	4,4	1,0	-0,10	2,0	4,3	1,0	11,3	1,5
P50	12,6	1,0	0,24	5,0	7,4	17,0	19,6	2,9
P90	25,5	2,0	0,70	17,6	12,7	37,0	37,5	4,3
Max	80,8	3,0	1,59	24,0	21,2	117,0	96,7	8,7

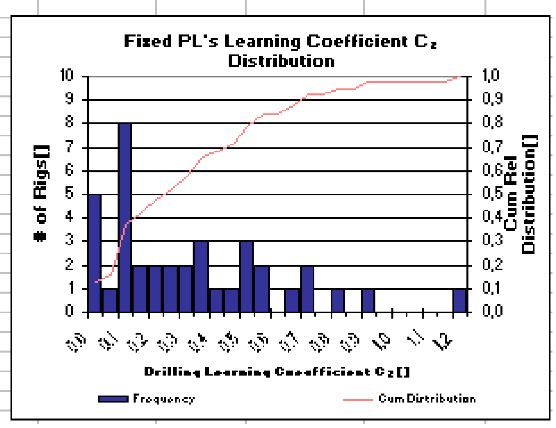






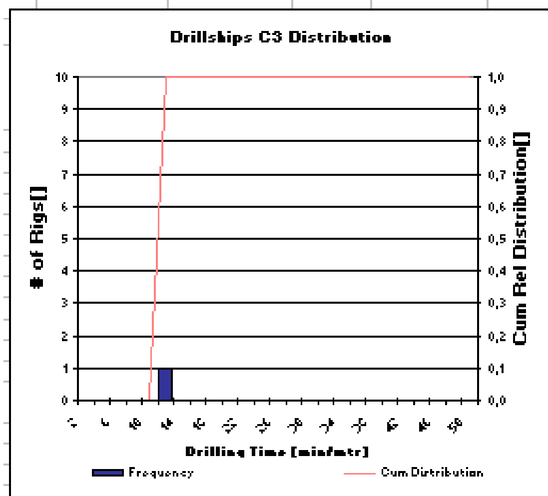


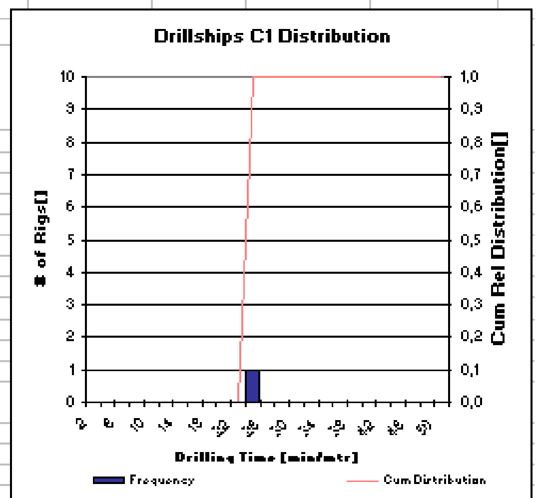


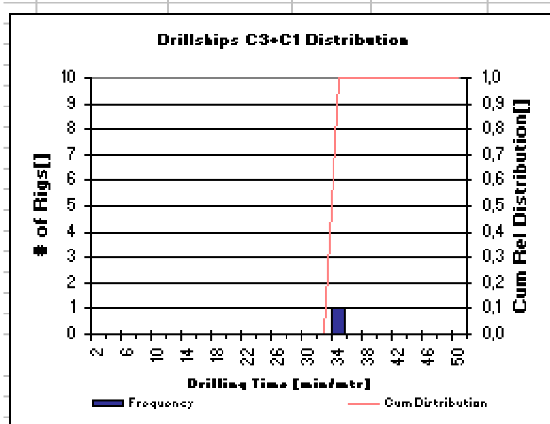


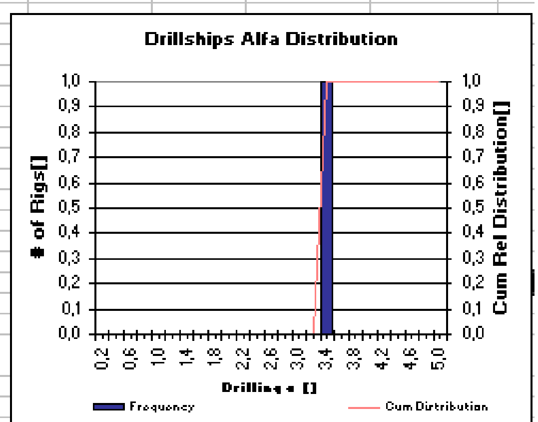
Drill Ships

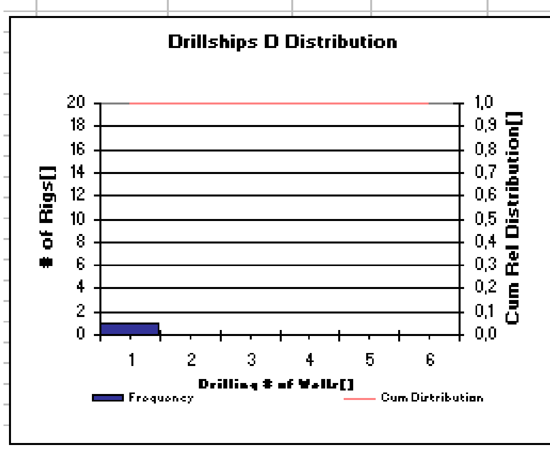
Drillships								
Statistical Parameter	C1	Delay	C2	LC Wells	C3	# Wells	C1+C3	Alfa
Unit	[min/mtr]	[ea]	[min/mtr]	[ea]	[min/mtr]	[ea]	[min/mtr]	[dim. less]
st dev.	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	1,5	#DIV/0!	#DIV/0!
Average	23,3	1,0	0,54	3,0	10,5	2,7	33,8	3,2
Median	23,3	1,0	0,54	3,0	10,5	3,0	33,8	3,2
Min	23,3	1,0	0,54	3,0	10,5	1,0	33,8	3,2
P10	23,3	1,0	0,54	3,0	10,5	1,4	33,8	3,2
P50	23,3	1,0	0,54	3,0	10,5	3,0	33,8	3,2
P90	23,3	1,0	0,54	3,0	10,5	3,8	33,8	3,2
Max	23,3	1,0	0,54	3,0	10,5	4,0	33,8	3,2

