Chapter 5

Conclusions and Recommendation

5.1 Enhancement over time based on losses – model 1

The collective production decline based on the produced results is depicted in the following diagram over a period of one year.

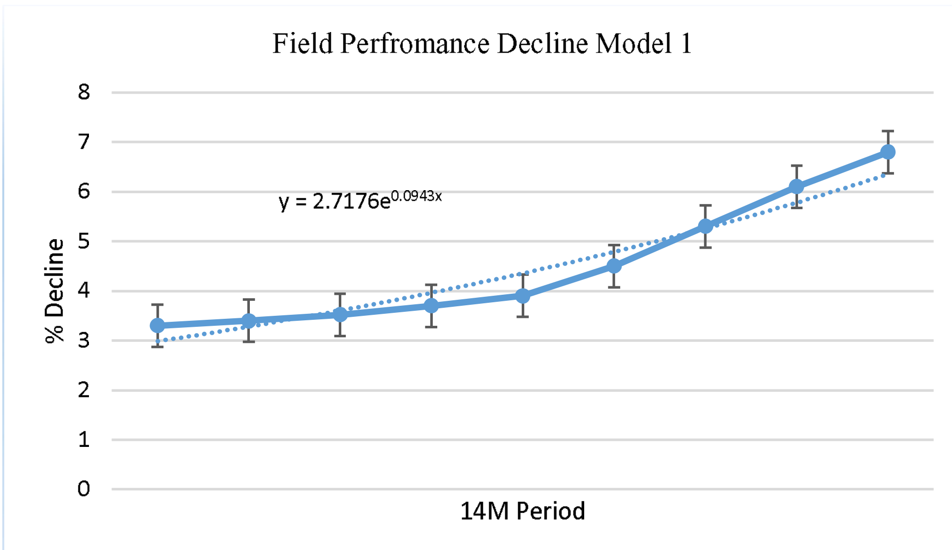

Figure 5-1 Model 1 field performance decline

Therefore, the field production percentage decline model is depicted by the exponential formula:

$$Y = 2.7176 * e^{0.0943x}$$

Equation 5-1 Field performance decline

Based on the above, if the strategy is to increase production by 10% to the current value, then the required increase in production can be calculated by the product of the targeted production and the model decline percentage:

$$\textit{Production-Increase} = \textit{Targeted-Production} * (2.7176 * e^{0.0943x})$$

Equation 5-2 Expected variance to future target

Using this value and based on the capacity of the new wells along with the capacities of the refurbished wells, a formula can be derived for the development strategy. This is achieved by accounting the gains of refurbishing a number of wells and computing the number of new wells from the balance.

Therefore, a plan can be assessed quantitatively with more accuracy than applying the traditional decline formula in the production system.

Based on the available data and the produced oil and gas demand trend of (Figure 1-1 Oil and gas demand in UAE - Source US Information Admin.); the trend equations (Equation 1-1 Gas demand trend formula) and (Equation 1-2 Oil demand trend formula) were applied in the simulator to generate the demand over time. The values are compared against the production decline ratios; the following is extrapolated to be the suggested strategy for wells development to meet local market demand and assuming the obtained decline rate:

Table 5-1 Strategy for future demand - model 1

Period	**Oil demand increase**	**Gas demand from this reservoir**	**Strategy / annually**	**Strategy for water injection**
2016	120 MBOD	75 MMSCFD	4 new wells (6 WO wells at 3MBOPD)	3 Wells with 18 MBWPD.
2017	132	85 MMSCFD	Same	Same
2018	144	95 MMSCFD	Same	Same
2019	156	100 MMSCFD	Same	Same
2020	168	110 MMSCFD	Same	Same

The strategy is on the basis of workover wells (WO) will double the well production after maintenance and the decline compensation is handled by stimulation program.

