Chapter 3
Research Design

3.1 The research problem

The existing models' limitations which includes stochastic variables, requires that a new model be developed that is capable of using all the variables to enhance production through;

- Define the decision variables to be used in the integrated production model.
- Study the decision variables' trends and rates of change over time in order to configure the simulation model.

3.2 The business problem

There is a lost production opportunity as a result of not accounting for all field activities due to the models' limitations. Therefore, a portion of the profit is lost and the production cost per barrel is affected.

3.3 The research question

Question number 1: What are the various decision variables that enhance offshore oil and gas production in the UAE?

Question number 2: Can a model be developed and used to fit all the decision variables and to forecast production?

3.4 The research objective

The objectives in the research are:

Objective number 1: To identify the variables that can be used to enhance offshore oil and gas production in the UAE.

Objective number 2: To develop a simulation model to forecast offshore oil and gas production in the UAE using decision variables behavior.

3.5 The research methodology

Studying the decision variables through a special literature review is the first step. This is supported by consultation with the subject matter experts to obtain their feedback through individual interviews. The SME's opinion is used to design a questionnaire that is distributed to production analysts and operators in order to identify all the key variables that can satisfy the second objective.

The second objective is related to the execution of the study by collecting related data and producing analysis through polynomial fitness testing, correlation analysis and obtaining probability functions for production and other decision variables. The identified data and constraints are used to develop a simulation for the purpose of running scenarios that can add value to production management (Woo, J.H., Ho Nam, J. and HeeKo, K., 2014). Objective two processes is briefed below:

- Collect data for two models and obtain trends in the decision variables over time (e.g. well production changes, oil and water ratios, maintenance history, shut-down profile, etc.)
- Develop a mathematical or statistical model (e.g. via a polynomial fit or probability distribution of key decision variables for extrapolation).
- Develop an overall simulation process for the system based on the data trends and configured on the overall production process (Appendix 12 - Process model)
- Use the wells' past period production data to run the simulation and test validity of the simulation model.
- Analyze the lost production opportunity through correlation testing of planned production (resulted from the lift curve) and actual production.
- Run the simulation based on the future extrapolated formulas (e.g. WOR/GOR values) for two operational fields with different facilities configuration.
- Analyze the results though correlation analysis against the targeted production requirements.
- Conduct a number scenarios for different time periods and additional production facilities to compensate for the natural decline.

- Modify the asset availability program seeking a better production forecast.

The process details of the research and the instruments used are discussed in the following paragraphs of this chapter.

3.6 Objective 1 – Instrument development

Identify various variables that can be used to enhance offshore oil and gas production in the UAE with the help of a questionnaire and literature review.

To achieve the first objective, using a primary data base study, a questionnaire was designed after conducting a literature review specific to production variables. This specific review defines various topics as a guiding sheet to interview subject matter experts (SME).

The subject matter experts are of senior level and directly involved in managing skilled professionals in the area of production, operations, petroleum engineering, reservoir engineering, process engineering and drilling.

A set of variables were recommended for short term optimization in Marlim field which excluded asset availability and market analysis (Dzubur, L. and Langvik, A., 2012). The data driven model of (Goh, K., Moncur, C., Overschee, P. and Briers, J., 2007) utilizes an existing model of variables related to process capacities. This review supports the objectives of the interview. The summary of the variables are related to;

- Flow rates of the production network
- Separators capacities
- Flow lines capacities
- Storage capacities
- Fluid Ratios
- Compressors capacities
- Lift Mechanism (injection and production ratios)

A mathematical model was developed by (Shah, N. and Mishra, P., 2012) based on the following variables;

- Expected total production (recovery)

- Rate of production (up to steady state)
- Rate of decline (after steady state)
- Costs per production unit (wells, pipelines and facilities)
- Failure costs including production loss
- Holding costs
- Leakage costs

(Haavardsson, N. F., Huseby, A. B. and Holden, L., 2008) presented an optimization mathematical model for simplified production system. The same variables can be utilized to construct the simulation:

- Wells, facilities, capacities
- Reservoir performance for many reservoir volumes
- Oil, gas, water production profiles based on simulator results

Except for costs related variables which qualify for research by their own (e.g. long term cost modeling with inflation and depreciation implications) all remaining variables are used to guide the interviewer with the subject matter experts.

