INTEGRATION OF RESERVOIR MODELLING WITH OIL FIELD PLANNING AND INFRASTRUCTURE OPTIMIZATION

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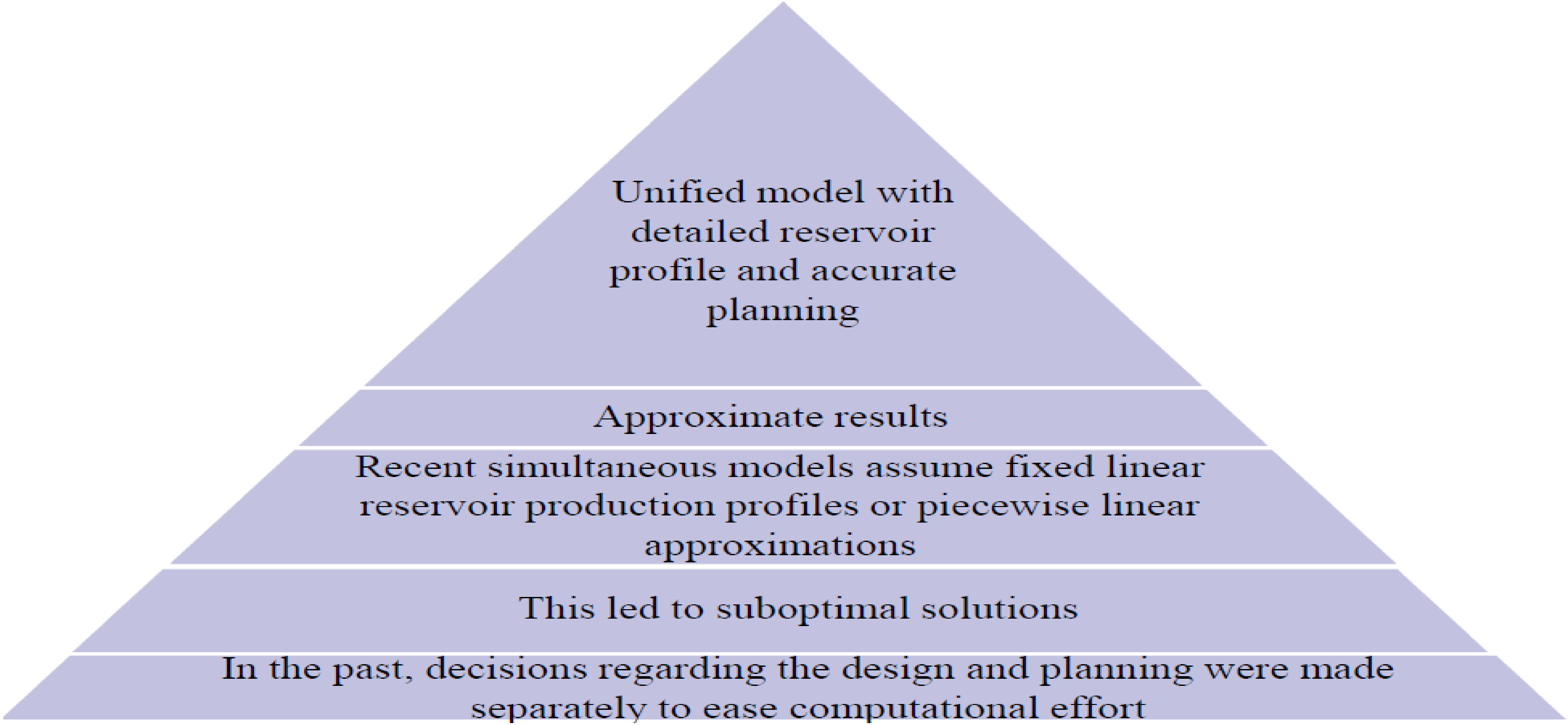
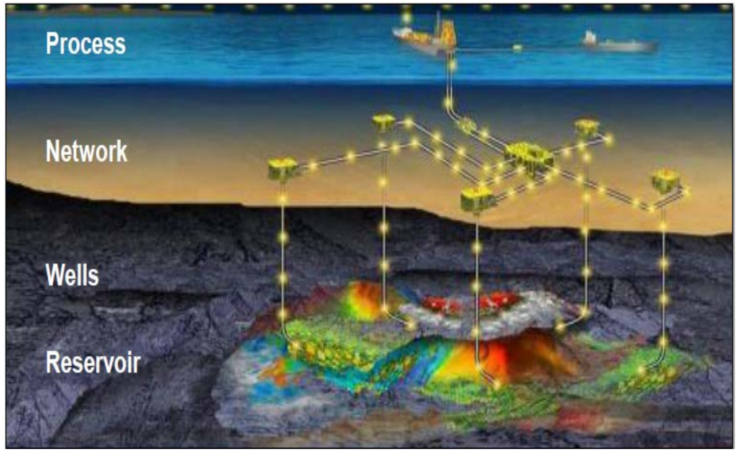
Motivation