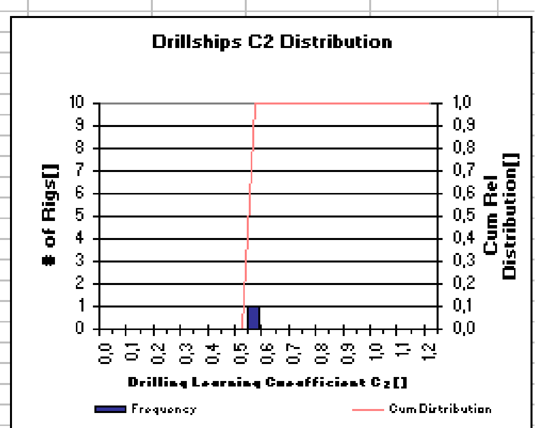






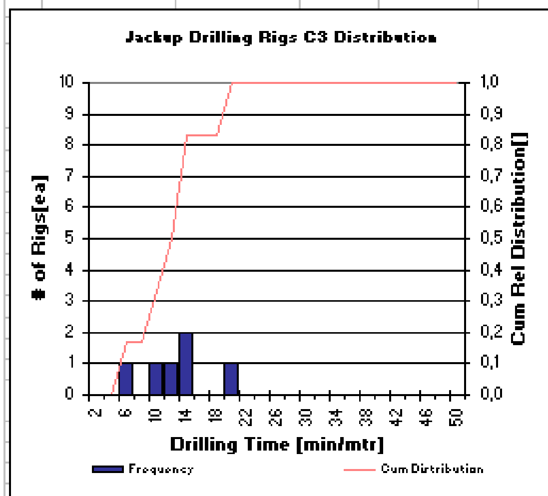


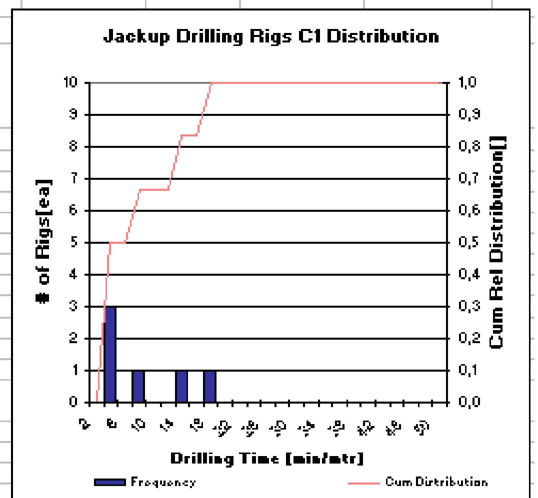


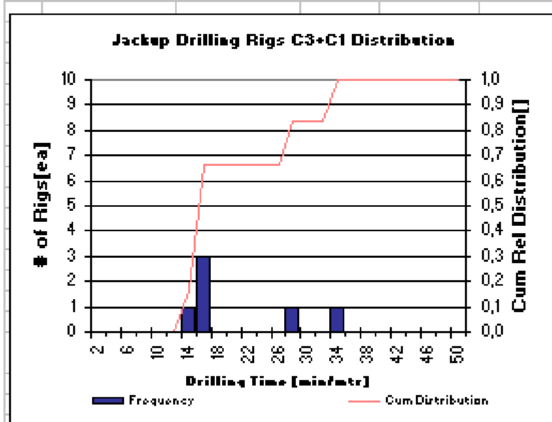


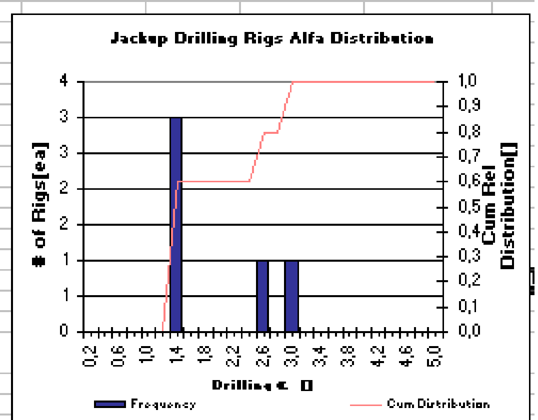
Jackup rigs

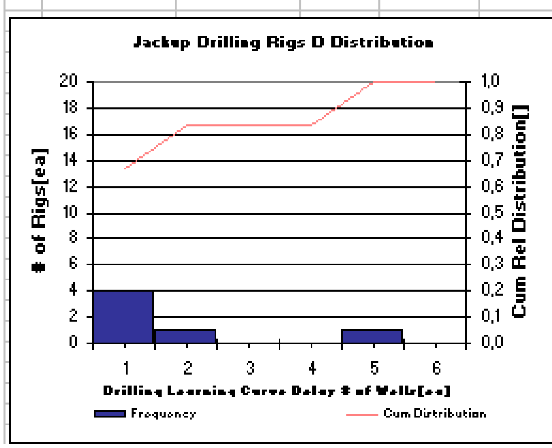
Jackup Drilling Rigs								
Statistical Parameter	C1	Delay	C2	LC Wells	C3	# Wells	C1+C3	Alfa
Unit	[min/mtr]	[ea]	[min/mtr]	[ea]	[min/mtr]	[ea]	[min/mtr]	[dim. less]
st dev.	6,4	1,6	0,79	2,7	4,5	3,0	8,1	0,8
Average	7,8	1,8	-0,04	4,7	11,5	3,8	19,3	1,8
Median	5,1	1,0	0,07	5,0	11,9	2,0	15,1	1,3
Min	2,6	1,0	-1,44	1,0	5,0	1,0	12,0	1,2
P10	2,7	1,0	-0,85	1,5	7,0	1,0	13,4	1,2
P50	5,1	1,0	0,07	5,0	11,9	2,0	15,1	1,3
P90	15,6	3,5	0,65	7,5	15,5	8,4	29,4	2,7
Max	17,4	5,0	0,86	8,0	18,6	9,0	32,4	3,0