The following is the guiding sheet of the interviews:

Table 3-1 Interview questions guidelines

Reservoir	Well	Pipe network	Separation (phases)	Storage, loading	Market demand
Oil in place per formation	Production model	Flow assurance	Type, total volumes	Capacity	Oil quantity
Balance sheet	Service rework	Availability	Availability/ outages	Availability	Gas quantity
Injection type (water, gas, CO2)	Type producer injector	Design pressure and current	Retention time	Failure rates outages	Blend type API
Recovery Strategy	Sea line pressure	Diameter	Failure and backup	Retention time	Local oil demand
Number of formations porosity	Bottom pressure	End points	Size	Inspection schedule	External market
Connectivity permeability	Annulus pressure	Manifold rate	Flow rate and pressure	Major service	Supply
Geophysical sediments	W/G Ratios	Flow Rate	Capacity	Pressure volume	Price
EOR	Lift curve	Planning	Planning	Planning	Delivery

Model	Shut-in	Major repairs	By-Pass	Repairs schedule	
Asset configuration, connections, bypasses, back-up, recovery and resources					

The decision variables were initially collected by interviews with twelve senior staff of subject matter experts (SME) in the oil and gas companies. The main feedback from the SMEs is that the model should not duplicate functions related to the existing specialized simulators handling thermodynamics and reservoir properties of the oil filed. The domain of this study is the capacities optimization based on the results of exiting simulators.

Due to the scope of this research, the interviewee was briefed with the following introduction:

"The purpose of this research is to produce an integrated model that can help compute effective production capacity for short and long term planning and to reduce production losses resulting from the facilities' conditions or the wells' potentials. The research will identify key variables that contribute to production. Some of the required parameters are obtained from the facilities' capabilities and existing special purpose simulators. Others will be based on formulation, averages or probability distributions for data changes over time. The outcome will be an enhancement to the total material extracted and the balance of the material left based on existing estimates. The following are to be analyzed:

- Process plant effective utilization
- Well interventions and maintenance
- Well planning and abandonment
- Fluid contents ratios

A questionnaire was prepared based on the interviews of the SMEs. On completion, it was sent to various stakeholders (reservoir engineers, petroleum engineers, production engineers, process engineers and maintenance planners) to survey their feedback.

3.6.1 Conducting the questionnaire

Two methods were used to contact the subjects. The first method was through e-mail or an on-line survey and the second method was through filling pre-printed forms in a face to face interview for data collection**.** (Table 4-1 Questionnaire contains a list of all accepted and used decision variables. The questionnaire was sent to various stakeholders (SMEs) to rank these variables.

In order to obtain an adequate sample size, the Yamane sample size ratio was used (91 out of 1 population **-** Appendix 5) to compute the number of subjects of the population who received the questionnaire. One thousand subjects were selected based on the limited number of SMEs in on-shore and off-shore companies. A stratified random sampling (strata: proportionate) was followed.

Accordingly, the model questionnaire was produced with the following introduction and nine questions:

The purpose of this survey is to compile the key decision variables that contribute to the hydrocarbon production chain. The variables will be used to build a discrete time based simulator using profiled variables to compute production and evaluate any lost opportunity. This is part of a university research paper and I appreciate your input.

Please indicate your agreement/disagreement by ticking the right button using Likert scale starting with Strongly Disagree and Ending with Strongly Agree.

The details of the questionnaire and answers summary are included in appendix 4

3.7 Objective 2 – Hypothesis testing and model development

To develop a simulation model to forecast offshore oil and gas production in the UAE using a decision variables trend model over time.

The second objective is to use primary and secondary data to produce formulas that can be used to configure the production simulation model. The decision variables (performance and design data) are studied to be used for the model. Performance history data is used to obtain the variables trend over time and the parameters used in the forecast model (Hillier, F. and Lieberman, G., 1975). Examples of this trending are the polynomial fitness of the production readings, the probability distribution densities for failure analysis, the well future contribution to the total production and the estimation of gas and water ratios changes between well tests. The process is briefed below:

- Data collection and analysis
- Develop a mathematical / statistical model
- Develop an overall simulation process and proof of model validity
- Run the simulation based on the future extrapolated formulas
- Run the simulation for production forecast and assess gains

Key decision variables (identified from objective one) are analyzed and formulated into the simulator. In this research, the models were developed and the above steps were achieved for two reservoirs. The validation was conducted along with the comparison of the various future scenarios.