5.2 Enhancement over time based on losses – model 2

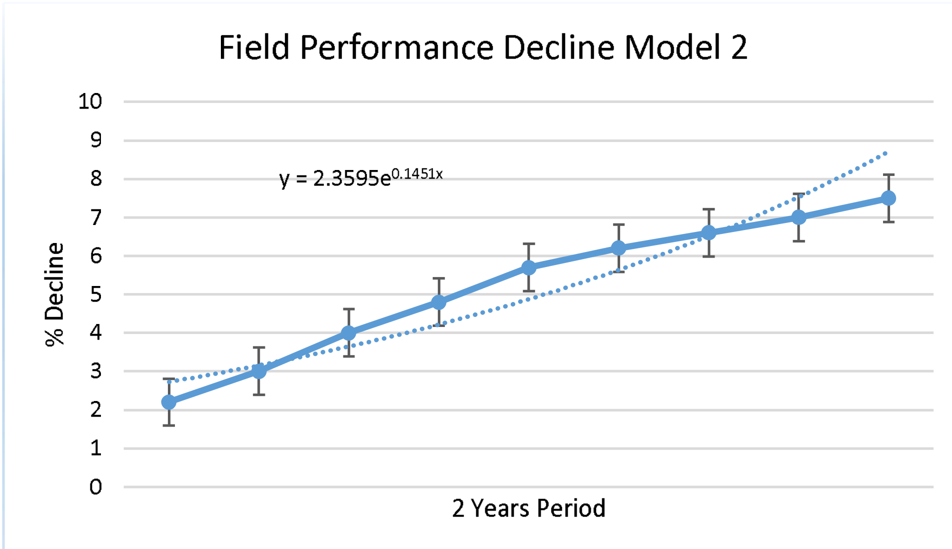

Figure 5-2 Model 2 field performance decline

The field production percentage decline analysis is depicted in the equation below based on data collected for the intercepted periods;

$$Y=2.3595*\boldsymbol{e}^{-0.1451x}.$$

Equation 5-3 Field performance decline - model 2

Table 5-2 Strategy for future demand - model 2

Period	Oil demand increase	Gas demand from this reservoir	Strategy / annually	Strategy for water injection
2016	75 MBOD	50 MMSCFD	3 new wells - 3 WO wells at 2.5 MBOPD	2 Wells with 12 MBWPD
2017	82.5	55 MMSCFD	Same	Same
2018	90	60 MMSCFD	Same	Same
2019	97.5	64 MMSCFD	Same	Same
2020	105	68 MMSCFD	Same	Same

Since the gas reinjection requirements are set at 35% of what is produced, the gas supply to the market is 38.5MMSCFD for model 1 and 125MMSCFD for model 2.

5.3 Decline models analysis

Exiting oil production decline models are divided into three categories;

- Exponential decline (constant fractional decline)
- Harmonic decline
- Hyperbolic decline.

The hyperbolic decline in Equation 5-4 (Garcia, A., 2008) is the general formula applied in reservoir assessment, feasibility and recovery strategy. The formulas of this research are derived for the surface facilities with the basis of the field's operational specifications. The formula that decides on which model to use is:

$$\frac{1}{q} * \frac{dq}{dt} = -bq^d$$

Equation 5-4 Hydrocarbons decline equation - Arps 1945[9]

Where b and d are constants based on production data. When d = 0, the equation degenerates to an exponential decline model, and when d = 1, the equation becomes harmonic. When $0 < d < 1$, the equation derives a hyperbolic decline model (Garcia, A., 2008).

The models represent the theory related to oil natural decline during primary and secondary recovery periods. Enhanced oil recovery can stretch the period and the quantities, but the decline model does not change.

The decline formulas obtained in section 5.1 and 5.2 are specific field performance declines based on operational strategy. It is not an alternative to the oil decline model. However, it needs to be formulated further to contribute to the computations of constants b and d. If this is achieved in future research, then it will the decline formula for computing the production plateau of the company. The formulation of b and d in

[9] Mr. J. Arps of Tesoro Petroleum Corporation of San Antonio holds 27 United States patents, 10 Canadian and five Venezuelan on inventions used in well logging. He obtained the Mineral Economics Award, established in 1965, is bestowed for distinguished contributions to the advancement of mineral economics

relevance to the produced decline of the collective field performance is a subject of another study that is specific to the different operational strategies of the companies.

5.4 Discussions

The existing optimization solution used by the company is based on an integer programming model which can't handle the linearity of the variables. The research does address this process. Additionally, non-linear past history data for flow rates, phase ratios, probabilities of failure and asset efficiency have been taken from history records and used in the simulator to produce more accurate forecasts.

The model is used to compliment the specialized simulators that do reservoir characterization, process simulation, thermodynamics modeling, flow assurance simulation of wells or pressure vessels simulators (Those are handled with products like Eclipse, PIPESIM, Prosper, DCS, GAP, MPAL, etc.)[10].