Unified model with detailed reservoir profile and accurate planning
Approximate results
Recent simultaneous models assume fixed linear reservoir production profiles or piecewise linear approximations
This led to suboptimal solutions
In the past, decisions regarding the design and planning were made separately to ease computational effort

Problem statement

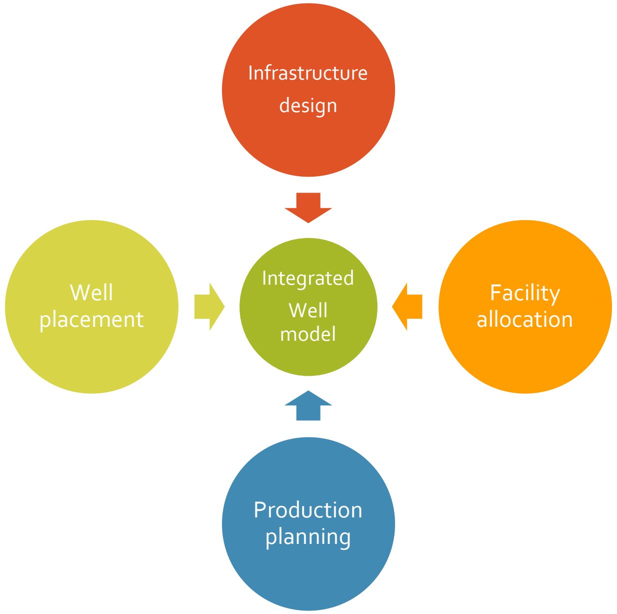
1) <u>Production planning problem</u>:

Maximize NPV(net present value) for production from a given number of wells under the desired production setup.



2) <u>Integrated well model</u>:

Development of a model that can predict the locations to drill new wells, surface infrastructure, well production profiles.



1. Operations Problem: Multiperiod NLP for Production Planning

❖ **Given information:**

➢ Number and location of wells.

➢ Productivity indices and Pressure Profiles.

➢ Variation of GOR and WOR.

➢ Maximum Separator Capacity of 8000 bbl./day.

➢ Selling prices and Costs.

❖ **Objective** is to maximize the NPV in the long term horizon.

Initial investment of 150 MUSD is not included in the objective function since it is constant and is paid up-front.