The hypothesis testing

The objective is to compute the correlation coefficient of the targeted production and the actual production (or the simulation output) results. The null hypothesis should be rejected for the model to be accepted based on the following:

H0: There is no correlation between planned and actual/simulated production in the model

H1: There is correlation between planned and actual/simulated production in the model

3.7.1 Model development - Data collection

The data related to production history is required to obtain trends and probability functions for use as parameters in the model. The data is available in electronic format in the relevant reports and systems for the subject fields. The formulation, confidence tests (P-value), trends results and parameters' reports are attached in appendices 2 and 3 and 6. Summary data tables are obtained covering the following:

- Process routing map used to design the model (appendix 12).

- Ten year production and WOR/GOR summary by well and reservoir used for profile fitting with Tableau software. The choice of ten years is used to cover all wells major workovers (graphs are in appendix 1)
- Two years wells allowable based on lift curve computations mandated by reservoir requirements of four well tests (summaries in appendix 17 - details in electronic format)
- Well testing and maintenance since inception (appendices 6 and 17)
- Injection data by well and reservoir (summaries in appendix 6 – data in electronic format)
- Phase separation (I, II and III) capacities (profiles in section 3.3.3 – details in electronic format)
- Wells shutdown days for operational and integrity reasons
- Storage and flow capacities (appendix 6)
- Maintenance plans (separators, wells, tanks, pipes and rigs)
- Configuration and constraints data based on plant design and used for model settings (appendix 6 and 7)

3.7.2 Model development guidelines for objective 2

The following are the general guiding principles applied in the simulation model as a result of the data mining part of Objective 2

- The reservoir model is based on the reservoir simulator results
- The well model setup is based on the actual production data mining extrapolation curve constrained by the allowable limits of the well.
- The simulator will inactivate the well when the production declines outside the lift curve allowable area tolerances. Well models are attached in the relevant appendices. (Appendix 2 - Well extrapolation model 1) and (Appendix 3 - Well extrapolation model 2).
- A simulation validation run utilizes the efficiency percentage which is the average sum of shut-in days due to repairs.
- Market demand ratio is proportional to the reservoir contribution ratio of the full production. Demand model is generated in parallel (section 1.2.1).

- Water and gas injection are used for material accounting and not for pressure maintenance. Pressure maintenance is subject to the specialized simulator and not in the domain of this research.
- Future wells development is handled by running special scenario.
- Manifolds, compressors, pumps and other equipment are handled as queues with no constraints.
- Subsea flow lines maintenance plans are associated with the wells plans.
- Storage and separation have a maintenance programs in the forecast model
- The assets are physically modeled in the simulator based on the production process diagram (appendix 12)
- Specific formula or parameters are defined for a production unit

Table 3-2 Simulation objects setting

Condition	Purpose	Setting
Well turn-off/on	Use of Resources	Decline curve limit
New wells	Dormant work-entry point	Time based logic
Rig	Rig is mobile resource	Rig is maintainable
Routing arrows	Connection between objects with no delay or process	Not maintainable
Product handling (Fluid flow) in the simulator	Inter-arrival time represents a key computation parameter for quantities and flows in simulators	Flow rate is 24 hours 7 days. Average barrel flow time in pipelines is 1 second per meter
Injection wells	Used to handle separated gas and water	Fixed flow rate
Supply and demand	Local demand	Demand formula
Working time and calendar	Resources are available around the clock to satisfy real life off-shore operations. Rigs and barges can work full day	Hourly calendar is used to satisfy the 24 hour and 7 day week. Minutes based simulation is more time consuming
Simulation duration	Depends on the complexity of the scenario	Scenarios run for 1, 3, 6, 12 and 24 months

3.7.3 The simulation model and constraints

The diagram in (Appendix 12 - Process model) represents the overall process and facilities that are critical to oil production. The simulation model is based on this diagram. Support systems such as glycol re-generation, instrument air, power generation, heat exchangers, water coolers, corrosion inhibitors, etc. are not included in this model since backup systems are normally in place. The process model is briefed as following;

