U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Decision Analysis for EGS

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MIT

Herbert H. Einstein

Massachusetts Institute of Technology

OBJECTIVES

CHALLENGE – How to develop EGS projects that are affected by many unknown and variable factors.

Uncertainties, particularly those related to the subsurface, have a major effect on cost, time and resources associated with EGS development and operations.

A large variety of uncertainties ranging from geological to constructional and operational have to be included.

The research intends to develop tools, which allow one for formally assess these uncertainties and include them in expressions of risk.

DECISION ANALYSIS FOR EGS
Relevance/Impact of Research

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INNOVATIVE ASPECTS

Integrated and effective fracture pattern – circulation model considering uncertainties.

Well cost-time model considering uncertainties.

Exploration and systems model for EGS.

IMPACT

Subsurface part of EGS, which is subject to the greatest uncertainties, can be related to time - and cost risks.

Makes it possible to compare EGS projects on the basis of risk.

All models based on easily accessible software.

Scientific/Technical Approach

Principles of probability theory, decision making under uncertainty and formal uncertainty estimation have to be considered. This will allow one to systematically compare the wide variety of uncertainties and include them in an integrated expression of risk.

Reliance on these basic scientific and methodological principles will ensure the rigor of the approach.

Reliance on estimates/tools and models that have been developed at MIT and practically applied will ensure the technical feasibility.

For example:

- Fracture pattern – and, eventually, flow/circulation models capture the relevant geologic uncertainties.
- Construction cost/time models can be adapted for geothermal well time/cost estimation.
- Systems model can integrate any set of other models

Scientific/Technical Approach

The model development and integration will be approached through a set of scientifically defined tasks.

1. Fracture Pattern Model for EGS
2. Drill Cost and Time Model Considering Uncertainties
3. Circulation Model for EGS
4. Subsurface Time/Cost Model
5. Exploratory Model for EGS
6. Systems Model