Therefore, the study is built on the decision variables relevant to the surface facilities' capacities and utilizing results obtained technically from numerical simulators. Furthermore, the data mined was used in the integrated asset dynamic simulator to enhance estimates and enhance the operability of the plant with understanding of the behavior of the data through data mining.

The decision variables are related to the metadata of the business role of the asset (i.e. production capacity, flow capacity, separation capability, availability, outages, decline curve, well model curve, pipeline network capability, process capacity, stabilization capacity, storage, flow control capacities and asset potential, etc.).

Generating realistic datasets was done by extracting production data, well tests data and maintenance history. The production data is profiled using polynomial fit. The maintenance data is analyzed to obtain planned interventions as well as failure history to extrapolate a probability of failure, mean time between failure, mean time to repair

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[10] Software products provided on multiple platforms

and critical equipment availabilities. The decision variables are analyzed for behavior change. The key formulas are used in the simulator (Simul8) to obtain various scenarios of production.

Adding heuristics of stochastic variables in the model is found to be an effective way of generating good results. When deciding what method to use, the trade-off between model realism and solution time must be weighted. A good, heuristically obtained path with practical implementation time is more useful than using a conventional formulation which requires a long process of modeling and results generation.

5.4.1 Example well number 55

Equation 5-5 represents the production trend of one example for well number 55 (Appendix 2 - Well extrapolation model 1):

$$\boldsymbol{Avg\ (BOPD) = 874.805 + e^{-0.4305X}}$$

Equation 5-5 Production trend well 55

The data analysis of the well test produced a theoretical well lift curve with the formula on the graph. There is no alignment between the theoretical well lift curve in Figure 5-3 and the actual production on (Figure 5-4 Well 55 Inflow performance relationship).

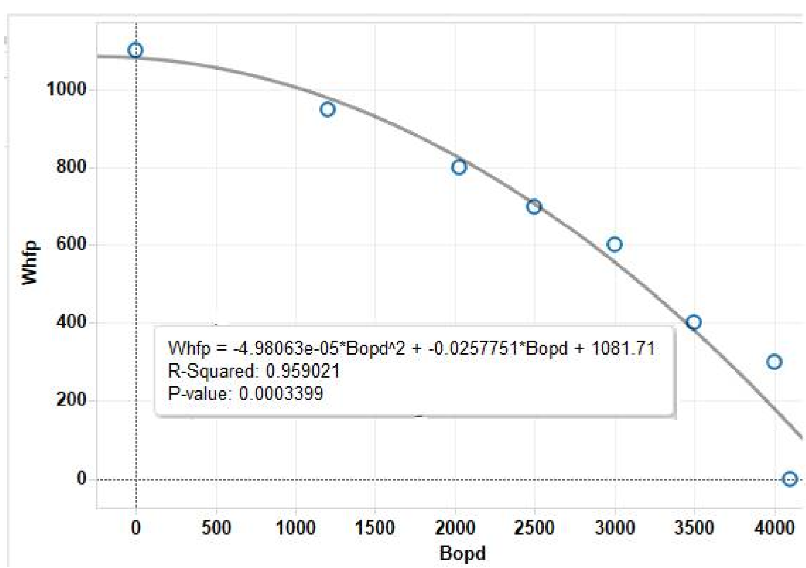

Figure 5-3 Well 55 theoretical lift curve

A ten years well model was extrapolated for wellhead pressure and oil rate along with surface back-pressure of the tubing performance. The graph produced an undesirable outcome with production readings falling outside the optimization area of the lift curve model that is based on well testing. Most of the production values (85%) are falling outside the optimized production area (Figure 5-4 Well 55 Inflow performance relationship).