The number of fifty-five wells for oil production for model number one includes one gas and ten water injection wells. Capacities are in

Table A-2 Static assets capacities - model 1) and nominal well allowable production (Table A-7 Wells maintenance program - model 1

) and (Table A-8 Wells maintenance program - model 2

). The produced fluid goes through three stages of separation, stabilization and storage. The stored material (gas/oil) is shipped to the market based on the market demand. Most water returns to the water processing facilities for re-injection. 35% of the gas returns to the gas processing facilities for re-injection. The balance goes through liquefactions and marketed to the consumer. The model is handling one reservoir with 100 MBOPD capacity representing 20% of the full fields capability (Appendix 6 - Simulation parameters).

Asset shutdowns by categories other than wells (i.e. pipelines, separators, tanks and pressure systems) are listed in appendix 9**.** Main plant piping and separators are used together in the overall plant efficiency. Assets with backup units have minimal impact in production (e.g. compressors, pumps, valves and manifolds).

Model number two is configured with the total of 30 wells for oil production, one for gas and twelve for water injection. The produced fluid goes through three stages of separation, stabilization and storage. The stored material (gas/oil) is shipped to the market based on the market demand. Most water returns to the water processing facilities for re-injection. 35% of the gas returns to the gas processing facilities for re-injection. The balance goes through liquefactions marketed to the consumer. The model is handling one reservoir with 75 MBOPD capacity representing 15% of the full field's capability.

The wells being the source of production are the main key elements in the process. Their availability is important for the settings in the simulator. They are subject to planned maintenance and frequent shut-in times for operational reasons (i.e. reservoir management, alternating between zones, monitoring, waiting for a tie-in, testing outside and stimulation). Occasionally, waiting for the tie-in after major maintenance reconnecting the well to the network may take several months.

(Figure 3-1 Well PDF of unavailable days) depicts the average count of occurrences of shut-in days per fraction of the month for maintenance reasons (un-planned or unknown shut downs) for model 1. The x-axis represents the shut-in period in a month and the y-axis represents how many times the well was off for the period. This model represents the distribution of the occurrence in an unavailable period within a production month.

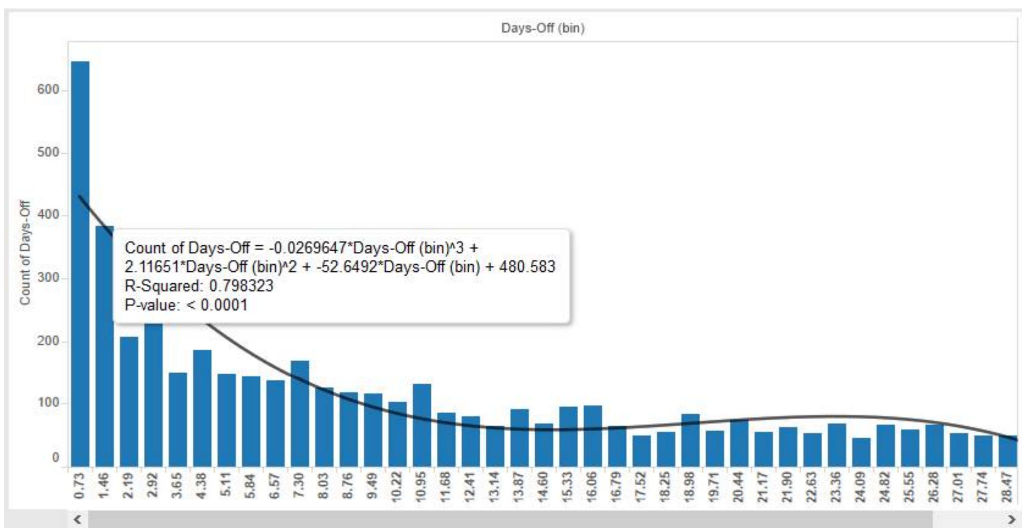

Figure 3-1 Well PDF of unavailable days

The model formula is included on the graph based on fifteen years of asset unavailability data. Additionally, (Figure 3-2 Days off production inclusive of operational days) statistics produced the average of unavailable time out of the total production time (approx. 25%).

