Multi-stage stochastic programming in natural gas networks:
Focus on investments and production assurance

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Agenda

- Background
  - Optimization models for NG transport
  - Ambitions in this work
- Modeling framework
- Stochastic programming
  Dealing with uncertainty in optimization
- Back to our model...
- Conclusions

Background

- Optimization models and decision support tools for NG transport on the NCS
  - Short, medium and long term focus:
    operational, tactical and strategic decisions
  - In daily use by our customers: Gassco and StatoilHydro
  - For example:
    - Infrastructure development and technology choice
    - Optimal utilization of the production and transport system
    - Value chain analysis
  - See also the next presentations

- Our goal in this project:

Bridge both worlds

Bridge both worlds

- Design of infrastructure influences operations:
  - Security of supply
  - Flexibility
- Substantial degree of uncertainty, e.g.
  - Daily demand and price variations
  - Network availability
  - New field discoveries
  - Quality in fields
  - Future demand development
- Uncertainty and decision flexibility from a robustness perspective:
  Long term uncertainty and short term operational flexibility both important

Bridge both worlds

- Combine decision models for investments and operations
- Time structure: long-term vs. short-term decisions
- Uncertainty: long-term, short-term, events
  $\longrightarrow$ robust & flexible decisions

- "Re-use" relevant available models
- Modularity – easily adaptable & extendable
- Solution approaches
  - Problem size & solution time
  - Decomposition / parallelization

Our model: Features/ capabilities.
Investment part

- Horizon 40-50 years, yearly resolution
- Uncertainty = long term trends

- Investment focus
  - Financial aspects:
    costs, net present value, risk, budget constraints,...
  - Infrastructure elements as single projects:
    fields, transport infrastructure, processing, ...
  - Timing:
    when which project and to what extend/ size
  - Development of fields: production profiles

Our model: Features/ capabilities.
Operational part

- Horizon 1 year, ”daily” resolution
- Uncertainty = short-term variations & unplanned interruptions (events)

- Operational focus – verification of strategic decisions
  - How to operate within given infrastructure: day to day
  - Production levels (within profiles)
  - Routing, blending, utilization of capacity & compressors (line pack)
  - Respond to/handle short-term uncertainty
- Precise technological detail: pressures, quality, ...

Stochastic programming.
Dealing with uncertainty

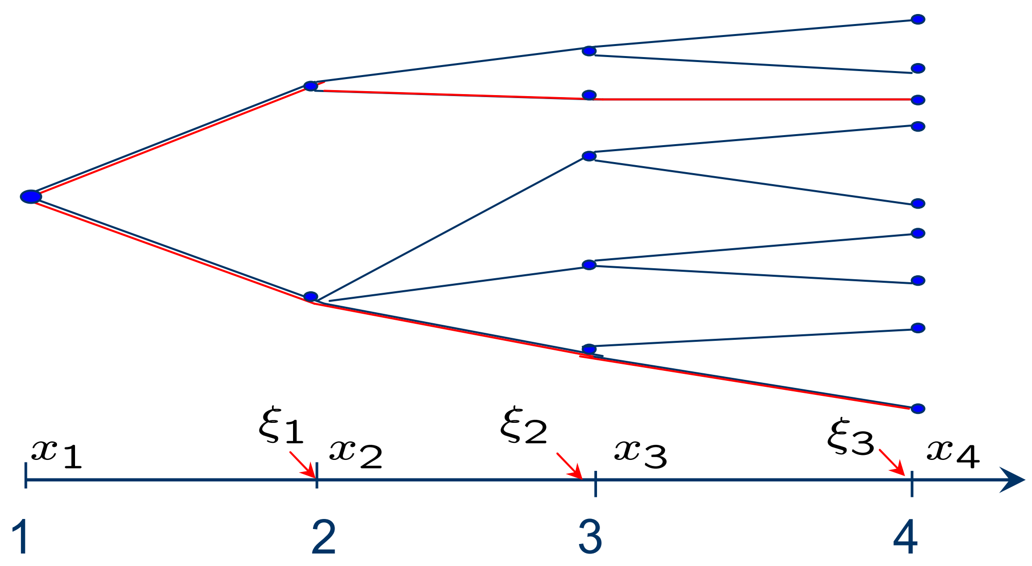
- Ideal world: all data known, no uncertainty – no surprises
  - Can plan investments and their timing exactly
  - Can schedule sales to optimum
  - Can always achieve 100% production assurance
    (know when events will happen and schedule accordingly)
- True world: don't know everything
  - Optimal scheduling of investments difficult
  - Where to sell, how much and when?
  - How to react to events
    – and still keep a good production assurance record?
- Challenge:
  find good decisions when not all data are known exactly
  - Optimality?
  - Feasibility?

