Integration of Reservoir Modelling with Oil Field Planning and Infrastructure Optimization.

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CONTENTS

- A brief review on Oilfield Planning and Reservoir Simulators
    - Simulators available for oil reservoir modeling
    - Oil Field Planning and Infrastructure Optimization (A)
    - Well location and Control Optimization (B)
- Integration of A & B
    - Motivation
    - Approach
- Conclusion

RESERVOIR SIMULATORS USED

NAME	STATUS	ORGANIZATION
JewelSuite	Commercial	Baker Hughes
PumaFlow	Commercial	Beicip-Franlab
IMEX	Commercial	CMG
GEM	Commercial	CMG
STARS	Commercial	CMG
MERLIN	Commercial	Gemini Solutions
VIP	Commercial	Landmark(Halliburton)
Nexus	Commercial	Landmark(Halliburton)
ECLIPSE	Commercial	Schlumberger
INTERSECT	**Commercial**	**Schlumberger**
Paradigm Dynamic reservoir modeling	Commercial	Paradigm
Sensor	Commercial	Coats Engineering
MEPO	Commercial	SPT Group
TDRM	Commercial	BP

NAME	STATUS	ORGANIZATION
MRST	**Free**	**Sintef Applied mathematics**
OPM	Free	Open porous media
DuMu	Free	Part of OPM
Tecsheme	Free	Russian
GLS	Free	GeoOil
GPRS	**Free**	**Stanford University**
IMprove	Commercial	Intelligent Solutions Inc.

- INTERSECT, introduced by Schlumberger in 2009 has new features for more complex.
- Uses ParMETIS reservoir partitioning algorithm to balance parallel computational workload.
- Offers a new multisegment well model, advanced gridding, scalable parallel computing linear solver and effective field management.
- In Gorgon project (Shell + Chevron + Exxon), Surmont project (TOTAL) and Chevron’s Tenzig field INTERSECT outperformed the respective internal simulators in computational time by an order of magnitude.

OIL FIELD PLANNING AND INFRASTRUCTURE OPTIMIZATION

- **Lee and Aranofsky (1958) -** expressed the performance of reservoirs linearly as a function of time.
- **Bohannon (1970) -** proposed an MILP model assuming a predetermined linear decline of production rate with cumulative oil produced.
- **Sullivan(1982) -** approximated a nonlinear reservoir performance equation using piecewise linear interpolation.
- **Harding et al. (1996) -** assumed a predetermined target production rate and prescheduled capital investment for a fixed time period and tested SQP, simulated annealing and GA for multi field development and planning.
- **R. R. Iyer et al. (1998)** - model incorporates nonlinear reservoir performance, surface pressure constraints, and drilling rig resource constraints. Piecewise linear approximation to the reservoir performance. Sequential decomposition algorithm was proposed to solve the multiperiod MILP problem.
- **Susara A.Van den Heever et al. (2001)** – Reservoir model quadratic and cubic functions. Economic model includes revenue, capital costs, taxes, tariffs, royalties. Iterative algorithm based on Langrangean Decomposition and heuristic to find feasible solutions. Subgradient upgrading for Langrangean Multipliers.

OIL FIELD PLANNING AND INFRASTRUCTURE OPTIMIZATION

- **Van Den Heever, S. A., Grossmann, I. E.,(2000) -** an iterative aggregation/disaggregation algorithm is proposed in which logic-based methods, a bilevel decomposition technique, the use of convex envelopes and aggregation of time periods are integrated.

- **Van Den Heever, S. A., Grossmann, I. E., Vasantharajan, S., & Edwards, K. (2000).** Integrating complex economic objectives with the design and planning of offshore oilfield infrastructures.

- **Ortiz-Gomez, A.; Rico-Ramirez, V.; Hernandez-Castro, S. (2002)** Mixed-integer multiperiod model for the planning of oil-field production

- **Carvalho, M. C. A., & Pinto, J. M. (2006)** An MILP model and solution technique for the planning of infrastructure in offshore oilfields.

- **Vijay Gupta and Ignacio Grossmann (2012) -** Reservoir profiles in terms of cumulative water and cumulative gas produced that derived from WOR,GOR.

WELL LOCATION AND CONTROL OPTIMIZATION

- **Well Control :** Problem involves determining the optimal values for continuous operating variables, such as well rates or bottom hole pressures (BHPs), in order to maximize an objective such as NPV **.**

GRADIENT BASED METHODS

FINITE DIFFERENCE

- I. Aitokhuehi. *Real-Time Optimization of Smart Wells (2005).*
- M. L. Litvak et al. *Prudhoe Bay E-field production optimization system based on integrated reservoir and facility simulation.*
- P. Wang et al. *Optimization of production operations in petroleum fields.*
- B. Yeten, L. J. Durlofsky, and K. Aziz. *Optimization of smart well control.*

ENSEMBLE BASED

- M. M. Chaudhri, H. A. Phale, N. Liu, and D. S. Oliver. *An improved approach for ensemble-based production optimization.*
- H. Su and D. S. Oliver. *Smart well production optimization using an ensemble based method*.

ADJOINT

- D. R. Brouwer and J. D. Jansen. *Dynamic optimization of waterflooding with smart wells using optimal control theory*
- J. D. Jansen et al. *Closed-loop reservoir management (2005).*
- W. F. Ramirez. *Application of Optimal Control Theory to Enhanced Oil Recovery.*
- P. Sarma et al. *Implementation of adjoint solution for optimal control of smart wells*.

WELL LOCATION AND CONTROL OPTIMIZATION

Well Location : The well placement optimization problem involves maximizing an objective function by varying well types (e.g., injector or producer, vertical or horizontal) and well locations.

- **Interpolation methods** derieved from history matching. Least squares , regression (Pan and Horne, 1998; Aanonsen et al., 1995).
- **Simulated Annealing** , Beckner and Song (1995).
- **Evolutionary strategies**, GA - E Montes et al. (2001); Tupac et al. (2007); Morales et al. (2011); Ding (2008)
- **Particle swarm optimisation (PSO)** - Onwunalu and Durlofsky (2009a), Onwunalu and Durlofsky (2009b) and Ciaurri et al. (2011).
- **Derivative based methods** like finite differences or adjoint gradient estimation methods (Bangerth et al., 2006; Onwunalu and Durlofsky, 2009b; Zandvliet et al., 2008; Sarma and Chen, 2008), A. Ebadat & P.Karimaghaee (2012).
- Cullick, A. S., Vasantharajan, S., & Dobin, M. W. (2003). Determining optimal well locations from A 3D reservoir model.