(Figure 3-2 Days off production inclusive of operational days) depicts the well availability for the subject reservoir for model 2.

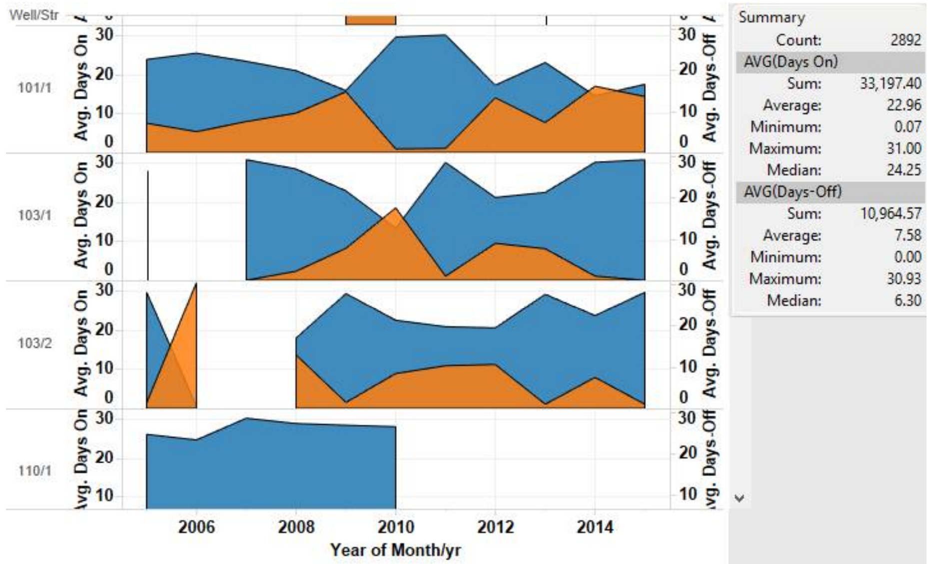

Figure 3-2 Days off production inclusive of operational days

The empty periods (Figure 3-2 Days off production inclusive of operational days) represents an unavailable well for operational reasons. The well is not producing for the required zone but can be available for another one. Also, it can be idle waiting for a maintenance opportunity. New wells are added by internal activation of standby wells.

The diversion of the well for production from other zones is considered as not available for operational reasons. However, if the well is available for another zone, then the well is defined in the other zone as available to produce.

Facilities are the units of the production system that facilitate flow, separation, injection, processing, storing and shipping the oil into its destination. The facilities are flow lines, pipelines, injection facilities, metering, tanks, oil loading and wells. The following table is a sample of the maintenance settings which is obtained from the Enterprise Resource Planning system (ERP)[5] and published annual report summary by asset type (appendix 9). The efficiency is used in computing the overall loss factor in the simulation setting. It is setup at some assets for non-

[5] ERP is the application that manages assets maintenance, availability, capacities and production

availability of failure probability (appendix 9) in addition to a known maintenance program.

3.7.3.1. Fluid production model at reservoir

A probability distribution function was obtained from the reservoir simulation model and used for a future production contribution profile. The values in (Figure 3-3 PDF for fluid production model) represent the overall flow capacity that can be delivered on the assumption that the pressure maintenance rules are adhered to. The distribution depicts two periods of moving averages, followed by a boost at the 3rd stage of enhanced oil recovery and exponential decline based on the company EOR plans.