   Combine 1-5 and Technology Transfer

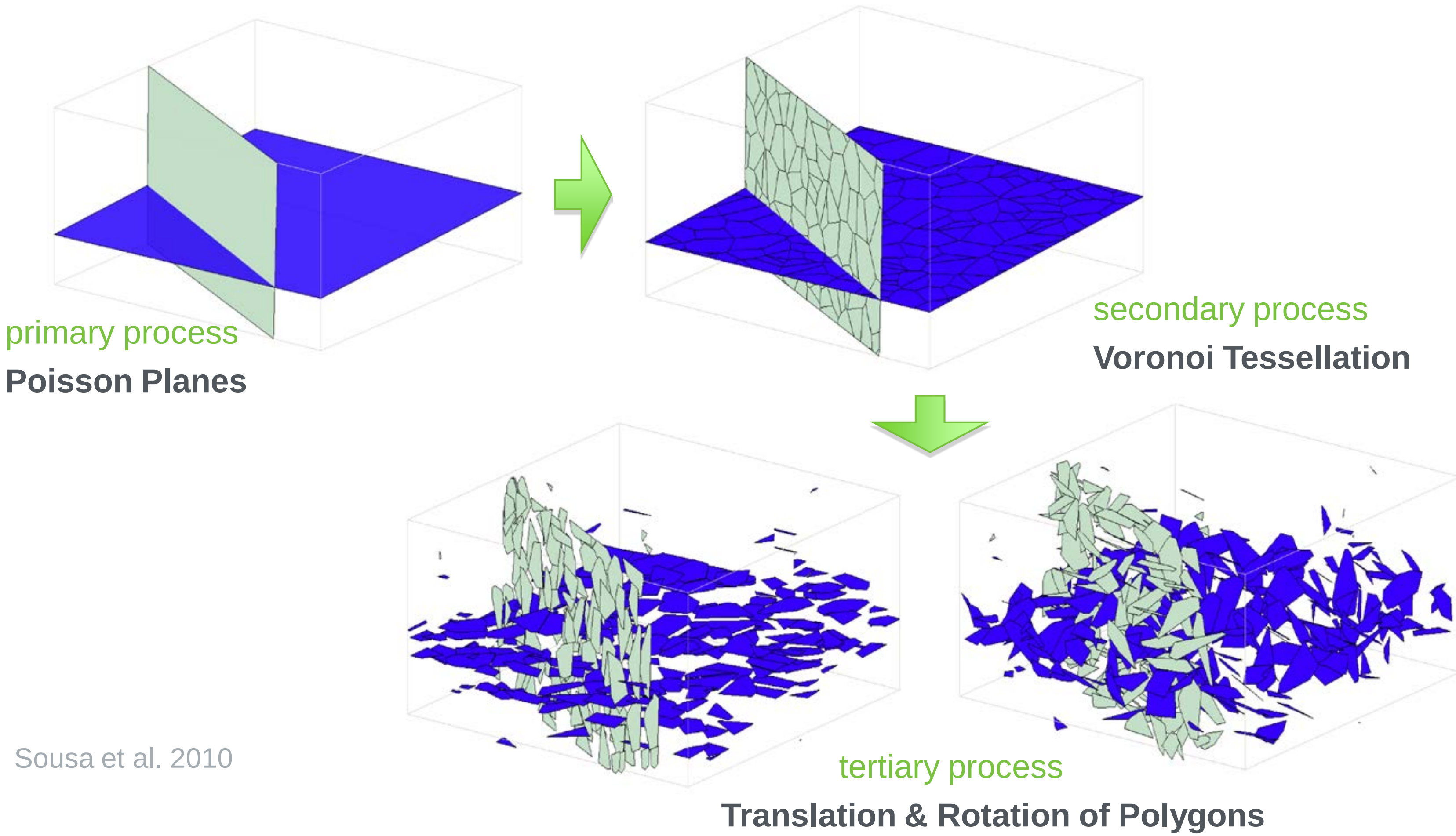
   Enhance Surface Part of Model

Results will be presented in the following order:

1 and 3 together – then 2.

STOCHASTIC FRACTURE PATTERN MODEL - GEOFRAC

GEOFRAC's stochastic processes were implemented and optimized in MATLAB.



Sousa et al. 2010

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FRACTURE PATTERN AND CIRCULATION MODEL

MATHEMATICS

Poisson planes

$$\mu(d,\ \theta,\ \phi) = \mu f_{\theta,\phi}(\theta,\ \phi)$$

μ – Poisson plane intensity

$f_{\theta,\phi}(\theta,\phi)$ □ orientation p.d.f.