WELL LOCATION AND CONTROL OPTIMIZATION

DERIVATIVE FREE METHODS FOR CONTROL AND LOCATION

- **D. Echeverr´ıa Ciaurri, T. Mukerji, and L. J. Durlofsky** *Derivative-free optimization for oil field operations.*
- **Masoud Asadollahi, Geir Nævdal, Mohsen Dadashpour, Jon Kleppe (2013)** *Production Optimization Using Derivative Free Methods Applied to Brugge Field Case.*
- **Isebor O.J. (2013)** *Derivative-free optimization for generalized oil field development.*
- **Isebor, O. J. (2009)** *Constrained production optimization with an emphasis on derivative-free methods.*
- **Afshari, S., Aminshahidy, B., & Pishvaie, M. R. (2011)**. *Application of an improved harmony search algorithm in well placement optimization using streamline simulation.*
- **Dadashpour M. et al (2010)** *A Derivative-Free Approach for the Estimation of Porosity and Permeability Using Time-Lapse Seismic and Production Data*

JOINT WELL CONTROL AND WELL PLACEMENT PROBLEM

- **C.Wang, G. Li, and A. C. Reynolds.** *Optimal well placement for production optimization.*
- **F. Forouzanfar, G. Li, and A. C. Reynolds**. *A two-stage well placement optimization method based on adjoint gradient.*

Gradient based in both works. Injection or production well added in every grid block of the reservoir model and wells that did not meet certain criteria eliminated

- **L. Li and B. Jafarpour.** *A variable-control well placement optimization for improved reservoir development.*

A sequential iterative procedure was used for the combined problem in which they alternate between the well placement and well control optimization problems. Coordinate descent random search method for the well placement part and a gradient-based procedure for the well control optimization.

- **M. C. Bellout, D. Echeverr´ıa Ciaurri, L. J. Durlofsky, B. Foss, and J. Kleppe**. *Joint optimization of oil well placement and controls.*

DFO for well placement and adjoint gradient based for well control problem

- **T. D. Humphries, R. D. Haynes, and L. A. James.** *Simultaneous optimization of well placement and control using a hybrid global-local strategy*

INTEGRATION OF WELL CONTROL, PLACEMENT AND OIL FIELD PLANNING AND INFRASTRUCTURE OPTIMIZATION

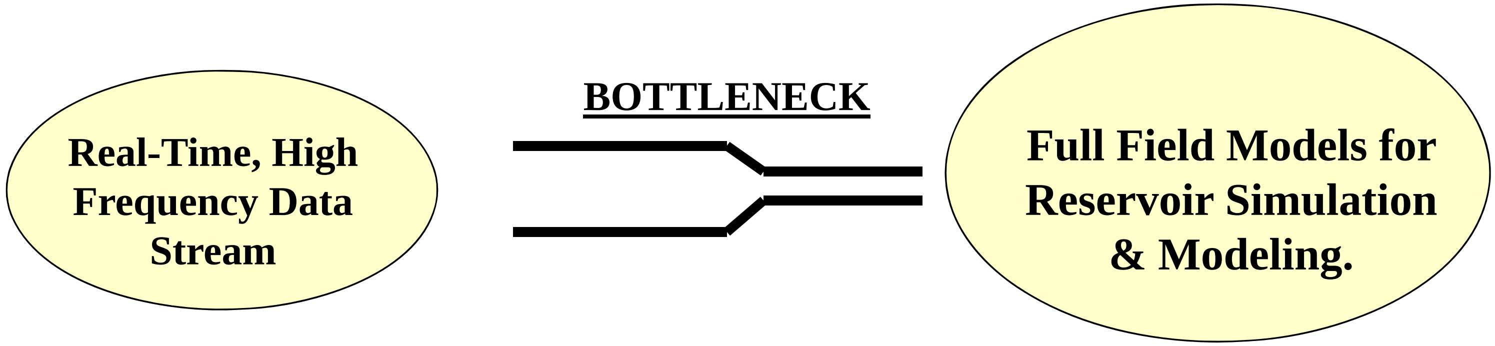
Limited work in this domain. Following works address it to some extent.

- **M.S. Tavallali a, I.A. Karimi et al. (2013)** ***Optimal producer well placement and production planning in an oil reservoir.***
  - A systematic model based approach that simultaneously considers drilling decisions along with production/injection profiles.
  - Subsurface physics , well geometry/dynamics, surface facilities, production profiles, market economics taken into account in the model. **Does not** consider Surface network dynamics.
  - Integrated model for oil well placement and production planning with detailed spatiotemporal 2D reservoir model. Results compared with ECLIPSE commercial reservoir simulator.

- **M.S. Tavallali a, I.A. Karimi et al. (2014)** ***Well Placement, Infrastructure Design, Facility Allocation, and Production Planning in Multi-Reservoir Oil Fields with Surface Facility Networks.***
  - Addresses well placement / surface network design (location and allocation) and production/ injection planning in a field with multiple irregular-shaped reservoirs supplying to a shared surface production-network facility.

MOTIVATION

To optimize the investment and operations decisions for oil and gas field development problem with computational ease and sufficient accuracy.



BOTTLENECK

Real-Time, High Frequency Data Stream

Full Field Models for Reservoir Simulation & Modeling.

Seconds, Minutes, Hours

Days , Months

Surrogate Models !

SURROGATE MODELS

- Size of the reservoir models grow, the time required for each run increases.
- Exhaustive search of solution space and quantification of uncertainties associated with geologic model.
- Grid computing and parallel processing helps to a certain degree but cannot close the large gap that exists between simulation runs and real-time processing.
- Surrogate Reservoir Models (SRMs)
  - Run in real time. Removes Bottleneck
  - Accurate replication of Full Field Model Results for each well.