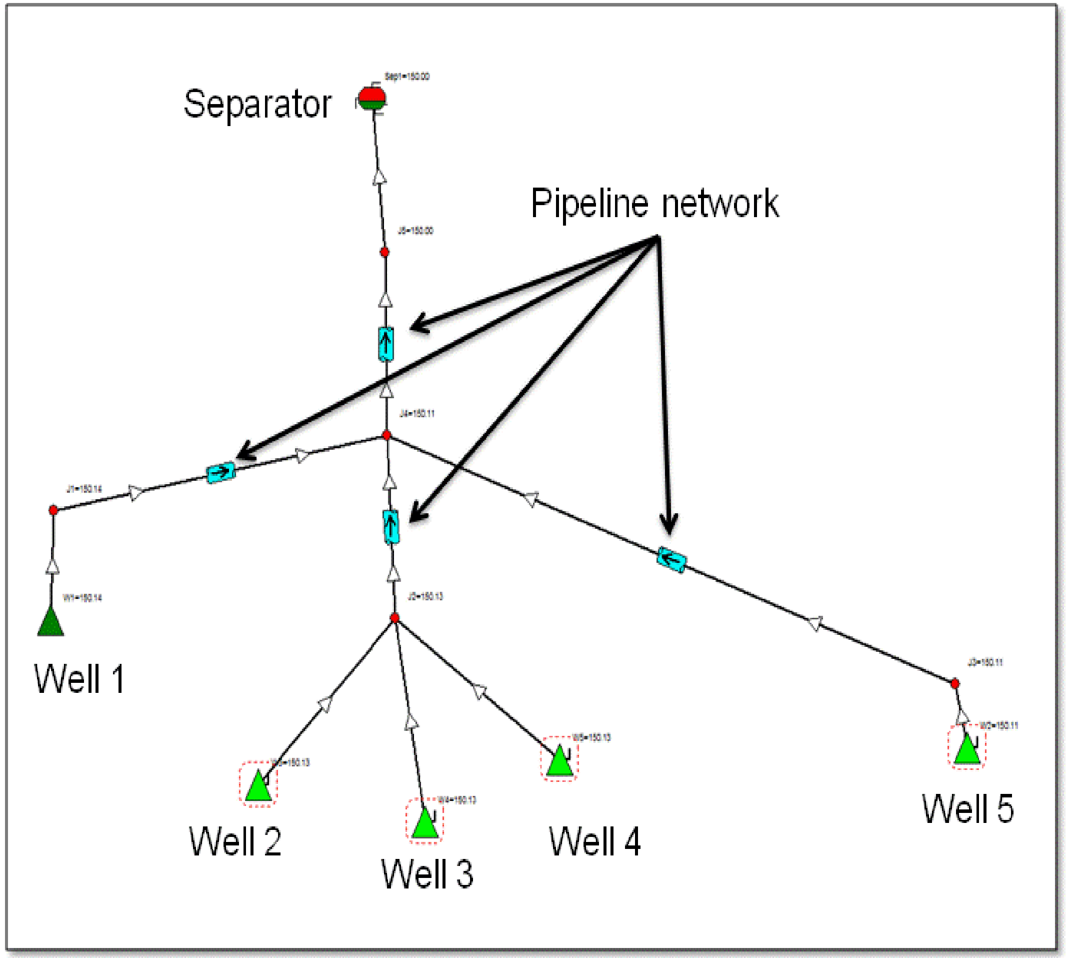
❖ **Assumptions:**

➢ Natural depletion of the reserves.

➢ Pipeline network is already established.

➢ Planning horizon is discretized into a number of time periods 't', typically 1 year.

➢ Water is re-injected into the well after separation and gas is sold.



Multi-period NLP model

- Objective function: Maximize NPV, **NPV =** $\sum_{\mathbf{time}}[\mathbf{REV}(\mathbf{t}) - \mathbf{COST}(\mathbf{t})] * \boldsymbol{disc}(\boldsymbol{t})$
- Total Revenue: **REV(t) = del(t) * (oil price(t) * oil produced(t)) + (gas price(t) + gas produced(t))**
- Total costs:

  COST(t) = del(t)*(gas compression cost * gas produced(t)) + (water treatment * water produced(t))
- Total Liquid Produced:

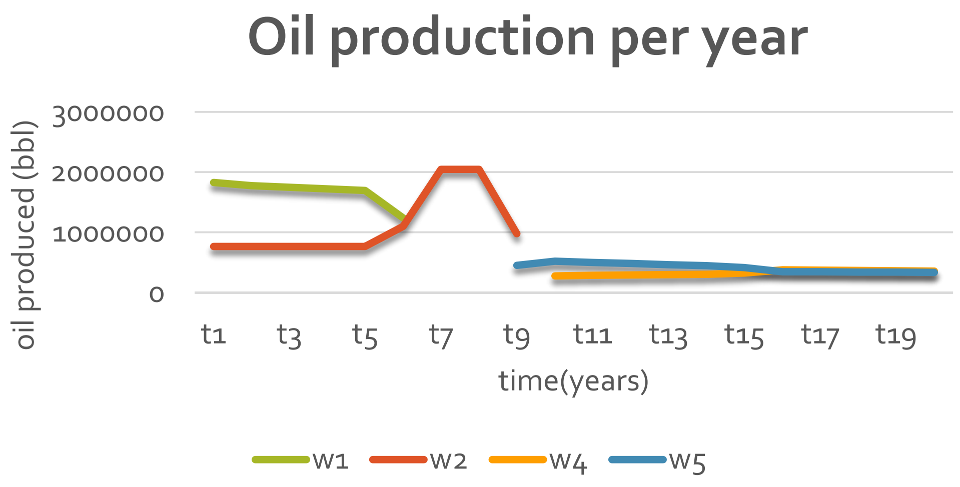
  Liquid produced (well, time) = Productivity index (well) * Pressure variation(well, time)
- Total liquid produced(time) = **Σ Liquid Produced(well, time)**
- Oil produced(well, time) = **Liquid produced * (1 – wct%(well, time))**
- Gas produced(well, time) = **Oil produced(well, time) * GOR(well, time)** ← Nonlinearity
- Upper bound for liquid produced: **Total liquid produced(t)** ≤ **Maximum separation capacity(t)**
- Upper bound for Oil production: $\sum_{\mathbf{well}} \mathbf{Oil\ recovered}(\mathbf{well}, \mathbf{time})$ ≤ **Cumulative Oil produced (well)**