Voronoi Tessellation

λ – Poisson point intensity

$E[A] = 1/\lambda$

$\sigma_A = 0.529/\lambda^2$

GEOFRAC PARAMETERS

$P_{32} = \mu$

$E[A] = 1/\lambda$

FRACTURE PROPERTIES

$$P_{32} = \frac{\sum_{i=1}^{N} A_{f,i}}{V}$$

P_{32} – Fracture intensity

$E[A]$ – Mean fracture area

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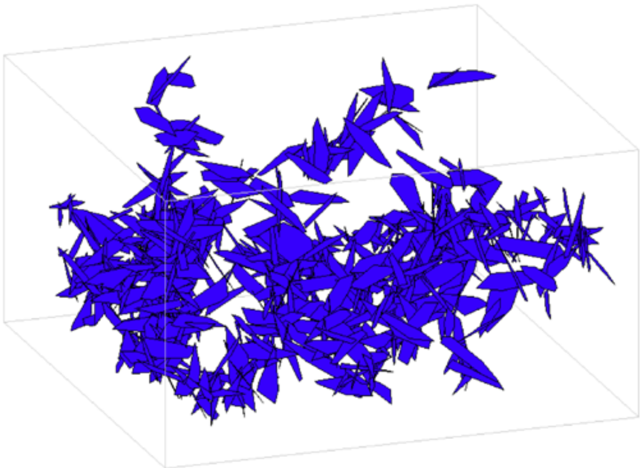
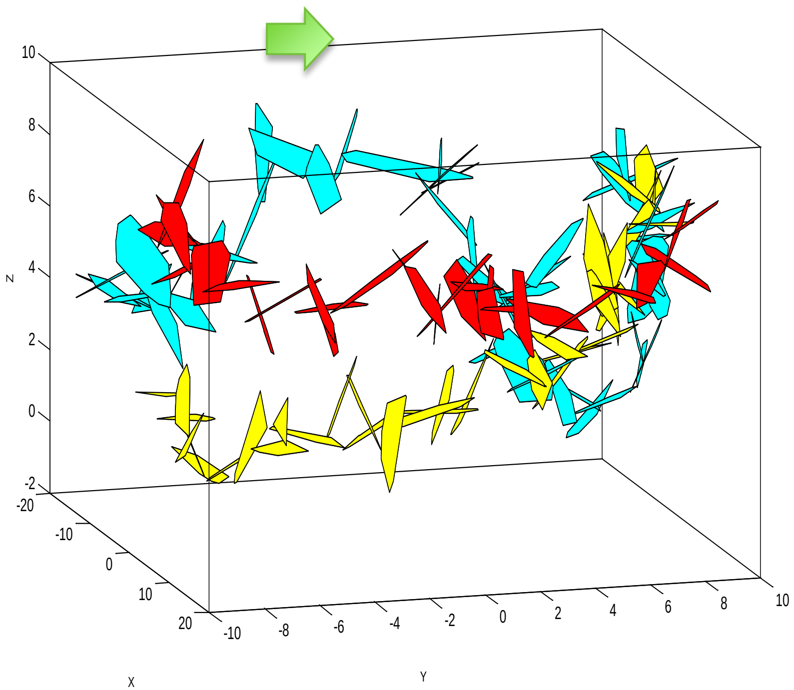
FLOW-PATH CONTRIBUTING FRACTURES

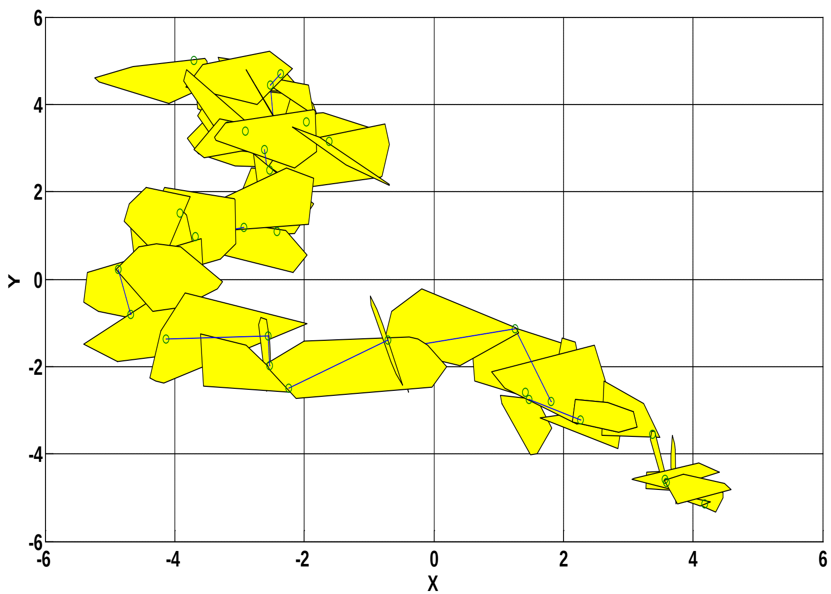


FRACTURE APERTURES: deterministic and probabilistic modeling of fracture aperture.

"CLEAN" FRACTURES: retaining only fractures that contribute to flow paths, i.e., those intersecting at least (1) two other fractures, or (2) a fracture and a boundary of the model.