Reduced-order models are

- Commonly derived using a projection framework that is, the governing equations of the forward model are projected onto a subspace of reduced dimension.
- This reduced subspace is defined via a set of basis vectors, which, for general nonlinear problems, can be calculated via the proper orthogonal decomposition.

TOOLS FOR SURROGATE MODELING

- Explore use of surrogate models of complex reservoir models using:

ALAMO

- *Learning Surrogate Models for Simulation-Based Optimization.* **Alison Cozad and Nikolaos V. Sahinidis (2014).**

SRM

- *Development of Surrogate Reservoir Models (SRM) For Fast Track Analysis of Complex Reservoirs.* **D. Mohaghegh et al. (2009).**
- **Mohaghegh et al., 1999; Mohaghegh et al., 2000).**

SUMO

- *A Surrogate Modeling and Adaptive Sampling Toolbox for Computer Based Design.* **D. Gorissen, K. Crombecq, I. Couckuyt, T. Dhaene, P. Demeester**

- Explore use of Reduced order models in reservoir simulation.

Development and application of reduced-order modeling procedures for reservoir simulation. M.A. Cardoso (2009)

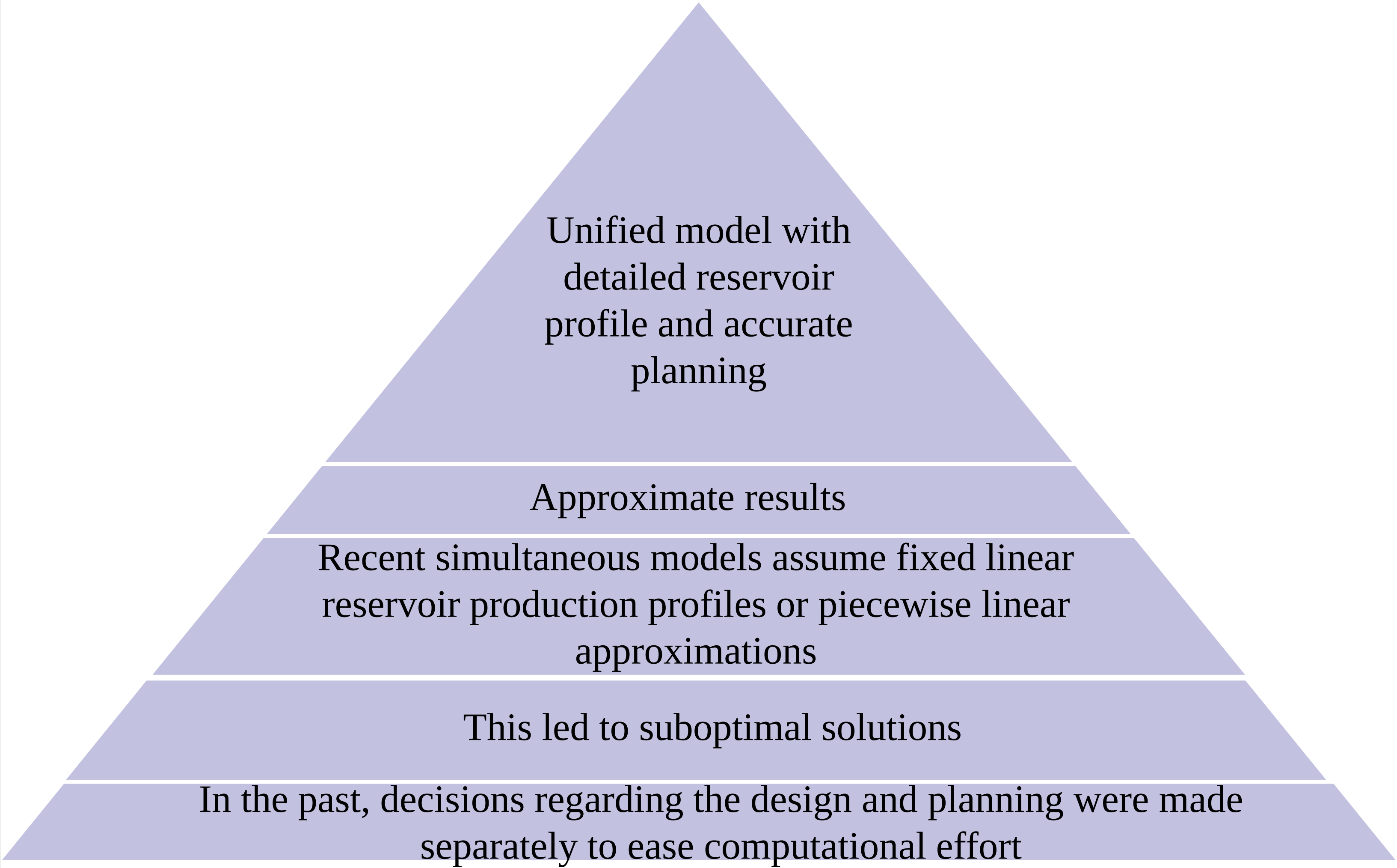
EXPLORING SRM

Software : IDEA^{TM}, Intelligent Data Evaluation & Analysis

Well-based Surrogate Reservoir Models (SRM):

- Developed by Intelligent Solutions Inc.
- Possible to perform large number of runs in short period of time
- Accuracy associated with the simulation models maintained
- Can mimic the reservoir model behavior both through time and space.
- Developed surrogate reservoir model can be used to forecast different scenarios by changing the related inputs

MOTIVATION FOR INTEGRATION



Unified model with detailed reservoir profile and accurate planning

Approximate results

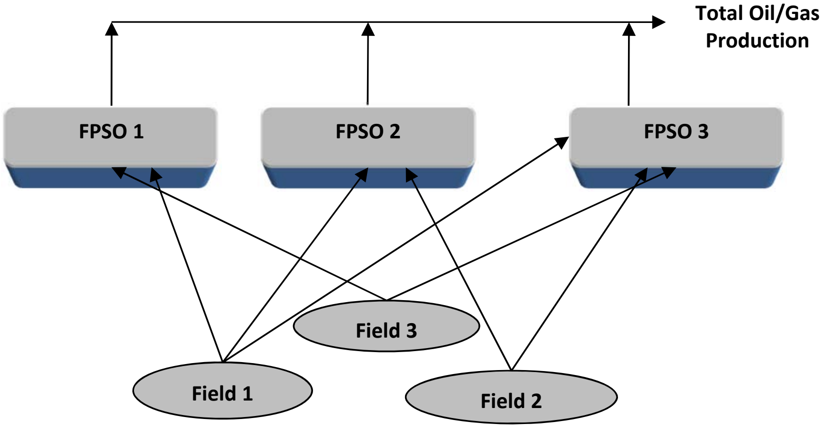
Recent simultaneous models assume fixed linear reservoir production profiles or piecewise linear approximations