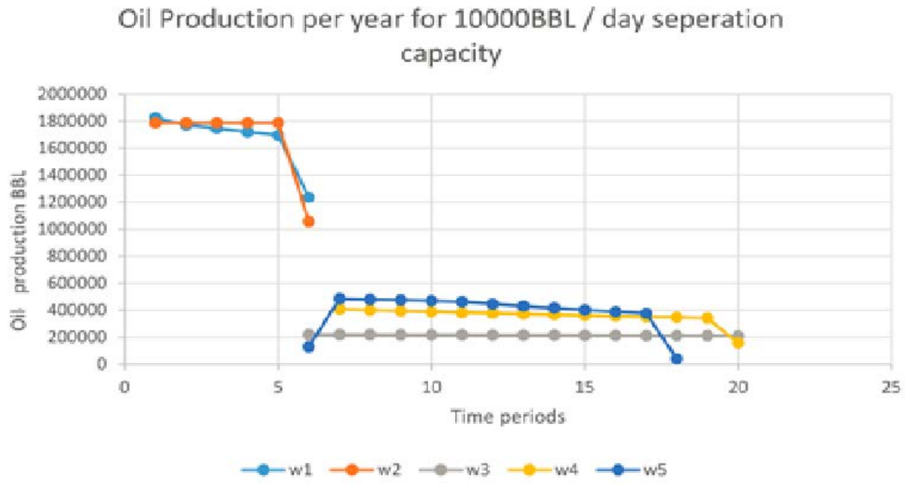
Results from the Multi-period NLP model

- **Model Statistics (BARON 14.4):**
- Number of wells: 5
- Number of time periods: 20 time periods of 1 year each.
- Number of Variables: 1303
- Number of single equations: 1408
- Solver CPU time: 67.54 seconds (1% relative optimality gap)
- **NPV = 1118.8758** MUSD
- Well number 3 is not producing.
- Two possible reasons:

  a) Liquid produced at maximum separating capacity.

  b) Unprofitable to produce from the well.
- An increase in separator capacity to 10,000 bbl./day leads to addition of well 3 to the planning horizon.





II. Well placement model

Given:

