Research Group in Reservoir Simulation and Management

Study Case for Reservoir Exploitation Strategy Selection based on UNISIM-I Field

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Summary

1. Introduction

The aim of this document is to present a reservoir study case to be submitted to decision analysis regarding exploitation strategy selection (project designated as **UNISIM-I-D**).

The chosen simulation model, shown in Figure 1, was built from the model entitled **UNISIM-I-R** (Avansi and Schiozer, 2013). In their article [1], the authors detail the construction of the model, in initial stage of the offshore oil field development with many uncertainties.

The required data for simulation for IMEX 2012.10 simulator will be available for download to the universities interested in the cases *(*http://www.unisim.cepetro.unicamp.br/benchmarks/unisim-i/*)*.

The case study has 1461 days (t_1) initial history production of 4 vertical wells. The objective of this project is to set an exploitation strategy between t_1 and the maximum final time (t_{final}).

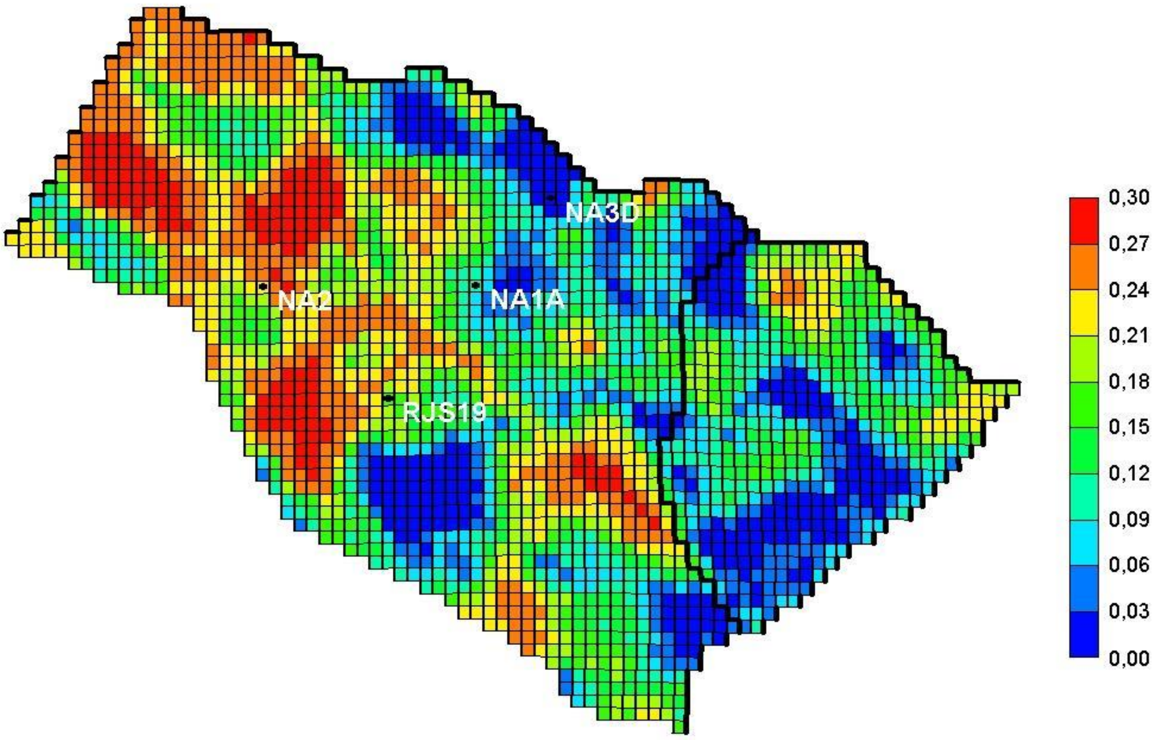

Figure 1: Porosity map (layer 1) with the location of the drilled wells.

The study will be done considering 2 approaches: (1) deterministic, no uncertainties and (2) probabilistic, geological, economic and operational uncertainties.

As this case is validation phase, any information, suggestions or problems are welcome. Send your comments by e-mail to unisim-becnhmark@dep.fem.unicamp.br.

2. Deterministic approach

2.1 Decision variables

The decision variables considered in the decision analysis process regarding the exploitation strategy selection are:

- Number of wells.
- Type of wells (vertical and/or horizontal conventional or intelligent).
- Wells location (i, j, k).
- Wells schedule (opening sequence of each well).
- Platform flow rates constraints on the liquid production (Cp_L), oil production (Cp_O), water production (Cp_W) and water injection (Ci_W). Assume oil processing capacity is equal to the liquid processing capacity in the simulation file.