This led to suboptimal solutions

In the past, decisions regarding the design and planning were made separately to ease computational effort

BENCHMARK PROBLEM

Real example case : Vijay Gupta and Grossmann (2012)



Given

- **3 Fields**

(Size: 230MMbbl, 280MMbbl, 80MMbbl)

- **3 FPSO's**
- **7 Possible Connections**
- **25 Potential Wells**
- **10 Years Horizon**
- **3 yr lead time for FPSO construction**
- **1 yr lead time for FPSO expansion**

Optimal NPV = 6.912 billion dollars

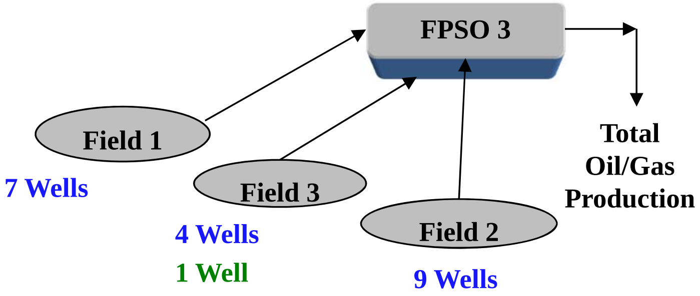
Optimal Installation and Drilling Schedule

1st Year: Install FPSO 3

Oil : 300 kstb/d
Liquid: 420.01 kstb/d
Gas: 212.09 MMSCF/d

4th Year: Drill 20 wells

5th Year: Drill 1 well



**Solved using DICOPT2x-C in GAMS 23.6.3 on an Intel Core i7 machine with 4 GB of RAM*

2-D RESERVOIR MODEL

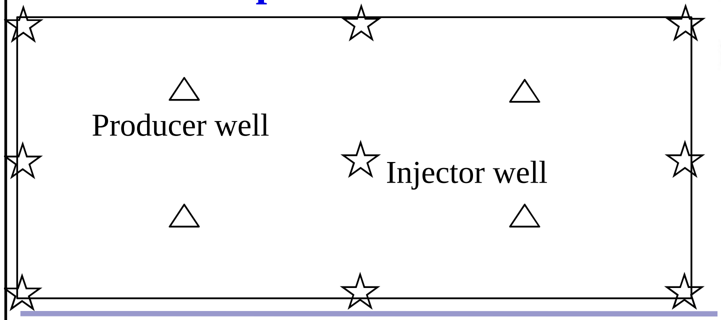
Reservoir Model: Tavallali, Karimi et al. (2012)

Case Study : Given

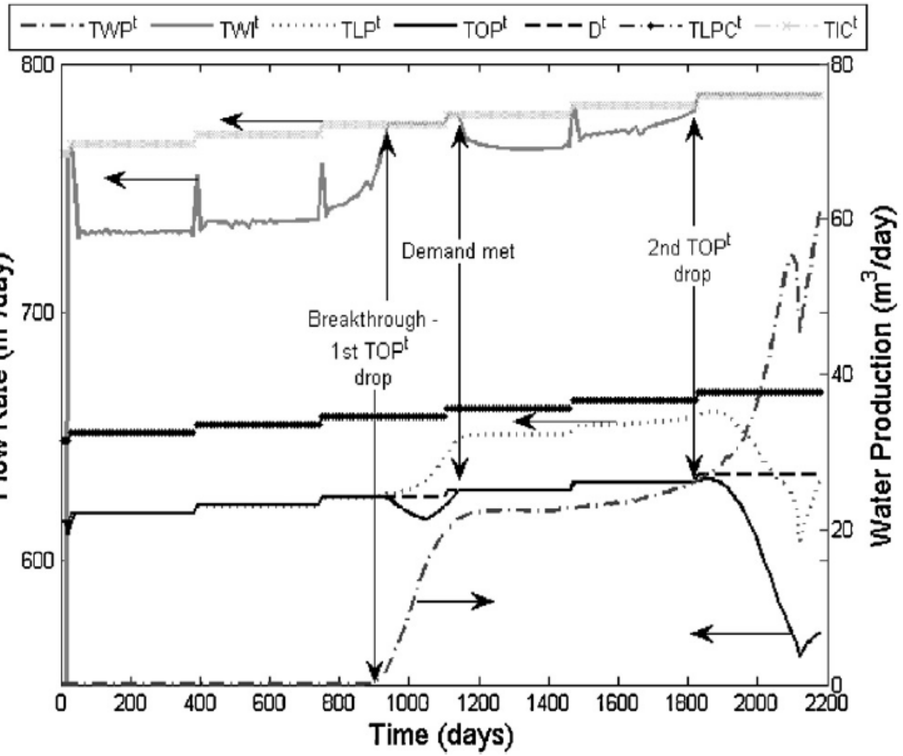
- 2D synthetic reservoir
- Time horizon 2180 days
- 1882m x 3184m x 5.56m
- MM$40 drilling budget,
- MM$5 cost of drilling each well

RESULTS

Number and locations of new producer wells.