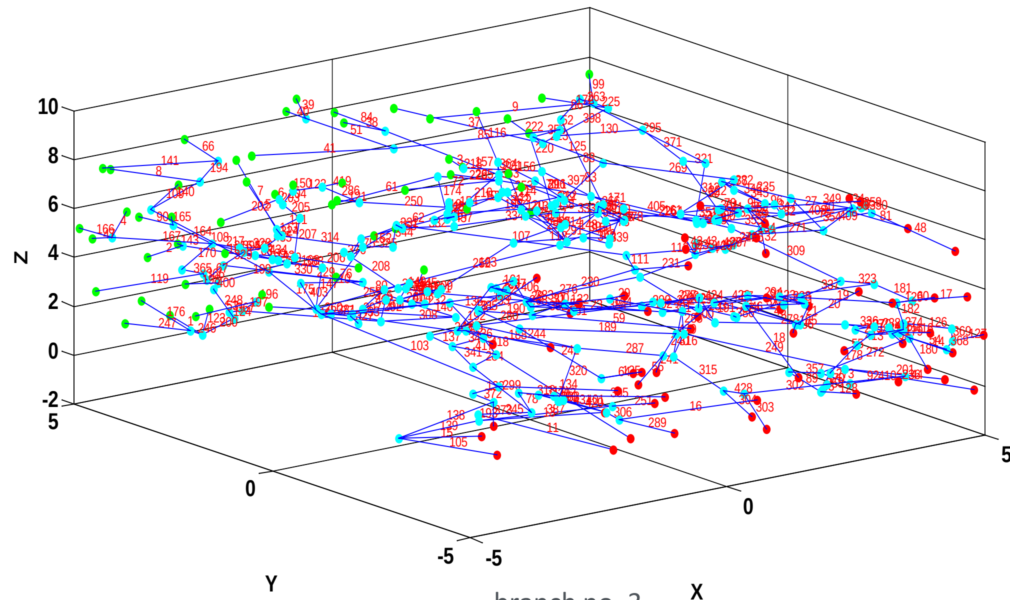
FLOW PATH COMPUTATION

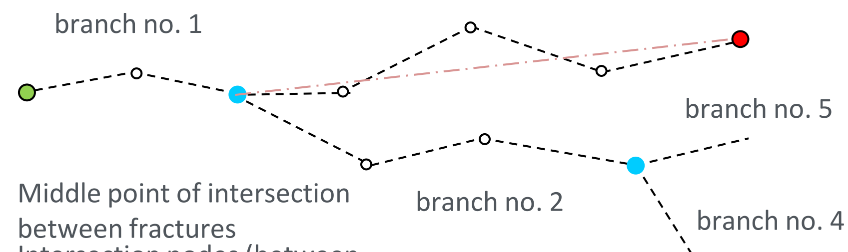




- Middle point of intersection between

- Fracture Length





- Middle point of intersection between fractures
- Intersection nodes (between branches)
- Initial nodes (injection boundary)
- Final Nodes (production boundary)
- Fracture Length
- Idealized Branch