Wells operational conditions must also be considered. If some types of operation with costs are inserted in the process, for example, wells recompletion, inflow control valves (ICV) etc., these costs must also be considered in the cash flow.

For the project to be executed similarly by all the groups, any additional cost should be communicated by email (unisim-benchmark@dep.fem.unicamp.br). The values and information will be sent for all the groups working in this project.

2.2 Important Date/Times

- 05/31/2013 (t_0) – 0 day:
    - Simulation initial time.
    - Production starting time.
- 05/31/2017 (t1) – 1461 days:
    - End of history production.
    - Analysis starting date (for updating cash flow).
- Between 05/31/2017 (t1) – 1461 days and 07/01/2018 – 1857 days: wells are drilled and completed.
- 07/01/2018 – 1857 days:
    - Date of incidence of investments on drilling, completion and platform/facilities.
    - Starting date for the implementation of the production system.
- Dates of opening each: Dates of incidence of investments on connection (well-platform).
    - Minimum interval for connection (well-platform) of each well: 30 days.
- 05/31/2043 (t_{final}) – 10957 days:
    - Maximum simulation final time.
    - Maximum date of field abandonment.

2.3 Premises

- Possible objective-functions of the deterministic case: Net Present Value (NPV), cumulative oil production (Np), cumulative water production (Wp) or their combination.
- Liquid production history of 4 vertical wells (NA1A, RJS19, NA3D e NA2): UNISIM-I_HistoryData_t1.zip file. The production history contains noise.

If history wells are used in the production prediction period, just connection (well-platform) cost must be considered (see data in

- Table 3); since drilling and completion costs had already been accounted for before analysis date (history period).

- Producers and injectors characteristics:
  - Vertical, horizontals.
  - Conventional, intelligent.
- Horizontal wells length: free.
- Minimum spacing between wells: 500 m.
- Maximum length of vertical wells: same configuration of history wells.

Table 1 presents the wells operating conditions for the production prediction period.

Table 1: Well data/operational conditions*

Type	Producer (Vertical)	Producer (Horizontal)	Injector (Vertical)	Injector (Horizontal)
Water rate (m^3/day)	-	-	Max 5000	Max 5000
Oil rate (m^3/day)	Min 20	Min 20	-	-
Liquid rate (m^3/day)	Max 2000	Max 2000	-	-
BHP (kgf/cm^2)	Min 190	Min 190	Max 350	Max 350
Radius (m)	0.156	0.0762	0.156	0.0762
GOR (m^3/m^3)	Max 200	Max 200	-	-
Geofac	0.37	0.37	0.37	0.37
Wfrac	1	1	1	1
Skin	0	0	0	0

* Modified SI system

Equation 1 presents how to calculate investments on platforms. This equation is based on data presented by Hayashi (2005) with some changes to incorporate other parameters other than those presented by her.

$$Inv_{plat} = 417 + (16.4 \times Cp_o + 3.15 \times Cp_w + 3.15 \times Ci_w + 0.1 \times n_w) \qquad \text{Equation 1}$$

Given that:

- Inv_{plat} : investment on platform (US$ millions).
- Cp_o: oil processing capacity = Cp_L: liquid processing capacity (1000 m^3/day).
- Cp_w: water processing capacity (1000 m^3/day).
- Ci_w: water injection capacity (1000 m^3/day).
- n_w: number of wells.

The 1st term of Equation 1 (417) comprises a fixed cost. Regarding the 2nd term, we assume that there is no gas injection; therefore there is not gas injection cost. In addition, the gas production cost is embedded in the coefficient (16.4) of the oil processing capacity variable.

The objective-function given by Equation 2 consists on Net Present Value (NPV) indicator, defined as the sum of the inflows and outflows of the cash flows, discounted at a discount rate in a given date.

$$NPV = \sum_{j=1}^{N_t} \frac{NCF_j}{(1+i)^{t_j}}$$ Equation 2

Given that:

- NCF_j: Net cash flow at period j.
- j: period time.
- N_t: total number of periods of time.
- i: discount rate.
- t_j: time of period j (average time of the period) related to the analysis date.