Production and injection profiles for all wells



INTEGRATION

Reservoir profile based on 4th order polynomial equations

$$Q^{wc}_{f,fpso,t} = a_{2,f,fpso}\left(fc_{f,t}\right)^4 + b_{2,f,fpso}\left(fc_{f,t}\right)^3 + c_{2,f,fpso}\left(fc_{f,t}\right)^2 + d_{2,f,fpso}\, fc_{f,t}$$

$$Q^{gc}_{f,fpso,t} = a_{3,f,fpso}\left(fc_{f,t}\right)^4 + b_{3,f,fpso}\left(fc_{f,t}\right)^3 + c_{3,f,fpso}\left(fc_{f,t}\right)^2 + d_{3,f,fpso}\, fc_{f,t}$$

$$\forall\ f,\ fpso,\ t$$

↑

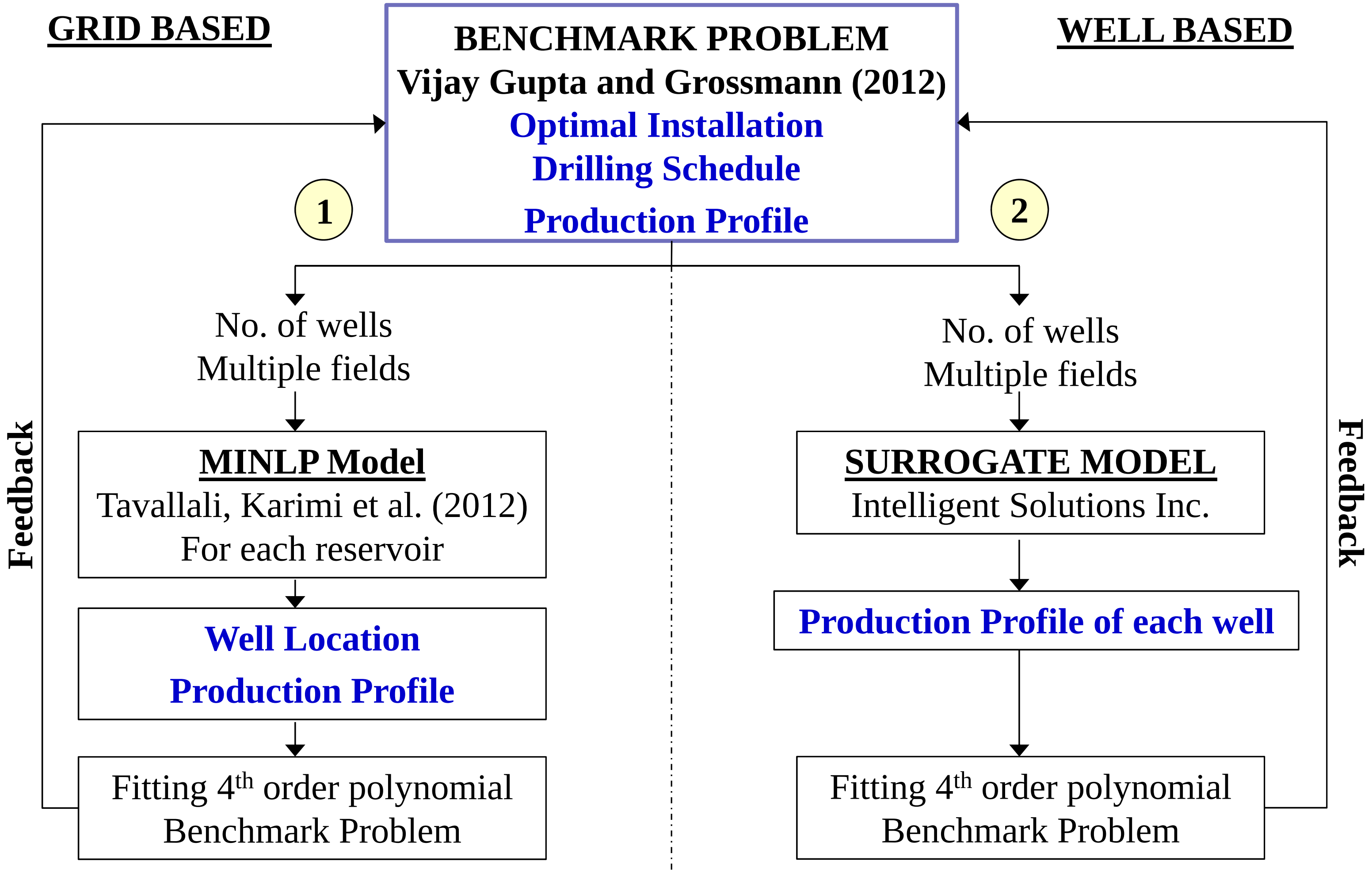
To be replaced by :

PDEs in Karimi's model

OR

Surrogate Model using SRM / SUMO / ALAMO

TWO WAY APPROACH



GRID BASED

WELL BASED

BENCHMARK PROBLEM
Vijay Gupta and Grossmann (2012)
Optimal Installation
Drilling Schedule
Production Profile

①

No. of wells
Multiple fields

MINLP Model
Tavallali, Karimi et al. (2012)
For each reservoir

Well Location
Production Profile

Fitting 4th order polynomial
Benchmark Problem

Feedback

②

No. of wells
Multiple fields

SURROGATE MODEL
Intelligent Solutions Inc.