Stochastic programming

- How to deal with uncertain data in an optimization problem?
  - Use average / most likely parameter value & go back to deterministic problem?
  - Solve separate deterministic problems for ”all” possible parameter values?
  - Exploit as much information about parameters as possible
    → scenario (tree) approach
- Scenario:
  - One realization of all uncertain parameters
    together with probability
  - Obtained through sampling, ”educated guesses”, ...
  - Several periods:
    one realization of uncertain parameters at **all** time periods

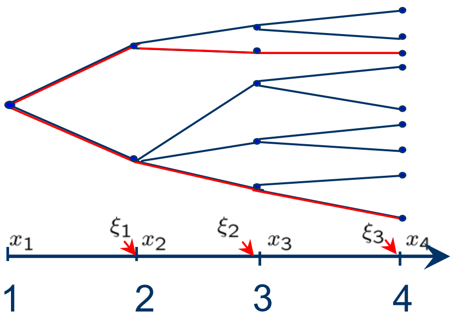
Stochastic programming

- Scenario tree – illustrates:
  - Possible development of uncertain parameters over time
  - Decision making process – related to new information

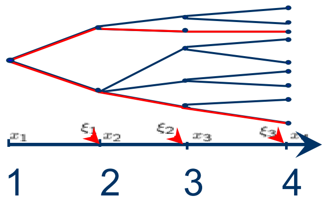


Stochastic programming.
Scenario tree approach

- Don't confuse time and stochastic structure:
  - **Periods**: When are *decisions* made and executed, e.g.
    - Start building a pipe line from A to B in 2012;
    - Sell x Sm^3 at market C in week 3 / 2010
  - **Stages**: When is *information* revealed and when does it make sense to make new decisions
    (why make new decisions if we do not know more?)
  - **Scenarios**:
    What will happen in the future and with which probability



Stochastic programming.
Scenario tree approach – challenges



- ”Curse of dimensionality” (+ complex underlying problem!)
  - Problem size grows quickly – computational tractability
  - Must select some parameter values
    - Should depict reality as good as possible
  - Methodology for generation of scenarios
    - Preserve statistical properties – e.g. moment matching
  - Tool developed at SINTEF
    - Independent of context – used in various applications
    - Choice between several forecasting methods
    - Modular – no need to include directly into implementation

  - Parallelization?
    Depends on problem structure and suitable solution approaches

Stochastic programming.
Scenario tree approach – back to our problem...

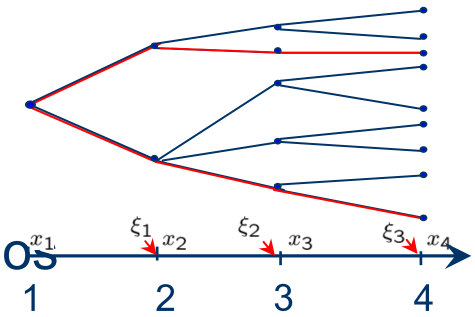
- Uncertainty:
  - Long term and short term uncertainty
    Trends, (seasonal) variations, events, ...
  - Scenario tree should be able to accommodate both

- Time structure:
  - Periods for investment decisions: ”years”
  - Periods for operational decisions: ”representative days”
    - within ”years”
    - possibly consecutive, grouped into ”weeks”
      (to capture seasonality)

Back to our problem...

- At each node:
  Set of realizations of all uncertain parameters
  = an instance of the problem constraints for these values
  - Mass balances, technical constraints, ...

- Additionally:
  - Time bindings – separately for scenarios
    - Line pack, storage, long term contracts, ...
  - Bindings over a few periods, over all scenarios
    - Production assurance, ...
  - Nonanticipativity:
    Decisions don't depend on which future scenario(s) will realize

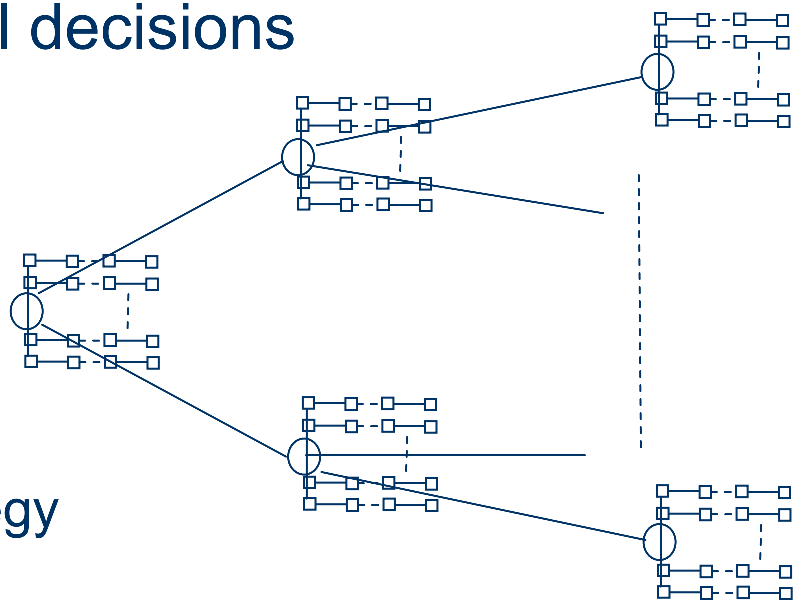


Back to our problem...