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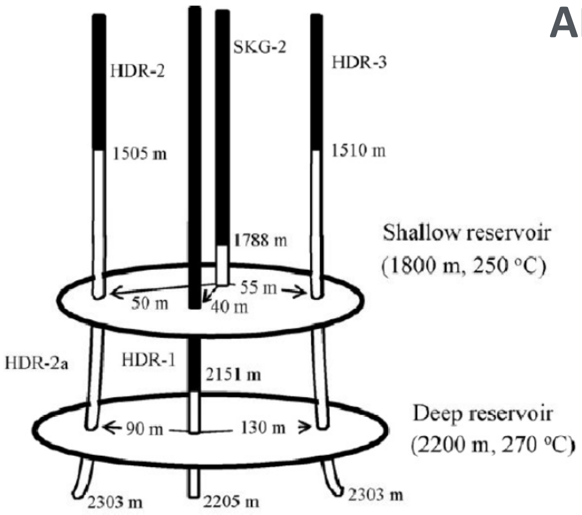
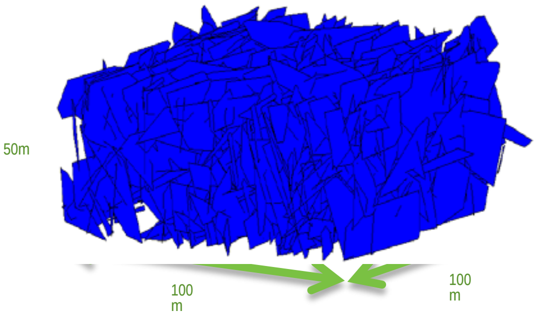
APPLICATION TO HIJIORI EGS - JAPAN



Cibich, 2008

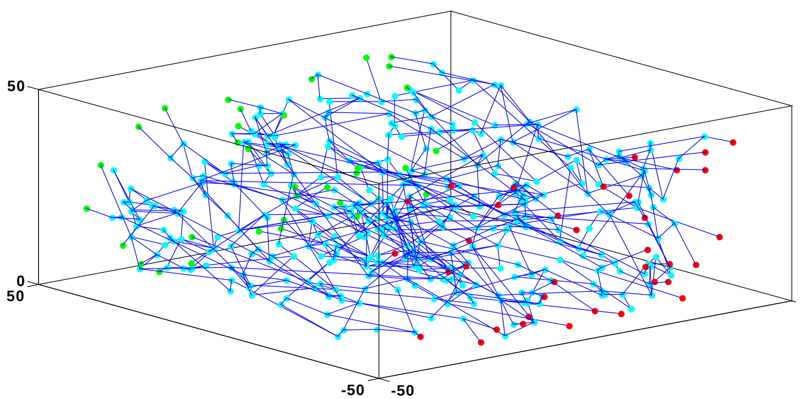
Flow between HDR-2a and HDR-1



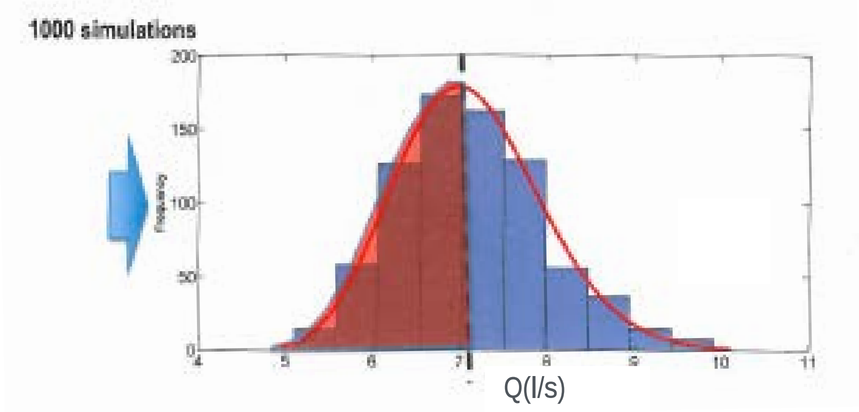
Geofrac Input (assumptions):

P32=1
E[A]=300m^2
h=0.5mm
Fisher distribution (k=10)

Simplified flow network (centerline of flow paths)



