Joint Optimization of Economic Project Life and Well Controls

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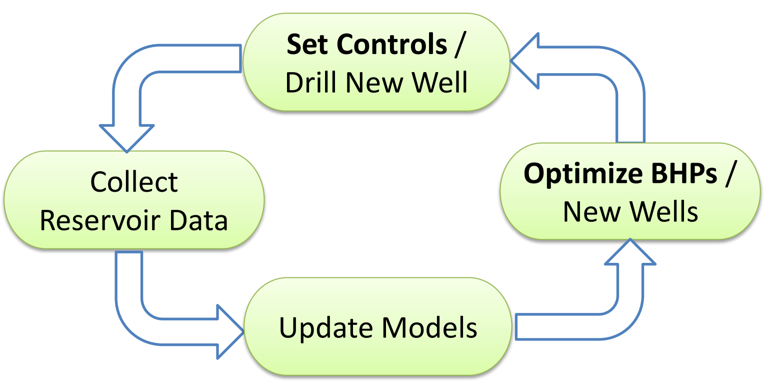
Closed-loop Field Development (**CLFD**)



- How to determine optimal project life in reservoir operation?

Shirangi & Durlofsky, *SPEJ* 2015

Outline

- Motivation
- Rate of return for reservoir optimization
- Joint optimization of well controls and economic project life (EPL)
- Computational results

Motivation

- In optimization, **project life** typically specified a priori
- Often assume that decisions are solely based on **NPV**
- In investment science, **rate of return** is as important as **NPV**
- Here we develop a new formulation that incorporates both **NPV** & **rate of return**

Motivation

- In optimization, **project life** typically specified a priori
- Often assume that decisions are solely based on **NPV**
- In investment science, **rate of return** is as important as **NPV**
- Here we develop a new formulation that incorporates both **NPV** & **rate of return**
- **Project life** refers to operation with current configuration (distinct from reservoir/contract life)

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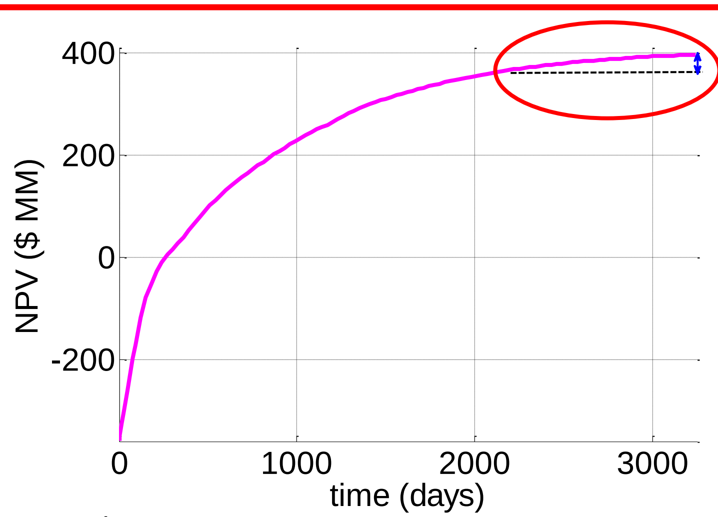
NPV Trajectory



- Last 1/3 of project life increases NPV by only 3.5%

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Rate of Return Computation

- Internal rate of return (**IRR**): discount rate for which NPV=0
- Modified internal rate of return (**MIRR**): requires specification of reinvestment rate for intermediate cash flows
- Companies also specify minimum attractive rate of return (**MARR**, hurdle rate)

IRR: Hazen (2003), Hartman & Schafrick (2004)
MIRR: Lin (1976), Kierulff (2008), Balyeat et al. (2013), Magni (2010, 2013)

Present Value vs Future Value

- Specify $T = n_{cs}\,\Delta t_{cs}$
- Net **present value**: $\sum$(cash flow)$\times$(discount factor)

$$\mathbf{PV} = \mathrm{CAP} + \sum_{l=1}^{n_{cs}} F^l \frac{1}{(1+r)^{t_l/365}}$$