In this Project, the net cash flow for each period may be calculated by the following simplified equation based on the Brazilian R&T fiscal regime (Equation 3):

$$NCF = [(R - Roy - ST - OC) * (1 - T)] - Inv - AC$$ Equation 3

Given that:

- NCF: Net cash flow.
- R: Gross revenues from oil and gas selling.
- Roy: Total amount paid in royalties (charged over gross revenue).
- ST: Total amount paid in Social Taxes (special taxes on gross revenues).
- CO: Operational production costs (associated to the oil and water production and water injection).
- T: Corporate tax rate.
- Inv: Investments on equipment and facilities (platform, production and injection wells, network systems, pipelines etc.).
- AC: Abandonment cost.

Tables 2 and 3 present fiscal assumptions and the deterministic economic scenario to be adopted.

Table 2: Fiscal assumptions

Variable	Value
Corporate tax rate (%)	34.0
Social taxes rates - charged over gross revenue (%)	9.25
Royalties rate - charged over gross revenue (%)	10.0

Table 3: Deterministic economic scenario (most likely)

Variable/Parameter	Value	Unit
Oil price	314.5	(USD/ m^3)
Oil production cost	62.9	(USD/ m^3)
Water production cost	6.29	(USD/ m^3)
Water injection cost	6.29	(USD/ m^3)
Investment on drilling and completion of horizontal well	61.17	(10^3 USD/m)
Investment on connection (well-platform) of horizontal well	13.33	(USD millions)
Investment on drilling and completion of vertical well	21.67	(USD millions)
Investment on connection (well-platform) of vertical well	13.33	(USD millions)
Investment on recompletion of horizontal well	10.00	(USD millions)
Investment on recompletion of vertical well	8.00	(USD millions)

Investment on well conversion	10.00	(USD millions)
Investment on the 1st ICV per well	1.00	(USD millions)
Investment on 2nd or plus ICV per well	0.30	(USD millions)
Investment on platform	Equation 1	(USD millions)
Abandonment cost (% investment on drilling and completion)	8.20	--
Annual discount rate (%)	9.00	--

3. Probabilistic approach

3.1 Decision variables and premises

All the decision variables described in the deterministic approach (2.1) must also be considered for the probabilistic approach. The objective-function for this case is:

- Possible objective-functions or the probabilistic case: expected monetary value (EMV), risk, average cumulative production etc.

3.2 Geologic uncertainties

An uncertainty modeling was carried out to generate equiprobable images to be integrated in this decision analysis project. In addition, other uncertainties are considered.

- Petro: petrophysical characteristics (porosity, horizontal and vertical permeabilities, net-gross and facies): 500 images.
- cpor: rock compressibility.
- Krw: water relative permeability.
- PVT: region 2 PVT data (east block).
- WOC: region 2 oil-water contact (east block).
- Kz_C: vertical permeability multiplier.
- Strut: structural model.

Tables 4 and 5 present, respectively, the levels and the probability density functions (pdf) of the geological uncertainties for each attribute.

Table 4: Uncertainty levels and probabilities of the discrete geological attributes

Attribute (Probability)	**Levels**				
	0	**1**	**2**	**3**	**4**
Petro	500 equiprobable petropysical images				
Krw*	Krw0 (0.20)	Krw1 (0.20)	Krw2 (0.20)	Krw3 (0.20)	Krw4 (0.20)
PVT* Region 2	PVT0 (0.34)	PVT1 (0.33)	PVT2 (0.33)	-	-
Strut	With east block (0.70)	No east block (0.30)	-	-	-

* Krw and PVT tables are provided. Files: *krw_alpha.inc* and *pvt_beta.inc*, given that *alpha* and *beta* correspond to the levels.

Table 5: Uncertainty levels of the continuous geological attributes*

Attribute	Unit	PDF**
WOC Region 2	(m)	$\begin{cases} 0, & x < 3024 \\ \frac{x-3024}{22500}, & 3024 \le x \le 3174 \\ \frac{3324-x}{22500}, & 3174 \le x \le 3324 \\ 0, & x > 3324 \end{cases}$
Cpor / (10^{-6})	cm^2/kgf	$\begin{cases} 0, & x < 10 \\ \frac{x-10}{1849}, & 10 \le x \le 53 \\ \frac{96-x}{1849}, & 53 \le x \le 96 \\ 0, & x > 96 \end{cases}$
Kz_C	-	$\begin{cases} 0, & x < 0 \\ \frac{2x}{4.5}, & 0 \le x \le 1.5 \\ \frac{6-2x}{4.5}, & 1.5 \le x \le 3 \\ 0, & x > 3 \end{cases}$

* Modified SI system. ** *Probability Density Function*

Table 6 summarizes the essential topics of the modeling step: geostatistical modeling technique, petrophysical property associated to the uncertainty, uncertain parameters and probability distribution of the uncertain parameter. Constructed scenarios maintain the relationship between properties and their distribution properties. The scenarios are provided on the same case description webpage.