- Objective function:
  - All time periods, expectation over all scenarios
    - Investment costs
    - Costs and revenue from operations (sales) – scaled up to ”years”
- Each node in scenario tree has info on:
  time (strategic & operational period), stage, ...
  - Gives flexibility:
    Can study various scenario trees for different purposes
  - E.g., operations verify feasibility of investment plans

Example 1.
Multistage model – ”collapsed” tree

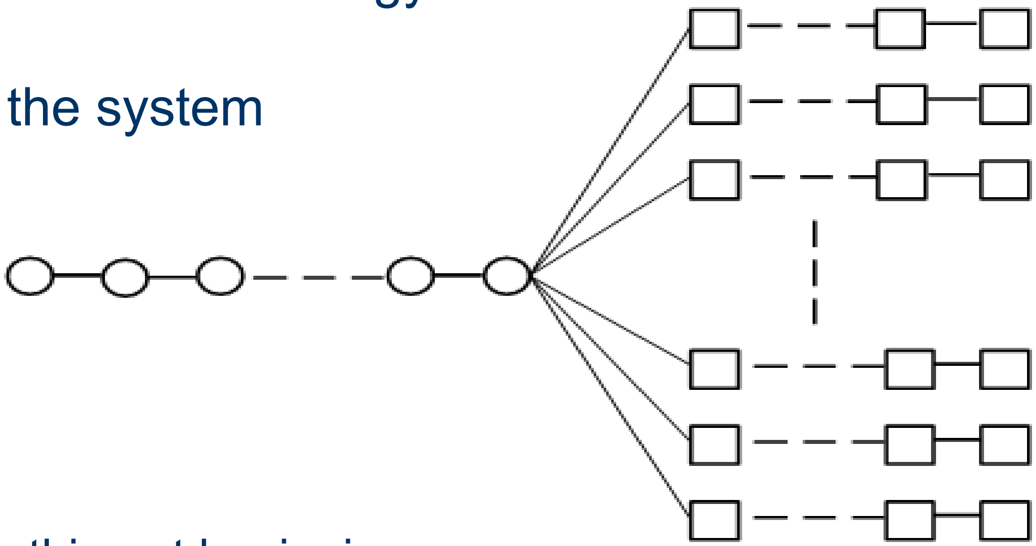
- Scenario tree branches on investment nodes
- Simulations for operational decisions on current network state



- Pros and Cons:
  - Can adapt investment strategy to new information
  - Feed back from operational part
  - Computational tractability (can run simulations in parallel)

Example 2.
Two-stage model

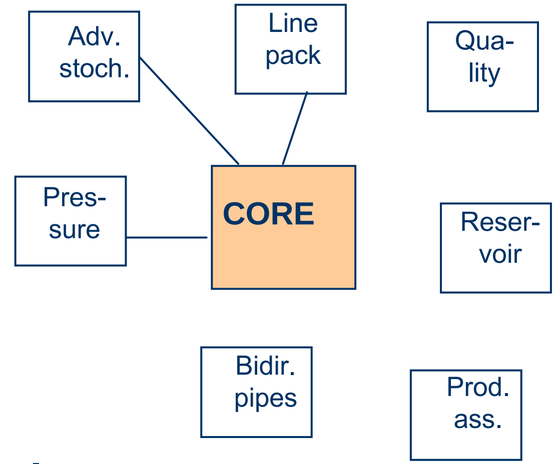
- First stage: find robust investment strategy
- Second stage:
  find best way to operate the system
  under given strategy



- Pros and Cons:
  - Impossible to plan everything at beginning: discoveries & development of new fields etc.
  - Can't adapt infrastructure when operational model reveals infeasibilities
  - Can't respond to changes underways – can't adapt investment strategy when uncertainty reveals
  - Allows for rich time detail
  - Computational tractability, decomposition

Model complexity.

Modularity



- Core model
  - Basic functionality
  - Most important aspects and details
- Develop & implement several modules:
  - Allow for finer technical detail
  - If ”switched on”: replace simpler formulations in core model
  - Enable more advanced study of specific aspects but keep model tractable, e.g.
    - thorough analysis of uncertainty
    - focus solely on investment strategy
  - User involvement
  - E.g. stochastics, line pack, pressure, reservoir, ...

Complexity
Stochastic structure
Technical detail

Conclusions and way ahead

- Develop modeling framework
  - Combines infrastructure design and operations
  - General formulation – not bound to NG transport
- Focus in this talk:
  how to deal with fundamental uncertainty
  - Short term, unplanned disruptions, long term
  - Scenario tree(s) – flexibility enables various analyses
- Complex model – propose modular approach
- Some of the next steps:
  - Modules
  - Solution methods
  - Case studies: NG, CO_2, H_2

THANK YOU

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