Flow rate histogram



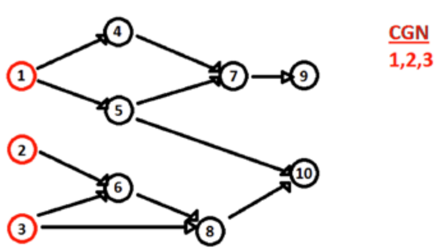
Thermal Circulation Model

Basics

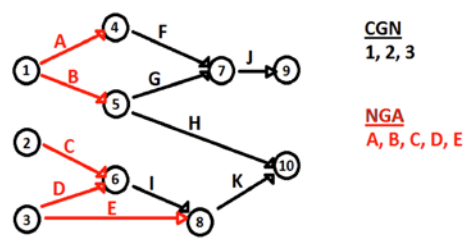
- Parallel Plate fluid flow (Gradient, Roughness)
  - Velocity profile - Reynolds
  - Heat transfer (solid, fluid) – Biot
  - Time dependence – Fourier
  - Lateral motion – Prandtl
  - Boundary solid/fluid – Nusselt

Structure of Model

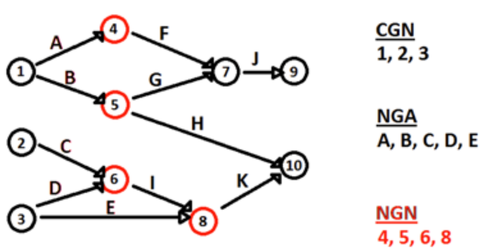
Create starting (parent) nodes



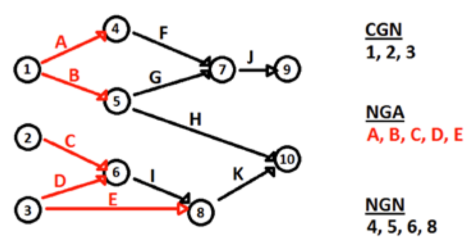
Create daughter arcs



Create nodes



Calculate heat transfer



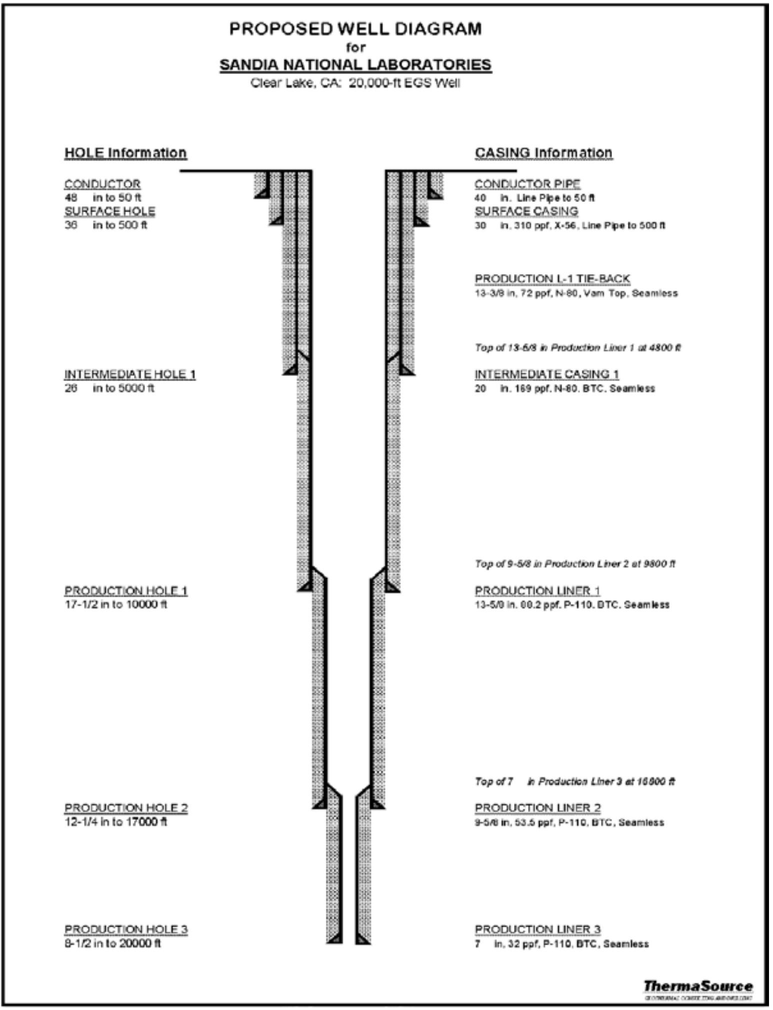
Drill Cost, Time and Cost Model Considering Uncertainties