Production Profile of each well

Fitting 4th order polynomial
Benchmark Problem

Feedback

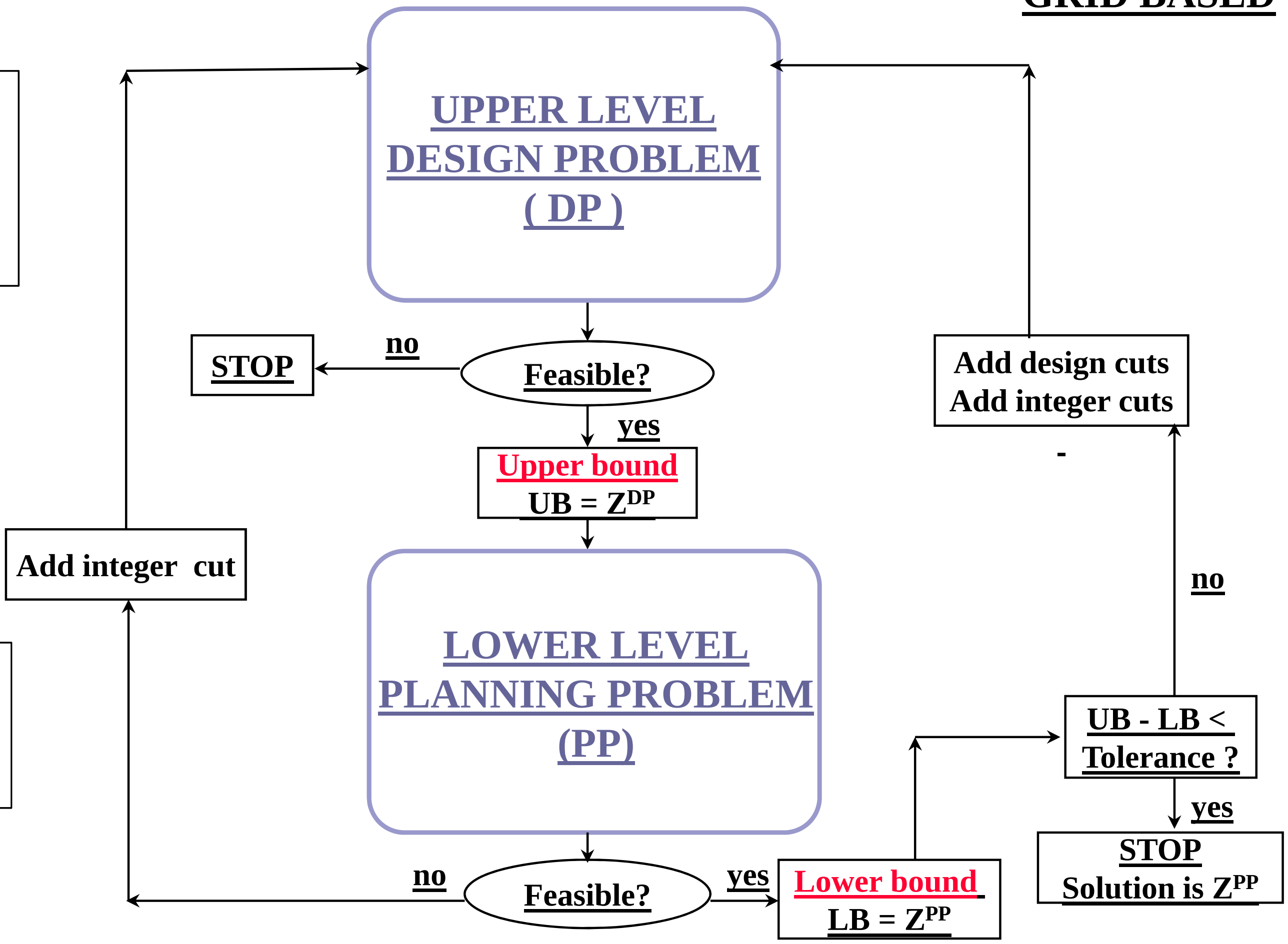
STRATEGY : Bi-Level Decomposition

①

GRID BASED

DP : Vijay Gupta and Grossmann (2012)

PP : Tavallali, Karimi et al. (2012)



UPPER LEVEL DESIGN PROBLEM (DP)

Feasible?

no → **STOP**

yes → **Upper bound** UB = Z^{DP}

LOWER LEVEL PLANNING PROBLEM (PP)

Feasible?

no → **Add integer cut**

yes → **Lower bound** LB = Z^{PP}

UB - LB < Tolerance ?

yes → **STOP** Solution is Z^{PP}

no → **Add design cuts** **Add integer cuts**

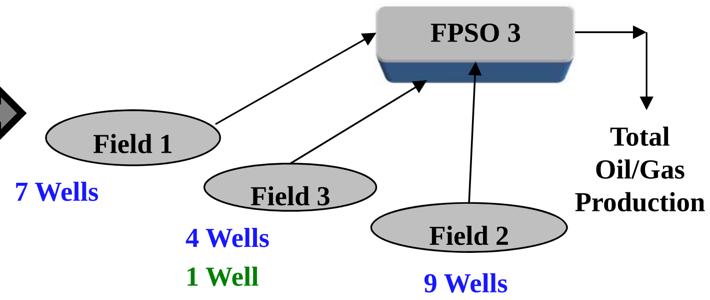
-

STRATEGY : Sequential

②

BENCHMARK PROBLEM
Vijay Gupta and Grossmann (2012)

Optimal Installation and Drilling Schedule



IDEA (Intelligent Solutions Inc.)

Training, Calibration, Verification
+
Sensitivity Analysis

Well based Surrogate model

Well data

Oil Production forecasting and uncertainty analysis

Assisted history matching using pattern recognition technology,
Alireza Shahkarami 2014