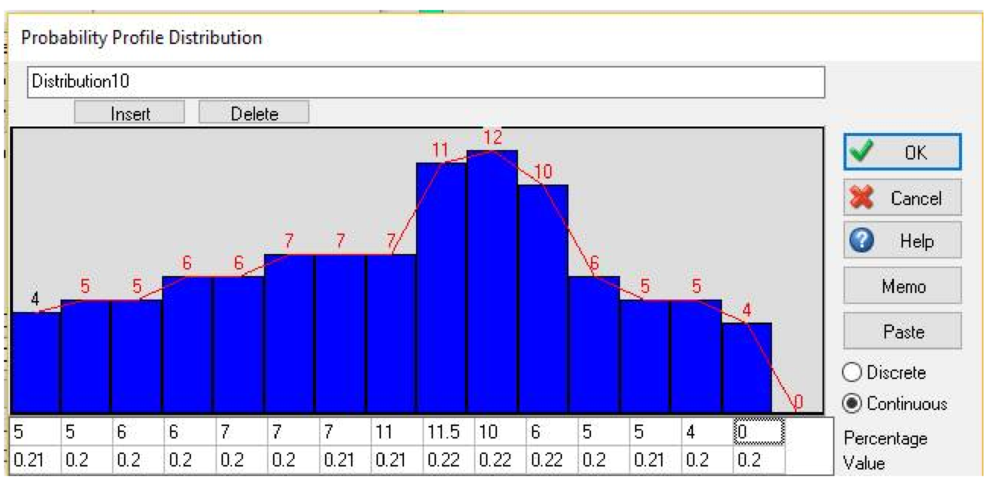

Figure 3-3 PDF for fluid production model

The value represents the reservoir productivity index based on the well configuration. The fraction (0.2) stands for the unit of time (1 hour) to produce one MBOPD. One hour produces 5 MBOPD; therefore, the one day contribution will be 24*5=120 MBOPD for this reservoir (Appendix 7 - Separators parameters) and (Table A-5 - Separators settings)

3.7.3.2. Fluid ratios discussions

A fifteen years analysis of oil, water and gas ratios has witnessed an increase in water and decrease in gas contents. This is an expected result. However, it may be interrupted in the unlikely event of injected gas reaching well perforations.

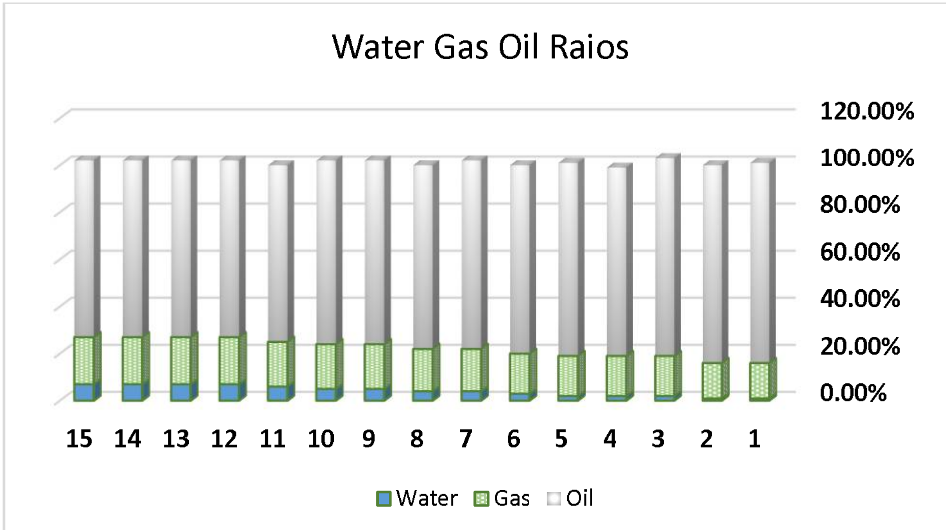

Figure 3-4 Oil water gas ratio in BOPD equivalent

This change can be interpreted as re-use of the injected gas that was not initially in the material balance. Geochemical analysis can have an answer to this question.

Data of produced oil, water and gas ratios is used to define the separation performance. The three phases' fluid plot below represents oil, gas and water produced over 10 years with a 3 years forecast.