Cash flow: $F^l = Q_o^l p_o - Q_w^l c_w - Q_{wi}^l c_{wi} - f_c$

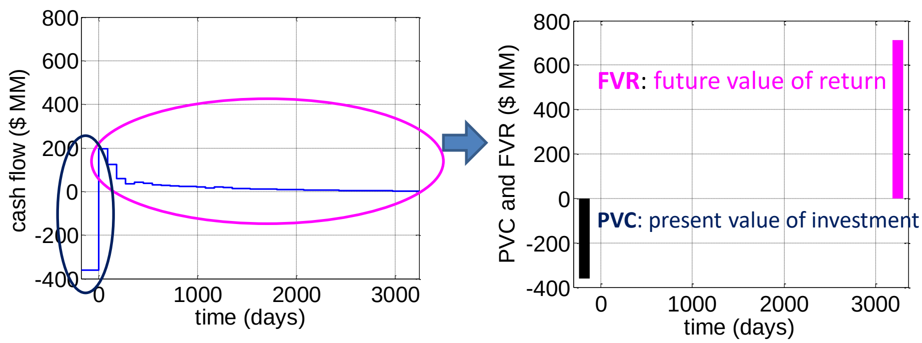
- Can also compound the cash flow to the end of project life, and compute net **future value**:

$$\mathbf{FV} = \mathbf{PV}(1+r)^{T/365}$$

r: discount rate

Cash Flow Stream

- Cash flow = Revenue – Cost



- Simplify cash flow stream to initial investment of **PVC** and total income of **FVR** at the end of project life

Refs: Lin (1976), Kierulff (2008), Balyeat et al. (2013)

Modified Internal Rate of Return (MIRR)

- **MIRR** is the discount rate such that future value of return equals present value of investment
- Compute MIRR (i_m) at each t :

$$\mathbf{PVC} = \frac{\mathbf{FVR}}{(1 + i_m)^{t/365}}$$

PVC: capital investment
FVR: future value of all positive cash flows (until t)

- Require $i_m \geq r_{\text{hurd}}$ (hurdle rate, MARR)

Joint Optimization of Life and Controls

- Optimization problem:

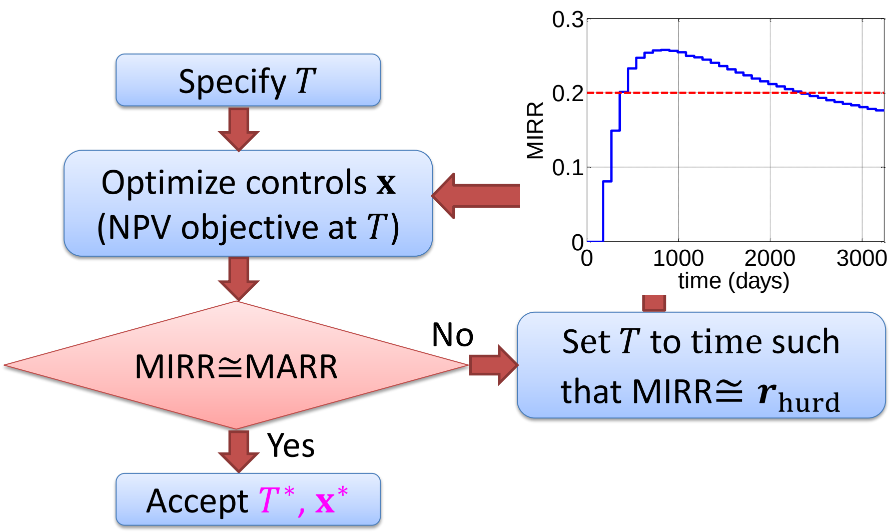
$$\max_{T}\left\{\max_{\mathbf{x}(T)} \mathrm{NPV}(\mathbf{x}, T)\right\},$$

$$\text{subject to } \left|i_m - \boldsymbol{r}_{\text{hurd}}\right| \le \epsilon$$