IDEA^{TM}, Intelligent Data Evaluation & Analysis

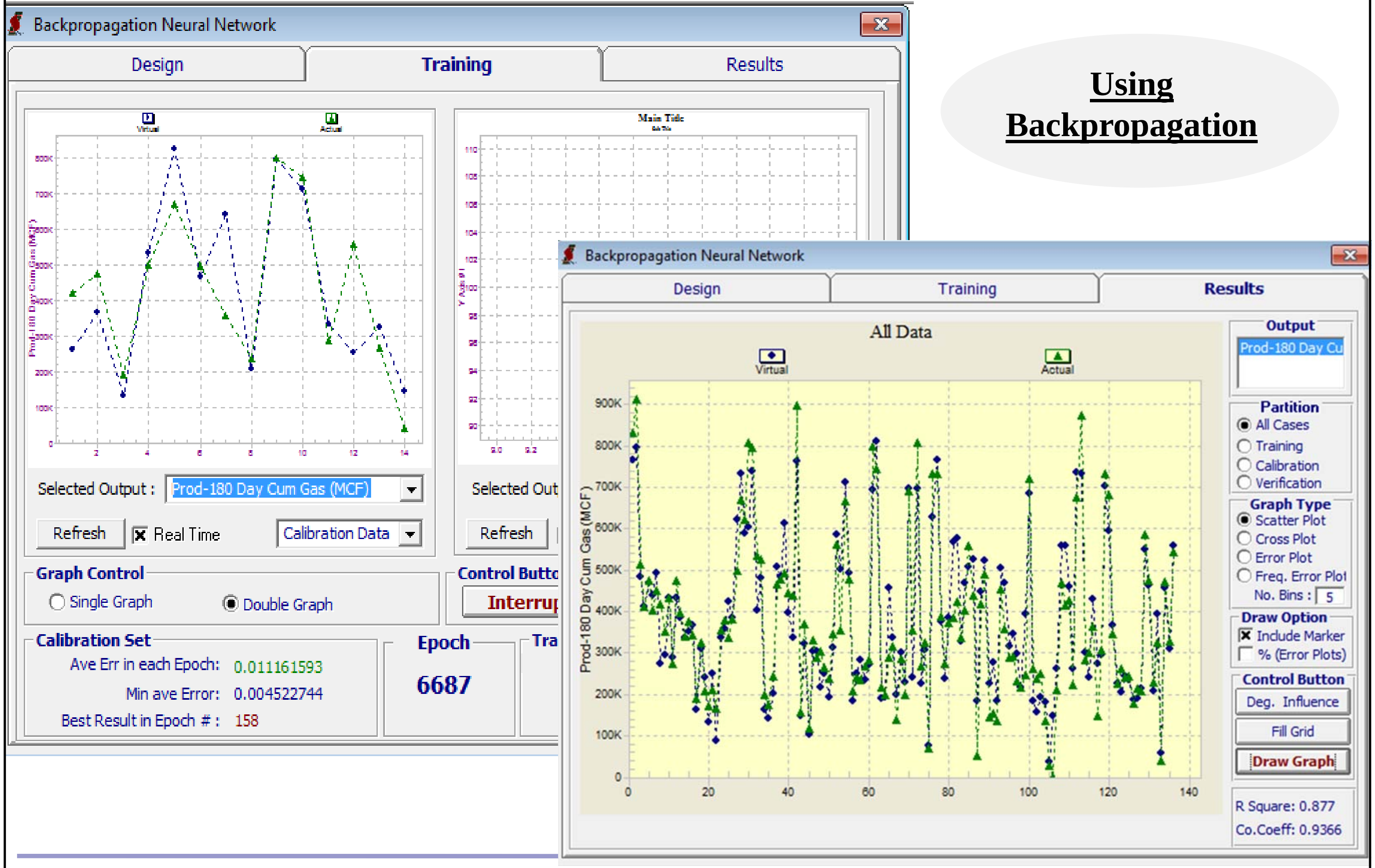
For Intelligent data analysis, data driven modeling and decision making by **Intelligent Solutions, Inc.**

Uses neural networks, genetic algorithms and fuzzy logic to solve complex problems.

- **Data Importing**
- **Missing Data Patching**
- **Data Mining**
  - **Data Analysis**
  - **Cluster Analysis**
- **Neural Model Development**
  - **Data preparation**
  - **Training**
  - **Analysis**
- **Neural Model Application**

NEURAL NETWORK DEVELOPMENT

Using Backpropagation



Selected Output : Prod-180 Day Cum Gas (MCF)

Refresh ☒ Real Time Calibration Data

Graph Control

○ Single Graph ● Double Graph

Calibration Set

Ave Err in each Epoch: 0.011161593

Min ave Error: 0.004522744

Best Result in Epoch # : 158

Epoch

6687

Output

Prod-180 Day Cu

Partition

- ● All Cases
- ○ Training
- ○ Calibration
- ○ Verification

Graph Type

- ● Scatter Plot
- ○ Cross Plot
- ○ Error Plot
- ○ Freq. Error Plot

No. Bins : 5

Draw Option

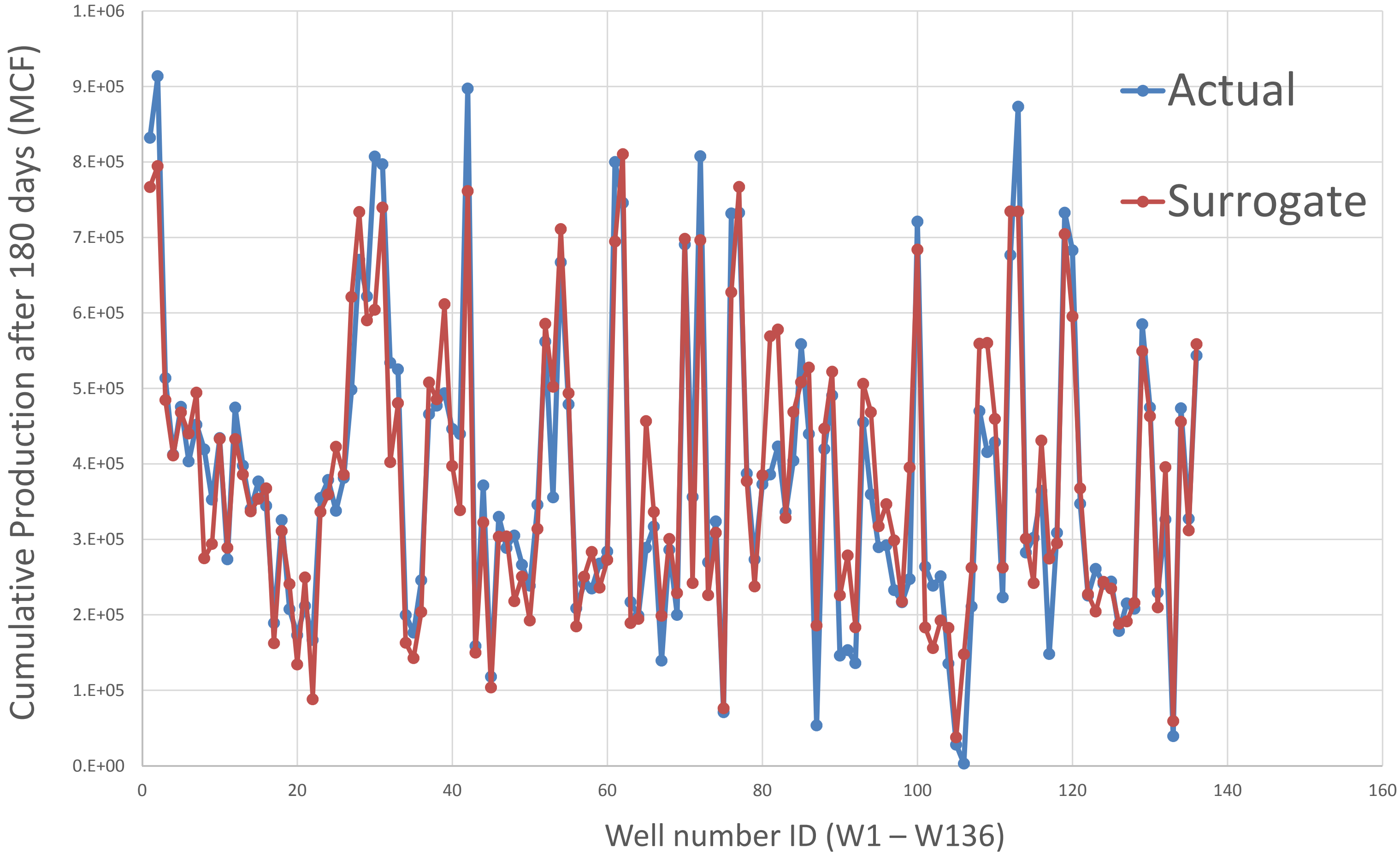
- ☒ Include Marker
- ☐ % (Error Plots)