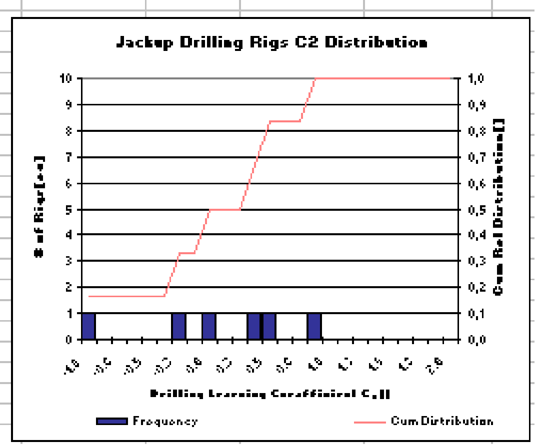






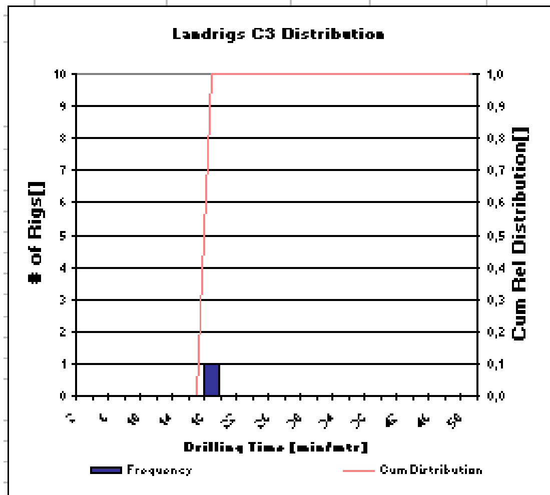


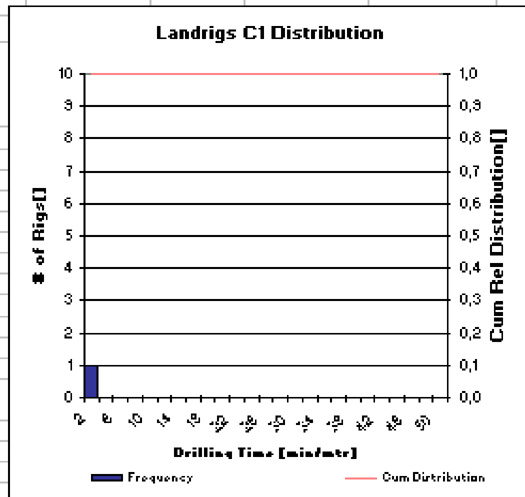


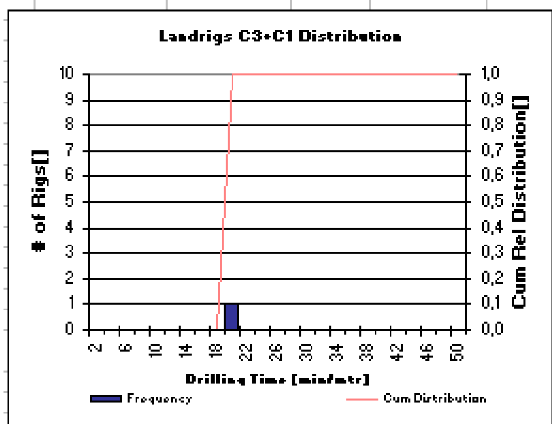


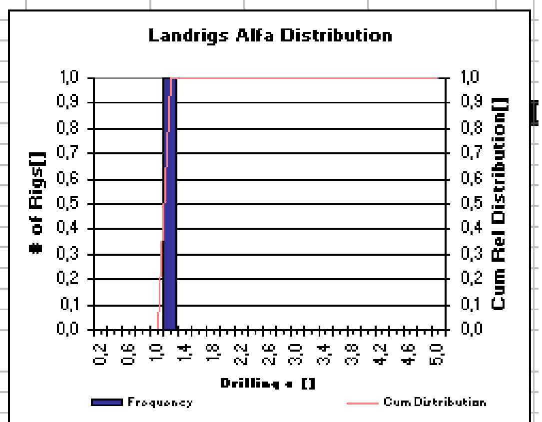
Land Rigs

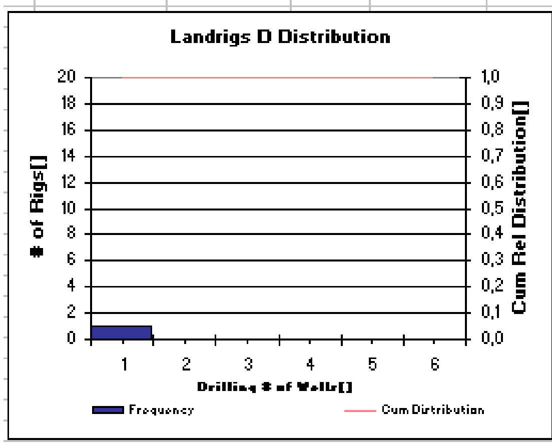
Landrigs								
Statistical Parameter	C1	Delay	C2	LC Wells	C3	# Wells	C1+C3	Alfa
Unit	[min/mtr]	[ea]	[min/mtr]	[ea]	[min/mtr]	[ea]	[min/mtr]	[dim. less]
st dev.	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
Average	1,9	1,0	-1,14	2,0	17,3	3,0	19,2	1,1
Median	1,9	1,0	-1,14	2,0	17,3	3,0	19,2	1,1
Min	1,9	1,0	-1,14	2,0	17,3	3,0	19,2	1,1
P10	1,9	1,0	-1,14	2,0	17,3	3,0	19,2	1,1
P50	1,9	1,0	-1,14	2,0	17,3	3,0	19,2	1,1
P90	1,9	1,0	-1,14	2,0	17,3	3,0	19,2	1,1
Max	1,9	1,0	-1,14	2,0	17,3	3,0	19,2	1,1

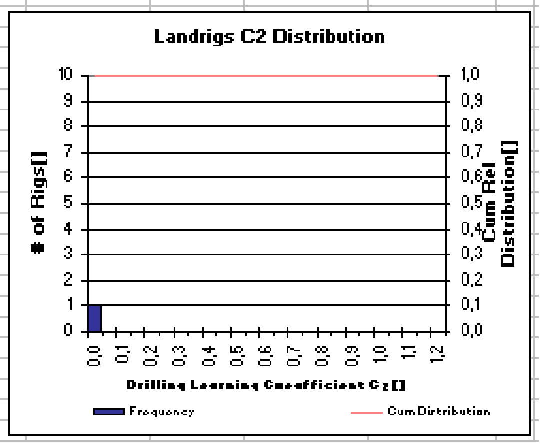












Appendix B (New rig Intakes & Name changes)

An overview showing the results found regarding:
- New rigs taken in
- Name Changes on rented drilling rigs

New Rigs taken in

Mobil - Statoil

Statfjord

Started with Mobil as operator, taken over by Statoil Jan-1987

Statfjord A start prd Nov 1979