  - Apply nested optimization
    - outer loop entails specification of T (project life),
    - inner loop optimizes $\mathbf{x}$ (well controls)
    - apply adjoint-gradient-based ADGPRS + SNOPT

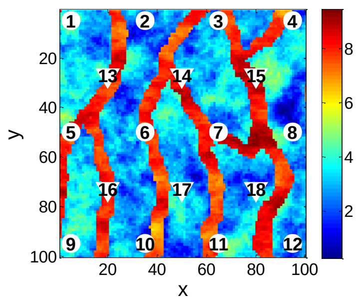
- Specify hurdle rate $\boldsymbol{r}_{\textbf{hurd}} = \boldsymbol{r} + \mathbf{0.1}$

Joint Optimization Flowchart



2D Bimodal Reservoir Example

- Determine optimal project life and optimal well controls
- Porosity=0.2 (sand), 0.1 (shale)
- 18 wells, capital investment of $360 MM
- Discount rate is $r = 0.1 \rightarrow r_{\mathrm{hurd}} = 0.2$



Parameter	Value
Prod BHP	70-310 bar
Inj BHP	310-483 bar
Oil price	$ 70 / bbl
Water cost	$ 7 / bbl
Discount rate	10%
Control step	90 days

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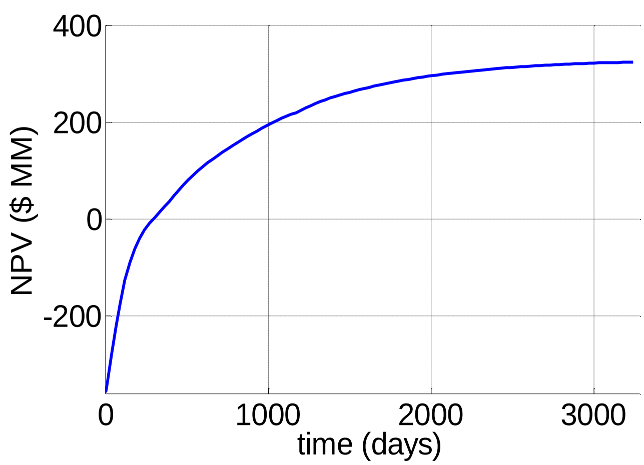
NPV Trajectory

- Specify $T = 3240$ days and optimize



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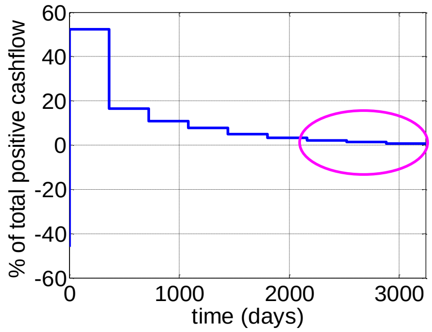
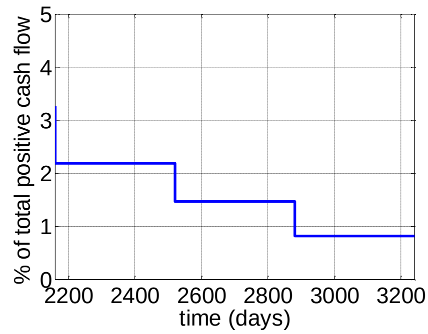
Cash Flow Stream for T= 3240 days

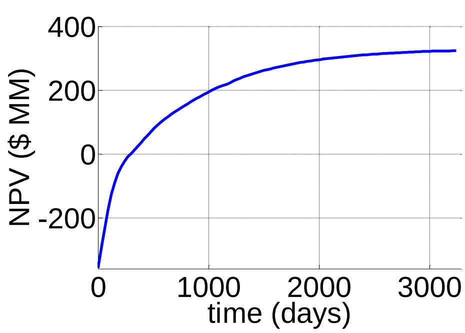


Cash flow percentage

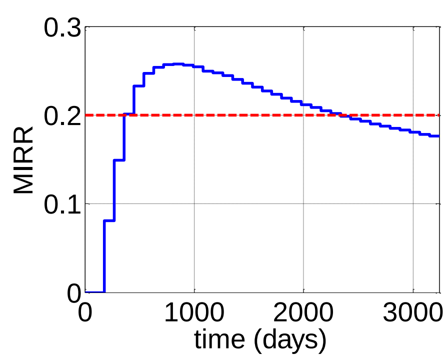


Magnification for last 3 years
(**4.5%** of total cash flow)