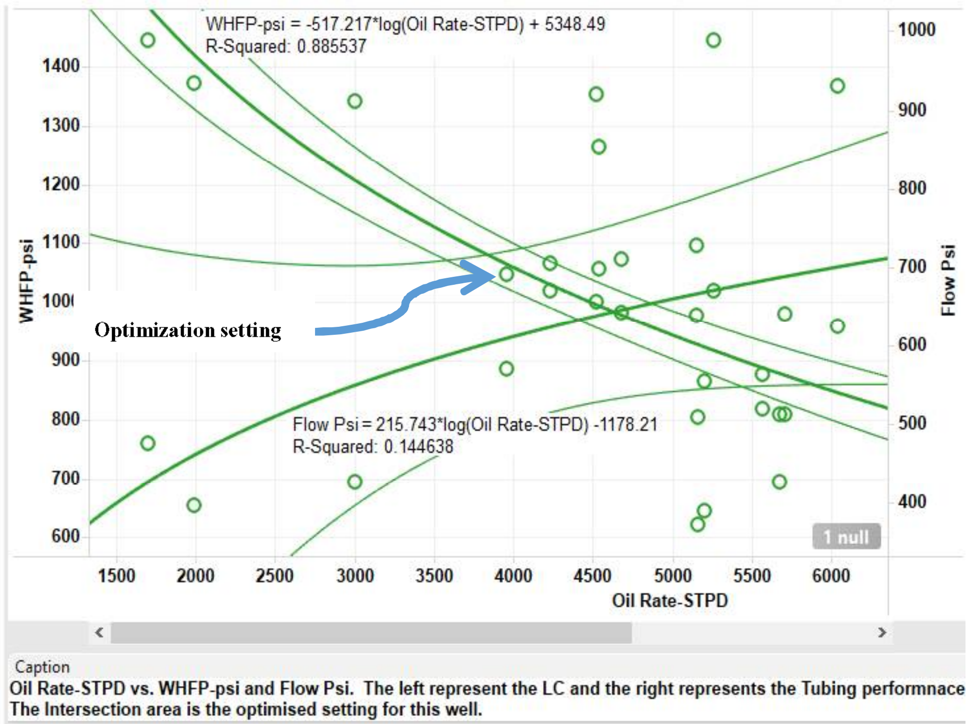

Figure 5-4 Well 55 Inflow performance relationship

The optimized production falls in the middle area between upper and lower limits of the curves intersections. Many other wells shared the same behavior according to the correlation analysis curve Figure 4-5 Correlation of planned nominal and actual production). The missed production opportunity for this well is computed as follows:

$$\sum \quad \textit{Actual Production} - \sum \quad \textit{LC expected Production}$$

Equation 5-6 Lost production opportunity

Applying the above, the result of the deviation from guidelines for this well in a one month scenario is:

- 15 averages of 500 BOPD above the expected production limit
- 12 averages of 300 BOPD below the expected production limit
- 4 readings within the guidelines

Although the losses are low for this well (average 200 Barrels per reading), the deviation from the guidelines of 25% constitute a production loss and deviation from the allowed production contribution for the well which impacts the long term reservoir sweeping strategy.

5.4.2 Example well number 50

The correlation model was tested in the Company for well number 50. The analysis is being used as a case for the justification of the model after the submission of the 2015 best initiative (Appendix 19 - Best Initiative Award). The lift curve and production correlation curve is produced from the Company production system (Figure 5-5 Company test - One well model lift curve versus pressure). The analysis is supporting this research.