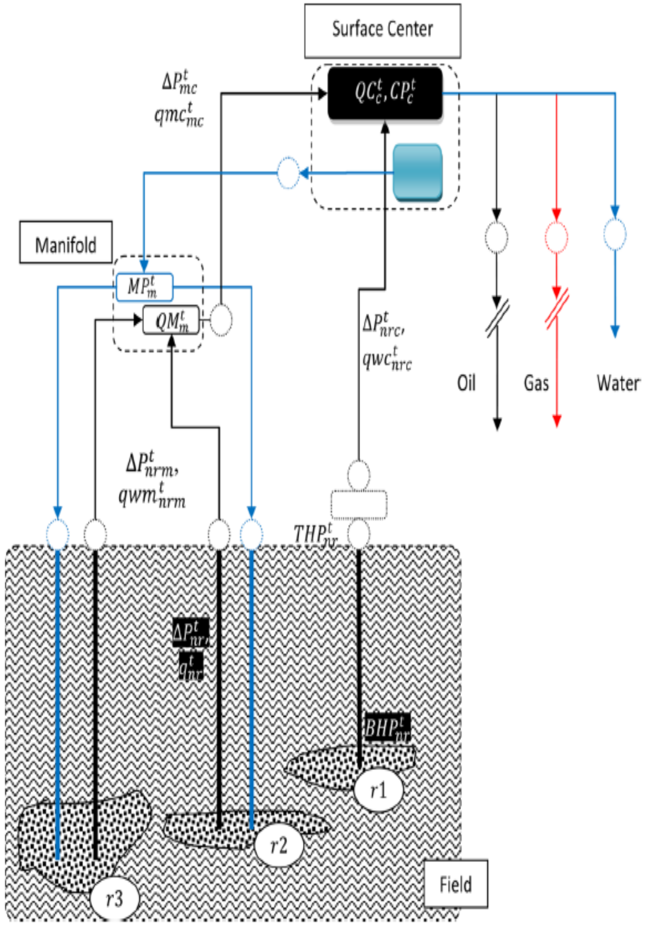
- Geological information such as dimensions, porosity, permeability.
- PVT information such as formation volume factor and fluid properties.
- Existing wells *and* their types.
- Minimum allowable well to well distance.
- Operational data such as water cut limits, max injection pressure, capacity expansion plans for surface facilities.
- Production horizons for 'H' years.
- Demand curve, drilling budget and costs.

Obtain:

- **Number and location of new producer wells and their production profiles.**
- Potential well-to-manifold, well-to-surface, and manifold-to-surface-center allocations.
- Dynamic pressure profiles along the network at processing centers, manifolds, wellheads, well bore holes.
- Number and location of manifolds and processing centers and incremental capacity expansion plan for surface processing centers.
- Dynamic pressure and saturation profiles for each reservoir.

Maximize NPV (Outer approximation algorithm)

- Reservoir dynamics and spatial discretization.
- Drilling and infrastructure design decisions.
- Well and surface Network flow management.



Schematic of a Hydrocarbon field

Reservoir modelling strategy

- Dynamic multiphase flow in a reservoir

$$\frac{\partial}{\partial t}\left[\varepsilon\frac{S_f}{B_f}\right] + q_f - \nabla\left[\frac{kr_f}{\mu_f B_f}\mathbf{K}\left(\nabla P_f - \rho_f\frac{g}{g_c}\nabla z\right)\right] = 0$$

- Backward finite difference approximation

$$\left(\frac{V_n}{dh^t}\right)\{d^t_{o,1,n}[P^t_n - P^{t-1}_n] + d^t_{o,2,n}[S^t_n - S^{t-1}_n]\} + q^t_{0,n\notin \mathbf{IW}}$$
$$+(\{M^t_{o,x-}\cdot T^x_{n-1}\cdot[P^t_n - P^t_{n-1}]\}_{(n-1)\in \mathbf{IX}} + \{M^t_{o,x+}\cdot T^x_n\cdot[P^t_n - P^t_{n+1}]\}_{n\in \mathbf{IX}}$$
$$+\{M^t_{o,y-}\cdot T^y_{n-I}\cdot[P^t_n - P^t_{n-I}]_{(n-I)\in \mathbf{IY}} + \{M^t_{o,y+}\cdot T^y_n\cdot[P^t_n - P^t_{n+I}]\}_{n\in \mathbf{IY}})$$
$$= 0 \qquad (35)$$

2-D discretization of reservoir

N1	**N2**	**N3**	**N4**
N5	N6	N7	N8
N9	N10	N11	N12
N13	N14	N15	N16

- Binary variable : y(n) → 1 if a well should exist in cell 'n'
- Use of decline curves for initialization of the model.

Application of models

❖ Production model:

Increase of the NPV for a given number of wells over a specified time horizon.

Model improvements :

a) Addition of network pressure drop in the production model.

b) Modelling of Gas lift.

❖ Integrated well model:

Development of holistic and integrated model for :

a) Number and location of new producer wells, manifolds and processing centers.

b) Production and injection planning for each well.

c) Well to manifold/center and manifold to center connections.

d) Spatiotemporal profiles of pressure and saturation in reservoir.

e) Pressure settings at various valves, manifolds and reservoir centers.

Thank you