Modified Internal Rate of Return ($r_{\min}$= 0.2)



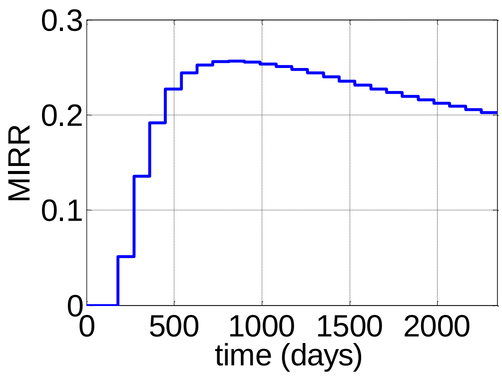
NPV trajectory



MIRR trajectory

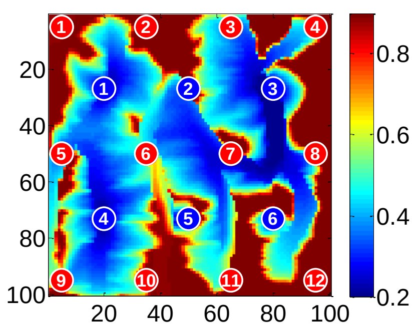
- Specify $T = 2340$ and repeat the inner control optimization

NPV & MIRR with T^*= 2340 days

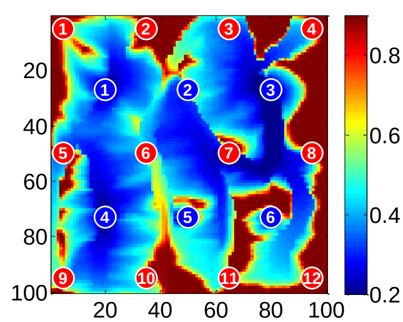


- Optimization required 3 outer iterations (optimizing T), inner control optimization takes about 100 simulations ($r_{\text{hurd}} = 0.2$)