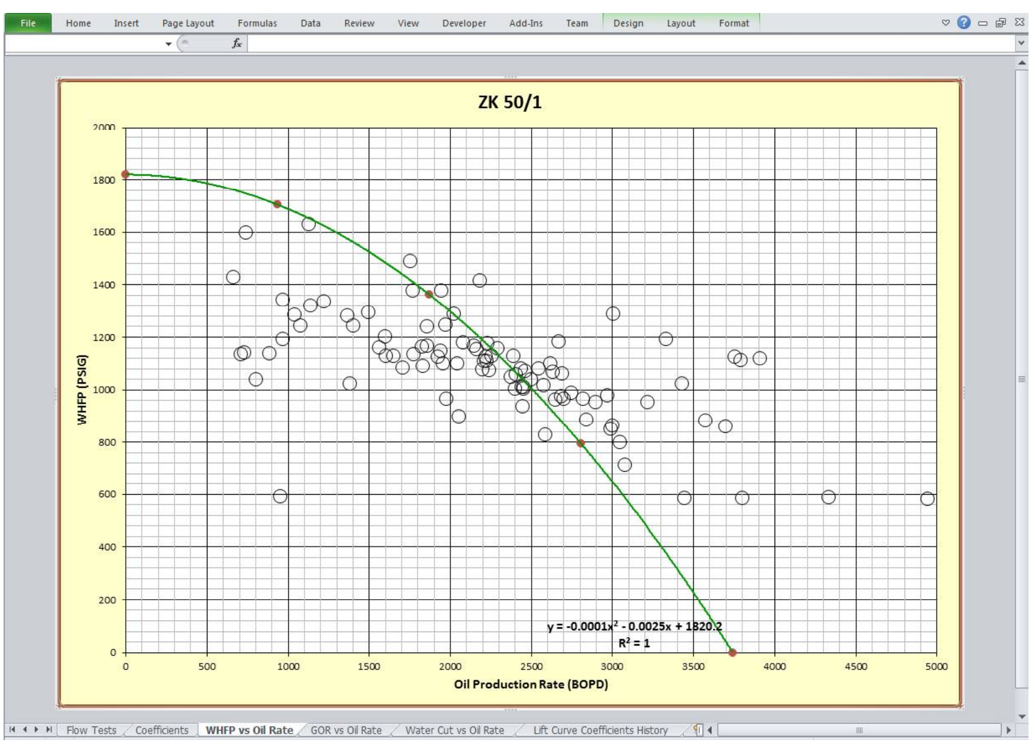

Figure 5-5 Company test - One well model lift curve versus pressure

5.5 Recommendations

Data mining is a powerful tool if analyzed and used in a simulation model without affecting the real system. The produced accuracy in the results helps companies to plan better and to make commitments based on accurate information.

It is important that the field performance is measured and studied to facilitate the evaluation of the constants of the Arbs decline equation. The performance is dependent on the organization's culture, agility and response process to the changing dynamics of the production facilities.

Well production allowable limits need to be further studied and formulated as part of the well lift curve process. In this study, the production decline factor was obtained after running a number of scenarios for different durations. The results vary between fields because of the uniqueness of the mode of operation of the field.

The suggested method for new developments to sustain production is indicative of the different operational philosophy. However, the concept testing different scenarios adds value to the analysis before committing investments.

5.6 The theoretical premise and research motive

The theory of Linear and Integer Programming in the reviewed literature is used for production modeling and forecast. It can't handle probabilities and facilities dynamics or changes in production strategies for enhanced recoveries (Hillier, F. and Lieberman, G., 1975).

The theoretical premise of the research is to apply an integrated discrete simulation model that is capable of handling random variables with the use of PDF where traditional linear programming and special purpose simulators are unable to model. Linear Programming faces limitations in modeling a dynamic oil field with large volume of variables and probability functions which calls for stochastic programming (Charle, V., Ansari, I.I. and Khalid, M.M., 2009). The discrete event simulation eases the stochastic programming formulation by introducing built in PDF and random number generators.

This was supported with the hypothesis testing and statistical correlation analysis. The results of the correlation analysis gave a strong reason to reject the company existing model on the basis of no correlation between the planned and actual production figures. The correlation analysis for the targeted production and the simulation results produced enough reasons to accept the simulation models' results. Additionally, the simulation results produced capabilities of identifying investment strategies based on the demand trend on the basis of data mining.

To achieve this, defining all the contributing factors or events is essential to model the deterministic and probabilistic events, to align the model with the physical production process and to provide an integrated simulation scenario for the company's strategies.

Based on the (ADMA production annual report, 2014) report;

- The current model is not capable of delivering the optimum production potential
- It can't help in planning future needs

The root causes of the problem in the current system are:

- Can't use trends and failure probabilities
- Does not account for all contributing variables
- Does not account for efficiency constraint
- Can't adapt easily to changes in strategy

The need to effectively manage the existing non-renewable resources along with a number of motivating factors related to:

- The uncontrolled lost production opportunity of 15%
- Increase in local demand
- Market competition which mandates more efficient operations
- The increase in diverse authorities which has increased bureaucracy

- The missing connectivity between the production process chains
- The need for integration to overcome delays in processing information

5.7 Contribution to the literature and body of knowledge

The reviewed literature mathematical programming issues and the most recent use of simulation to accommodate limited number of variables related to asset availability, mandates the search for comprehensive, timely and spontaneous model.

This research aspired to extend the use of new simulation technique in a fully integrated production chain from the well to the market, inclusive of all recognized data patterns to produce accurate production forecasts that serves the sought operational excellence by the Company.

A Discrete Event Simulator (DES) is fast to configure and modify and can accept stochastic variables and polynomial based parameters. Additionally, including production patterns in the model went a step further beyond (Burchel, S., 2014) model of BP, (Codasa, A., Campos, S., Camponogarab, E., Gunneruda, V. and Sunjergae, S., 2012) and a software product (DNVGL RAM Discrete Simulator, 2016).