Table 6: Summary of the modeling step

Geostatistical Process	Petrophysical Property	Uncertain Parameters	Probability Distribution	Modeling Technique
Petrophysical Modeling	Porosity (Por)	Stocastic Modeling	Uniform	Sequential Gaussian Simulation
		Interval of the Variogram (See Table 7)	Normal	
		Mean (See Table 7)		
	Permeability (K)	Correlated with porosity	–	–
	Net-to-gross (NTG)	Correlated with facies	–	–

Porosity

Table 7: Parameters used for the specification of the effective porosity variogram model

Spherical Variogram Model					
Property	**Direction**	**Sill**	**Range**	**Mean**	**Standard Deviation**
Effective Porosity	Parallel	0.977	1000	14.34	10.83
	Normal	0.977	700		
	Vertical	0.977	9		

Permeability

Permeability was calculated from the correlation with porosity from core data from the UNISIM-I field (Avansi and Schiozer, 2013).

Net-to-gross

The facies type was associated with porosity. This criterion was used to set up reservoir net-to-gross. Facies cut-off, shown in Table 8, was defined based on the distribution analysis of facies 0, 1, 2 and 3 obtained from the well data regularization.

Table 8: Facies cut-off

Facies	NTG
3	0.0
2	0.6
1	0.8
0	1.0

Correlation coefficient

Table 9: Correlation coefficient – geological model used to generate the simulation model (before upscaling)

Property	Por	K	NTG
Por	1.000	1.000	0.395
K	1.000	1.000	0.395
NTG	0.395	0.395	1.000

Table 10: Correlation coefficient – simulation model (after upscaling)

Property	Por	Kx	Ky	Kz
Por	1.000	0.898	0.898	0.873
Kx	0.898	1.000	0.999	0.807
Ky	0.898	0.999	1.000	0.807
Kz	0.873	0.807	0.807	1.000
NTG	0.133	0.325	0.327	0.387

3.3 Economic Uncertainties

In addition to the most likely scenario, the optimistic and pessimistic economic scenarios are defined for each uncertain geological model as shown in Tables 11 and 12. Probabilities of occurrence considered to the pessimistic, the most likely and the optimistic scenarios are 25%, 50% and 25%, respectively.

Table 11: Optimistic Economic Scenario

Variable/Parameter	Value	Unit
Oil price	440.30	(USD/ m^3)
Oil production cost	81.80	(USD/ m^3)
Water production cost	8.18	(USD/ m^3)
Water injection cost	8.18	(USD/ m^3)
Investment on drilling and completion of horizontal well	76.46	(10^3 USD/m)
Investment on connection (well-platform) of horizontal well	16.66	(USD millions)
Investment on drilling and completion of vertical well	27.34	(USD millions)
Investment on connection (well-platform) of vertical well	16.66	(USD millions)
Investment on recompletion of horizontal well	12.50	(USD millions)
Investment on recompletion of vertical well	10.00	(USD millions)
Investment on well conversion	12.50	(USD millions)
Investment on the 1st ICV per well	1.50	(USD millions)
Investment on 2nd or plus ICV per well	0.50	(USD millions)
Investment on platform	1.25 x Equation 1	(USD millions)
Abandonment cost (% investment on drilling and completion)	8.20	--
Annual discount rate (%)	9.00	--

Table 12: Pessimistic Economic Scenario

Variable/Parameter	Value	Unit
Oil price	251.60	(USD/ m^3)
Oil production cost	52.40	(USD/ m^3)
Water production cost	5.24	(USD/ m^3)
Water injection cost	5.24	(USD/ m^3)
Investment on drilling and completion of horizontal well	54.00	(10^3 USD/m)
Investment on connection (well-platform) of horizontal well	11.66	(USD millions)
Investment on drilling and completion of vertical well	18.96	(USD millions)
Investment on connection (well-platform) of vertical well	11.66	(USD millions)
Investment on recompletion of horizontal well	8.80	(USD millions)
Investment on recompletion of vertical well	7.00	(USD millions)
Investment on well conversion	8.80	(USD millions)
Investment on the 1st ICV per well	0.70	(USD millions)
Investment on 2nd or plus ICV per well	0.20	(USD millions)
Investment on platform	0.80 x Equation 1	(USD millions)
Abandonment cost (% investment on drilling and completion)	8.20	--
Annual discount rate (%)	9.00	--

3.4 Other Uncertainties

Uncertainties for technical attributes are also considered as shown in Table 13.