Final Saturation Maps



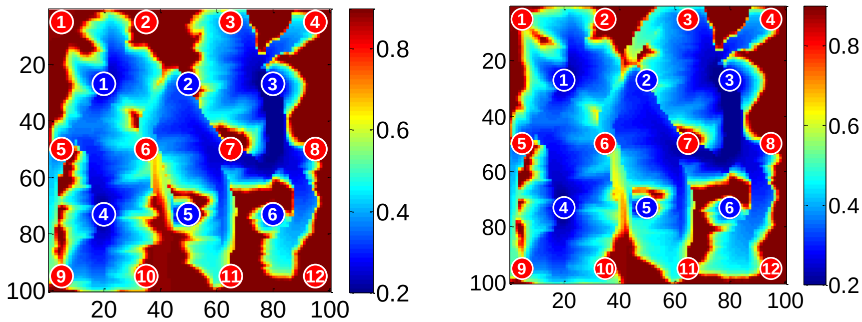
T^*= 2340 days



T= 3240 days

T (days)	MIRR	NPV ($ MM)
2340	0.20	311.6
3240	0.17	323.3

Final Saturation Maps

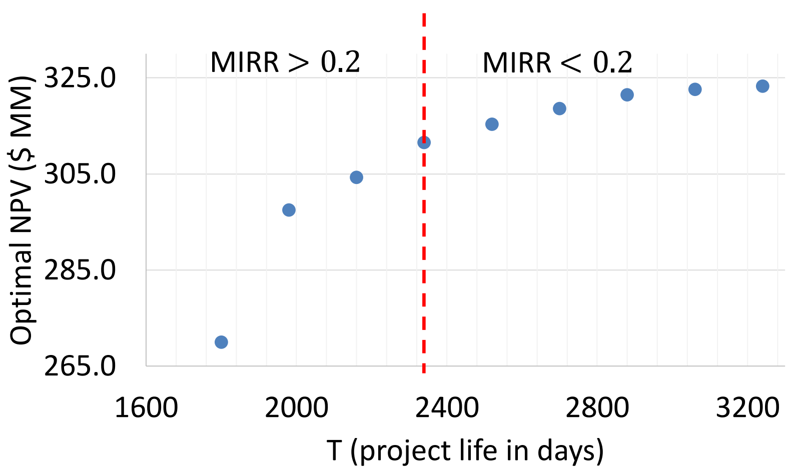


T^* = 2340 days T = 3240 days

T (days)	MIRR	NPV ($ MM)	Q_{oil}	Q_{wat}	$Q_{wat,inj}$
2340	0.20	311.6	2.66	2.69	5.22
3240	0.17	323.3	3.05	4.14	7.05

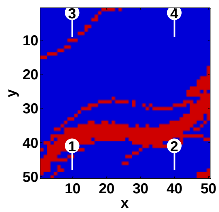
Fluid volumes are in MM STB

NPV versus MIRR

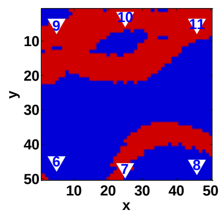


3D Binary Channelized Reservoir (50 × 50 × 6)

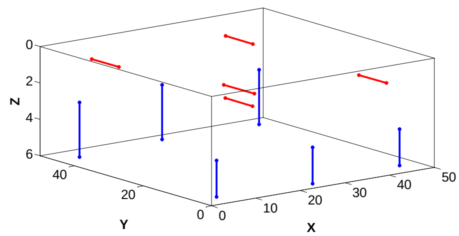
- 5 horizontal producers & 6 vertical injectors
- Capital investment = $700 MM, discount rate = 10%
- Jointly optimize well controls & economic project life



Layer 1



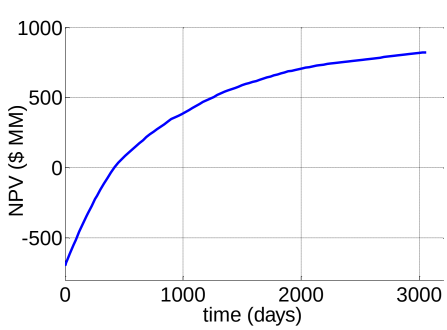
Layer 5

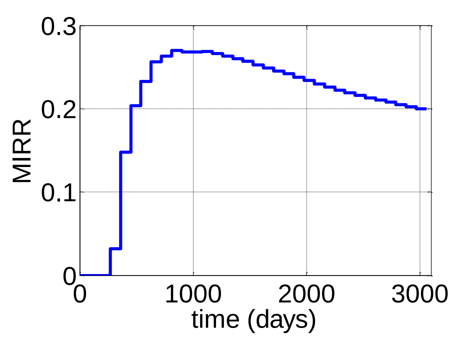


Well configuration

Results with Optimal Economic Project Life (EPL)

- Initial guess: T= 4950 days
- Two outer iterations to get T^*=3060 and optimal controls $\mathbf{x}^*$





Summary

- Introduced the joint optimization of well controls and economic project life (EPL)
- We believe this to be **the first formulation** for production optimization incorporating **rate of return** in addition to **NPV**
- Methodology provides optimal EPL and optimal controls
  1) **maximum NPV** is obtained at the end of project life
  2) **rate of return** of the project is equal to hurdle rate
- Enables formal short-term/long-term production optimization

Future Work

- Develop an approach for the **joint optimization of well location, control, and EPL**
- Extend EPL methodology to include multiple realizations
- Incorporate and test the methodology in the closed-loop field development (**CLFD**) framework

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Thank you! Questions?

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