Hence, the contribution of this research is to introduce a dynamic model to overcome limitations by:

- Including the stochastic variables which were not part of the previous models for the full production chain.
- Using data mining to handle equations' trends and constraints in one model which was not easily possible in previous models.
- Applying a practical integrated simulation method that is faster to implement while the readings used to build the model are still current when the optimization results are used.

The business and knowledge relevance of this contribution is in:

- Exploiting the use of production data mining to overcome the gaps between well tests which have been ignored in the computation of effective capacity. The assumptions that the lift curve results stay valid between tests is challenged and proved to be inaccurate.

- Introducing a new method to evaluate total production, injection and multiphase ratios by applying an integrated model for to all components of the production chain utilizing results from the existing specialized simulators.
- The new simulator flexibility allows for investment and divestment scenarios in the attempt to match the market volatility.
- Addresses the key variables through collective interviews and questionnaires with subject matter experts providing a collaborative approach which the company strives for.
- A challenge to the integer programming model suitability. The current model is being used with known shortfalls due to non-working alternatives that have been attempted through the literature review and in the case studies.
- The correlation analysis added a business intelligence factor that was not done before due to business priorities of operational nature.
- The research demonstrated that a development plan can be done quantitatively. It can materialize after evaluating the total production decline in the process chain. Scenarios of adding or removing assets are accounted for in a very timely manner.

5.8 Research limitations and future studies

Water injection is based on company policy and results of the reservoir studies. Therefore, no trending of injected material is conducted. Trending water injection has no added value being set as constant by the business. However, this can only add value if the injectors are equipped with a control mechanism to implement the simulation's recommended setting. Most injectors in mature fields do not have the controls to increase or decrease the injection ratios at the well site even when simulators consider it. Resource optimization is another limitation and may be achieved in a parallel model without complicating the facilities constraints.

Additional areas raised by this research and not included due to absence of data:

- Integration of discrete and numerical simulators in one model
- Enhance the configuration and graphics to be easily portable across facilities
- Enhance the network simulation and include flow lines with capacities and maintenance plans
- Introduce an HSE factor which has an impact on production due to regulations and emerging standards
- Integrate the injection into the formulation of reservoir contribution and material balance
- Integrate the pipeline flow assurance into the model to overcome bottlenecks

5.9 Chapter summary and highlights

The objective of this study is to optimize the use of the existing facilities to overcome lost production opportunities and for better utilization of the assets. The conventional methods proved to be long and impractical to implement due to the changes that take effect by the time the solution is ready. (Saputelli, L., Nikolaou, M. and Economides, M., 2006). Field operators require fast responses to the challenges they face. The use of a discrete simulator that can handle many variables and an unlimited number of production units results in both a shorter response time and more accurate production results.

This study addresses solving the business problem of lost production opportunity from two reservoir zones of petroleum in the Gulf region. Other researchers addressed similar problems using conventional means. Table 5-3 contains highlights of similarities and differences of previous researches.

Table 5-3 Highlight of differences with previous researches

Approach	Similarity	Differences
Literature review on production optimization	Previous studies conducted literature reviews on enhancing production	Use of mathematical programming for optimization. Few studies have used discrete simulation on a limited scale for asset reliability assessments to enhance

		outputs.
Survey of subject matter experts	Previous studies relied on authors' experiences in the subject	Having SME streamline the model and focus on the premise of benefiting from all disciplines is specific to this study.
Data mining of decision variables for trends	Used in the context of fit for purpose models	Used for correlation analysis and parameters settings for the integrated model
Executing simulation scenarios of the full production chain	Use of scenarios in the boundary of its limited fit for purpose models	Used collectively for handling production dynamics

This chapter explains how the model adds value to the body of knowledge of production optimization. This is achieved by introducing the factors that need to be considered to calibrate the production model. To reach this conclusion, a section of the chapter analyzed production decline and produced a method to calculate the number of wells required to sustain production.

Current practice for oil companies is to optimize the different phases of a production system separately. To avoid suboptimal decisions, there is a need for integrated optimization models that consider the relevant decision variables simultaneously. This research is about a preferred economical option to produce as much oil as possible within the facilities designed capacities.