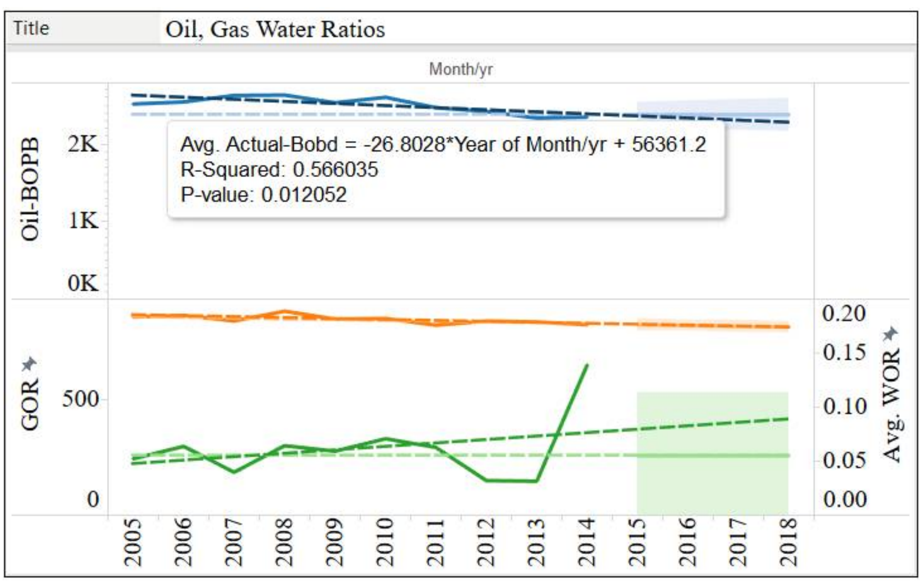

Figure 3-5 Separated averages of oil, water, gas ratios trends and forecast

Table 4-3 summarizes the trend model for fluid ratios over fifteen years' data covering all wells.

Table 3-3 Trend lines model for separated fluid

Model formula:	Y(BOPD) = -26.8X +56561.31 **Equation 3-1 Oil production trend** P value = 0.00358
Model formula:	Ln(Y)= 0.02234 * X +47.191 Equation 3-2 Gas production trend P value = 0.1
Model formula:	Ln(Y)= 0.00925 * X +20.0237 Equation 3-3 Water Production Trend P value = 0.756

3.7.3.3. Fluid handling at separators

(Figure 3-6 Gas correlation with well-produced fluids (BOPD)) represents the correlation of the GOR ratios versus the wells production. The R-square test depicts no relationship or correlation between gas ratio and oil quantity produced at the well level. The GOR is not constant as it should be and depicting randomness around the 1000 MMSCFPD. However, most wells have the ratio between 750 and 1250 SCFPD.

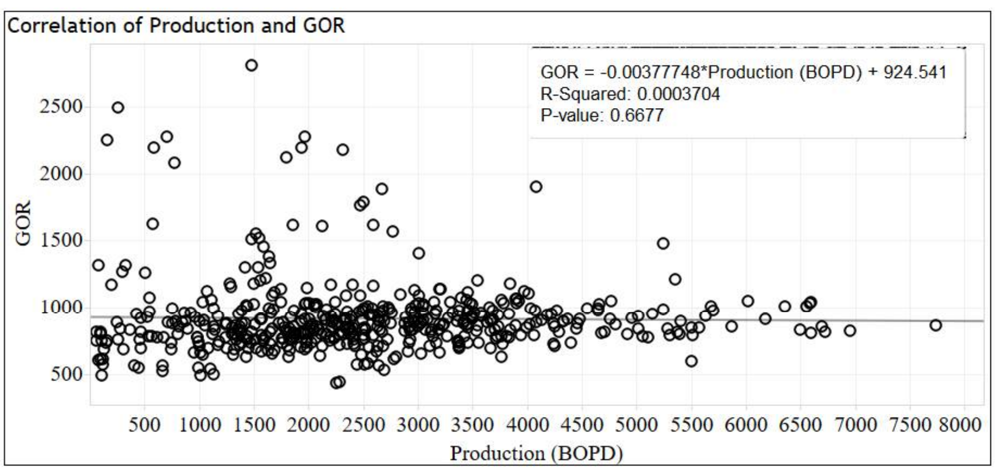

Figure 3-6 Gas correlation with well-produced fluids (BOPD)

Due to the gas randomness and the high P-value for water at the well level, a profile can't be extrapolated and a PDF model is setup at the separators with adherence to the overall separation ratios trend (Figure 3-7 PDF for water, gas and oil ratios separation).

The probability distribution model of water and gas separation is depicted in this section (Figure 3-7 PDF for water, gas and oil ratios separation) based on the separation ratio's overtime. The basis of the PDF is the wells random testing (Figure 3-6 Gas correlation with well-produced fluids (BOPD)) ratios and separators design capacity. Oil, water and gas values are in the x-axis. The values 1, 2 and 3 represent water, gas and oil are results of (Figure 3-5 Separated averages of oil, water, gas ratios trends and forecast) well sampling data of the produced fluids during testing.