- SA: systems availability; (observe: IMEX keyword ON-TIME can be used). Applied to platform, groups, producers and injectors.
- dWI: well index multiplier; 3 level discrete variable.

Table 13: Uncertainty levels and probabilities for technical attributes

Attribute	Type	Levels (Probabilities)		
		0 (0.34)	1 (0.33)	2 (0.33)
SA	Platform	0.95	1.00	0.90
	Group	0.96	1.00	0.91
	Producer	0.96	1.00	0.91
	Injector	0.98	1.00	0.92
dWI	dWI	1.00	1.40	0.70

4. Expected Results

After the decision regarding the strategy selection, a report should be generated including:

1. Selected Strategy Configuration (coordinates {i,j,k}, operational conditions of each well and groups constraints).
2. Process indicator data: chosen methods, number of simulation runs and computational cost, objective-function evolution.
3. Selected strategy indicator data:
    a. Main indicators: NPV, oil cumulative production (Np), recovery factor (RF).
    b. Secondary indicators: gas cumulative production (Gp), water cumulative production (Wp), water cumulative injection (Winj) and average field pressure (Pavg).
4. Producers indicators: oil rate, gas rate, water rate and costs.
5. Injector indicators: injected water rate (Winj) and costs.

5. References

1. Avansi, G.D., Schiozer, D.J., "Reference and Simulation Model UNISIM-I: Geological Modeling under Uncertainties and Reservoir Development Application" to be submitted to the International Journal of Modeling and Simulation for the Petroleum Industry, August 2013, Brazil.

2. Hayashi, S.H.D. *Valor da Flexibilização e Informação em Desenvolvimento de Campo por Módulos* [Value of Flexibility and Information in Field Development by Modular Implantation]. Campinas, São Paulo – Brazil: Faculty of Mechanical Engineering, State University of Campinas. 138p., Master thesis, 2006.

6. Provided files

The necessary files such as simulation data, Krw and PVT tables, images, history data etc are available for download in http://www.unisim.cepetro.unicamp.br/benchmark/unisim-i/.

7. Appendix-I

7.1 Wells Completions (reference model)

Wells NA1A, NA2, NA3D and RJS19 were completed as indicated in Table 14.

Important remarks: In the UNISIM-I-D, deterministic and probabilistic cases, the simulator can present some warnings due to completion in null blocks. These warnings indicated that the simulation model has some incompatibility with real completions.

For the deterministic case, we have made the correction by closing the completion where the warning message was occurring.

For the probabilistic case, this problem can be treated in the history matching problem. As each image has a different realization, the warnings can occur in different layers. This must be corrected during the history matching up to t1.

Therefore, the completions for the data files of the deterministic case (UNISIM-I-D-deterministic.dat) and probabilistic case (UNISIM-I-D-probabilistic.dat) are different.

Table 14: Wells Completions

NA1A	Well completions	
Interval	**Top* (m)**	**Bottom* (m)**
1	2962.6	3000.2
2	3001.2	3003.2
3	3007.2	3008.2
4	3011.2	3019.2
5	3020.2	3051.5
6	3052.5	3054.5
7	3055.5	3065.5
8	3066.5	3074.5

**True Vertical Depth*

NA2	Well completions	
Interval	**Top* (m)**	**Bottom* (m)**
1	3008.6	3031.6
2	3032.5	3047.6
3	3048.6	3050.6
4	3052.6	3053.6
5	3054.6	3058.6
6	3059.6	3063.6
7	3064.5	3073.5
8	3074.5	3088.5

NA3D	Well completions	
Interval	**Top* (m)**	**Bottom* (m)**
1	3021.2	3037.2
2	3043.2	3057.6
3	3058.6	3060.6
4	3062.6	3063.6
5	3064.6	3073.4
6	3074.4	3077.4
7	3079.4	3080.4
8	3081.4	3084.4

RJS19	Well completions	
Interval	**Top* (m)**	**Bottom* (m)**
1	2967.0	2984.0
2	2991.1	2992.1
3	2998.1	3001.1
4	3002.1	3007.1
5	3008.1	3009.1
6	3021.1	3024.1
7	3032.1	3033.1
8	3034.1	3035.1
9	3039.1	3041.1
10	3043.1	3044.1
11	3045.1	3058.0
12	3061.0	3067.0
13	3072.0	3073.0
14	3080.0	3081.0

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