Nov-1982, Start prd Statfjord B PDQ Platform

Jun-1985, Statfjord C start prd.

Norsk Hydro –Statoil

Dec-1985, Heimdal

Sep-1993 Brage started production, Developed by Norsk Hydro,

Sep-1997, Njord A

Sep-2003, Grane Started production.

1988 Oseberg B

Dec-1991, Oseberg C

Sep-2000, Oseberg Sør

May-199-, Oseberg Øst

Statoil

Aug-2001,	Glitne start prd, Petrojarl 1
Dec-1986,	Gullfaks A Concrete Gravity Based Structure
Feb-1988,	Gullfaks B Concrete Gravity Based Structure
Nov-1989,	Gullfaks C Concrete Gravity Based Structure
Oct-1995,	Heidrun Concrete Tension Leg Platform (TLP) including drilling facilities.
Sep-2004	Kvitebjørn
Oct-1993,	Sleipner A
Jun-1996,	Troll A
1989,	Veslefrikk B
Oct-2005,	Visund

Saga – Norsk Hydro 1999 – Statoil 2003

Aug-1992 Snorre A TLP PDQ

Jun-2001 Snorre B TLP PDQ

New rental Rigs (Semi's, Drill ships, Land rigs and Jack Ups)

1970's

Statoil ~28-July-1975, the first new rig broken in by Statoil was Ross Rig that came straight from the yard of Framnes Mekaniske Verksted in Sandefjord Norway. The first well was 15/12-1 and is not registered in DBR.