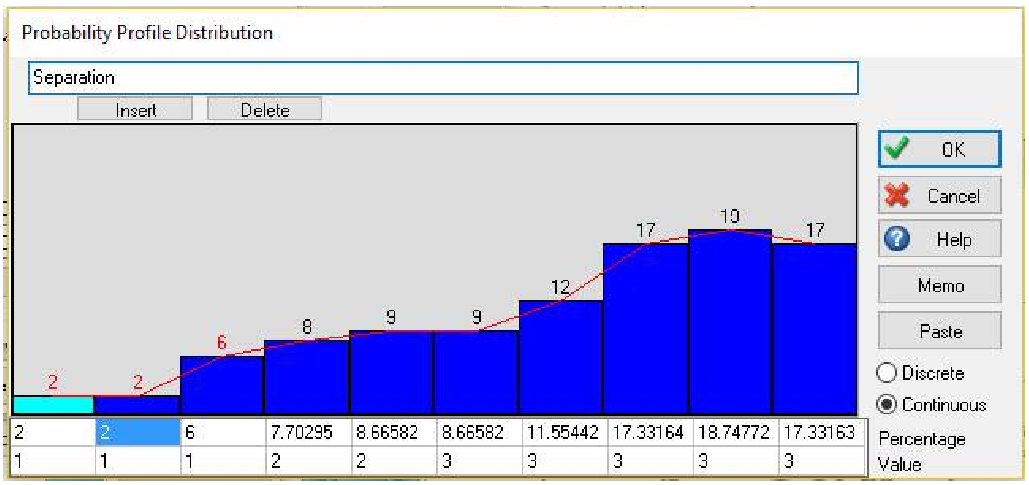

Figure 3-7 PDF for water, gas and oil ratios separation

The water ratio (value 1) shows the same trend with averages 2% to 6 %. Gas ratio (value 2) is 15% to 20% (due to recycling of injection). The balance is used for oil ratios in the manually adjusted PDF.

3.7.3.4. Injection ratios

The data was collected to segregate the injector's wells from producers and to study ratios. The water and gas injection data is also needed to analyze gas availability for the market and to assess the injection strategy and requirements. There are no flow controls or an optimization system included in the physical water injection model. Therefore, constant injection ratios are used for water. Gas injection is done through a limited number of wells and constrained by the compressors' capacity (standby units are in place). The purpose of including the injection system in the model is to manage the fluid flow, to handle the separated material, to balance available gas for market, to obtain sea water processing requirements and to obtain the injection requirements of gas and water for the subject zone. The total injection capacity is therefore constant. Hence, produced water is supplemented by sea water and processed through water injection facilities. (Table A-2 Static assets capacities - model 1) and (Table A-3 Static assets capacities – model 2) contain gas and water injection ratios.

3.8 Chapter conclusions

This chapter describes the methodology, the data collection and the settings of the production units in the simulation model. The chapter describes the instrument used to define the decision variables required for the model.

Objective number 1 methodology is addressed with interviews and questionnaires with key experts in the area of hydrocarbon production. The feedback is used to define the key variables that are required for an integrated simulation model to meet objective number 2. There are two types of key information needed for the model. The first is related to the process design, facilities capacities and maintenance program. The second is related to the performance data over time and related to production history and breakdown history. The performance data along with the asset capacity are used to extrapolate the future performance of the asset in respect to objective number 2.

Objective number 2 uses the results of the analyzed data to configure a simulation model of the process facilities based management using the RAM concept (Woo, J.H., Ho Nam, J. and HeeKo, K., 2014). Therefore, that asset and history of values are collected and analyzed to produce a trend or probability distribution functions that are used in the simulation model either by defining the formulas in the model or defining the probability distribution function graph manually. When the variable is random, the PDF can present the probabilistic behavior for the simulator to produce the required value within the range and the specified distribution. When efficiency is used, the simulator uses it to constrain the asset productivity in the defined limit. Hence, efficiency is relied on to account for the asset unavailability outside the maintenance time.