Control Button

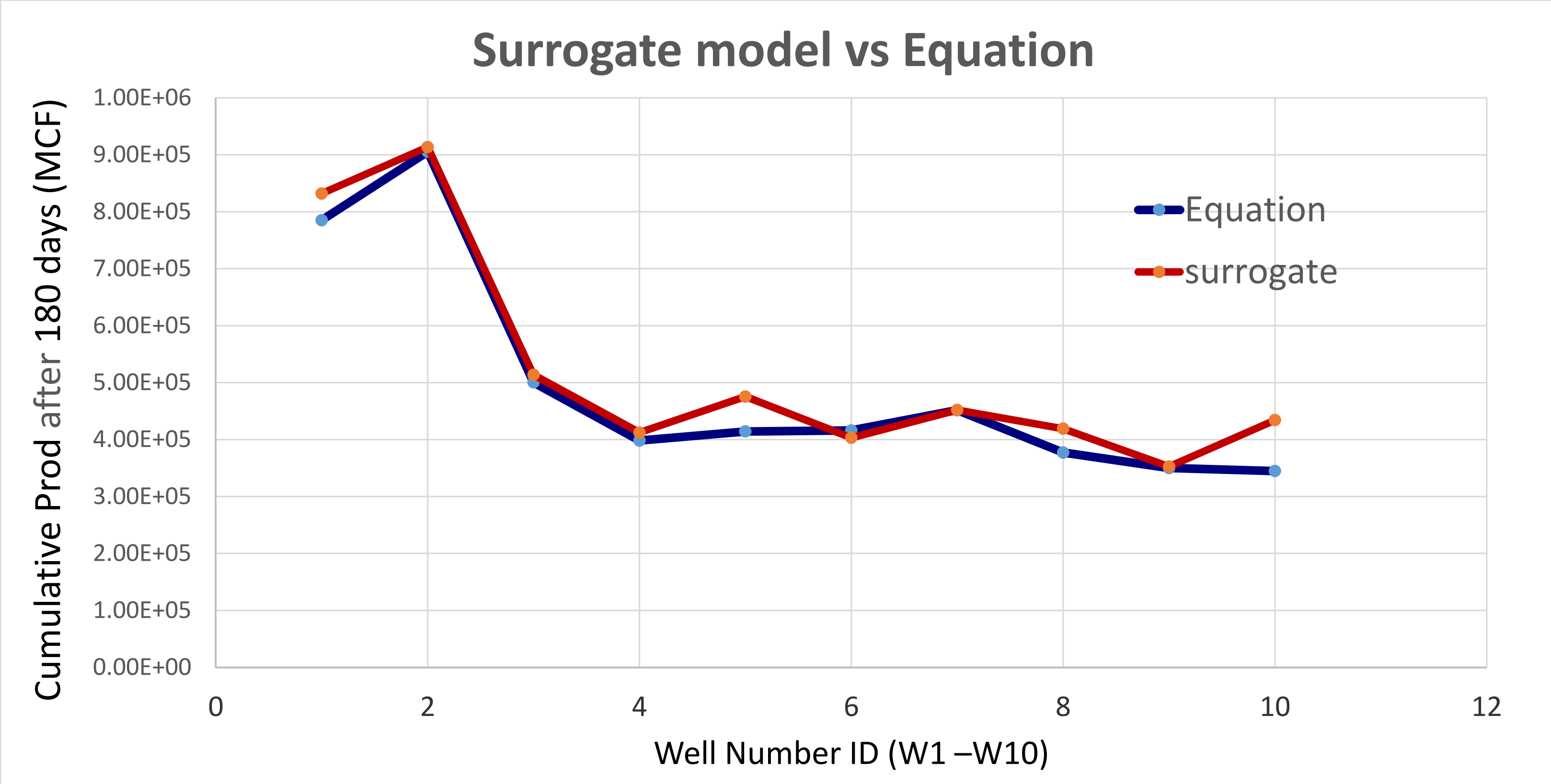
R Square: 0.877

Co.Coeff: 0.9366

Accuracy of Surrogate Model by IDEA™



Accuracy of ALAMO based equation



$$Cumulative\ Prod._{180\ days} = 0.55\text{x}10^4\ Ø^{2.5} - 0.27\text{x}10^8\ (K \text{ x } GT)^{1.8} - 0.32\text{x}10^9\ (Ø/K)^{2.2}$$

Ø = Porosity **K = Permeability** **GT = Gross Thickness**

CONCLUSION

WORK PLAN

- GRID BASED APPROACH
  - Reproduction of Karimi’s MINLP Optimal well placement model
  - Integration with Oil Field Planning model
  - Bi-Level decomposition and subsequent optimization.
- WELL BASED APPROACH
  - Development of Well Based surrogate model
  - Fitting polynomial reservoir profile
  - Production forecast
- Comparison of results with Benchmark problem.

Acknowledgement

Intelligent Solutions Inc. for IDEA™