Statoil Later 70's, two new build Jack Ups from the rig company Dyvi. Rig names Dyvi Beta and Dyvi Gamma. The wells drilled from these rigs are not registered in DBR

1980's

Jan-1980, Dyvi Delta arrived from the yard of Raumo Repola in Finland. (This rig was almost lost on its outside Jæren costal line, on its way to Stavanger. The first wells of this rig are not registered in DBR.

1982-1983, Deepsea Bergen arrived as a new build. The first wells drilled by this rig are not registered in DBR.

West Vanguard arrived at Statoil as a new build. The first wells y this rig are not registered in DBR.

1986/1987, West Vision came from Smedvig as a new build and drilled only a few wells before it was modified into a combined Drilling pump room, and production facility for Veslefrikk, today known as Veslefrikk A. Supporting the Veslefrikk B Wellhead and Drilling Platform. The wells drilled are not registered in DBR.

Later in the 80's it started to take time between each new rig intake.

Spring 1987, Ross Rig Arrived to Statoil as a new build from the yard in Sandefjord. The first wells are not registered in DBR .

1990's

West Navion arrived as a new build from Smedvig. Drilled its first well in the Norwegian Sea for possibly for BP. Hence no data in DBR.

Dec-2001, Stena Don arrived as a new build and the wells drilled by Stena Don are registered in DBR.

Jan-2000, Borgland Dolphin come from a large rebuild in Glasgow and went into operation for Statoil. Wells are in DBR.

The New Super Rigs

Aug-2009, Deepsea Atlantic arrived from the rig provider Odfjell Drilling. A rig designed and built for Ultra Deep Water and HPHT. Attempted used on two wells, both resulted in doubtful success because of excessive forces induced on wells, and larger problems after the rig went on, then before It arrived.

Difficult to foresee a Learning Curve for a rig like this. It is new, and new of its kind. Supposedly the best systems in the world, however some of the up scaling might have gone to far and resulting in undesired consequences. 3wells attempted
Doubtful results on 3 wells

Jan-2010, Aker Spitsbergen taken in as a new semi submersible from the rig contractor Aker Drilling. Working on first well right now. P&A? -7days until now.

~Jan-2010, Maersk Drilling Maersk Developer, as of 26-Apr-2010 still working on ints first well in GOM. Ultra Deepwater? Still on first well?
Transocean Discoverer Americas Higher learning curves, standards?

Norsk Hydro New Builds

Oct-1985, Polar Pioneer
Apr-2000, West Venture First Dual Ramrig on a semisubmersible

Contracted Discoverer Americas, however taken in after the fusion between Statoil and Hydro.
Contracted the new build semisubmersible's Cosl Innovator and COSL Promoter however these are not in operation yet. Start of operation is scheduled for later 2010 and 2011.

Saga

No data available.

Floating Drilling Rigs that changed name

Ocean Vanguard (Diamond Offshore) used to be West Vanguard(Smedvig)

Songa Trym, used to be Deep Sea Trym

Songa Dee used to be Stena Dee

Songa Delta (from 15-Mar-2009), used to be Deepsea Delta, West Delta, Dyvi Delta

Transocean Arctic used to be Ross Rig

Transocean Driller used to be Drillmar 1

Transocean Leader used to be Transocean 8

Transocean Prospect used to be Treasure Prospect

Transocean Searcher used to be Ross Isle

Transocean Wildcat used to be Vildkat Explorer, Vildkat

Transocean Winner used to be Treasure Saga

West Alpha used to be Dyvi Alpha

West Navigator used to be West Navion