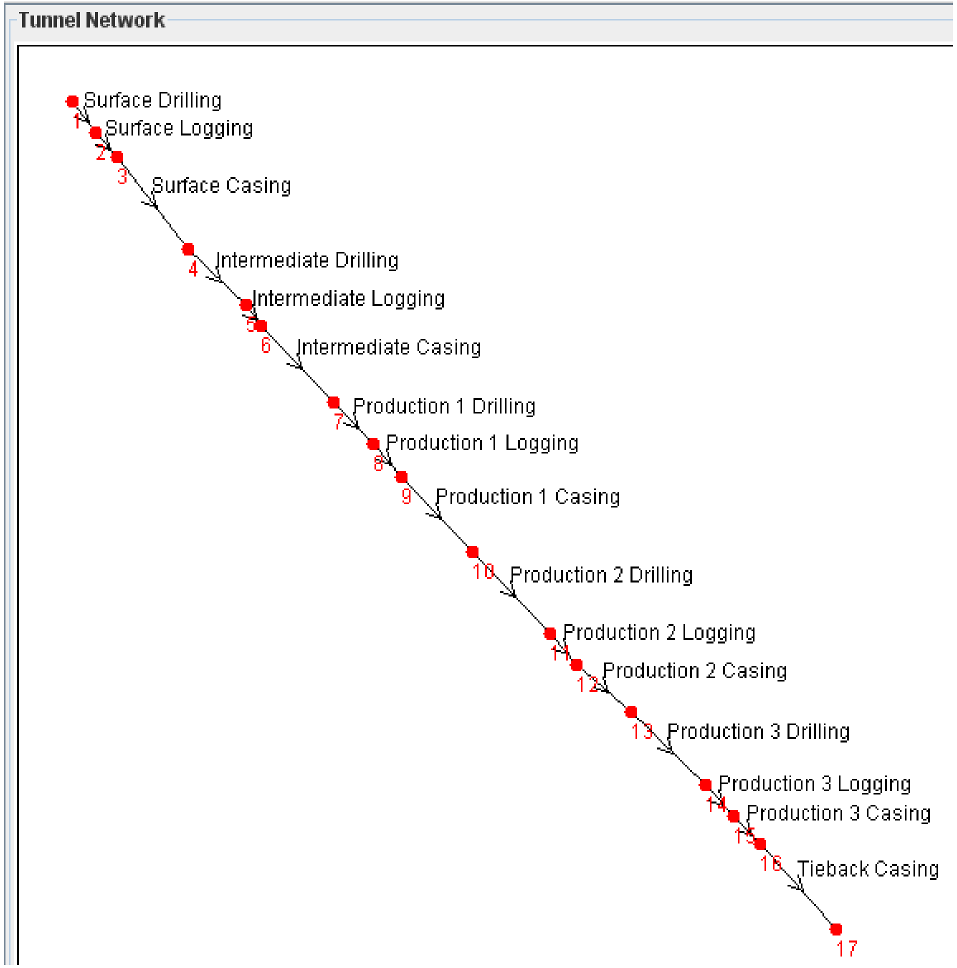
Develop existing Decision Aids for Tunneling (DAT) to consider for a geothermal well:

- Various drilling, logging, casing stages
- Component costs and uncertainties (Labor, Material, Equipment)
- Trouble costs and uncertainties (Fishing, Stuck Drill Pipe, Casing Failure)
- Geologic features and uncertainties (Effect of strength and abrasivity on drill time and bit life)
- Temperature related failures and uncertainties (effects on logging, fluid loss and cementing)

Note: Other parameters can be included.

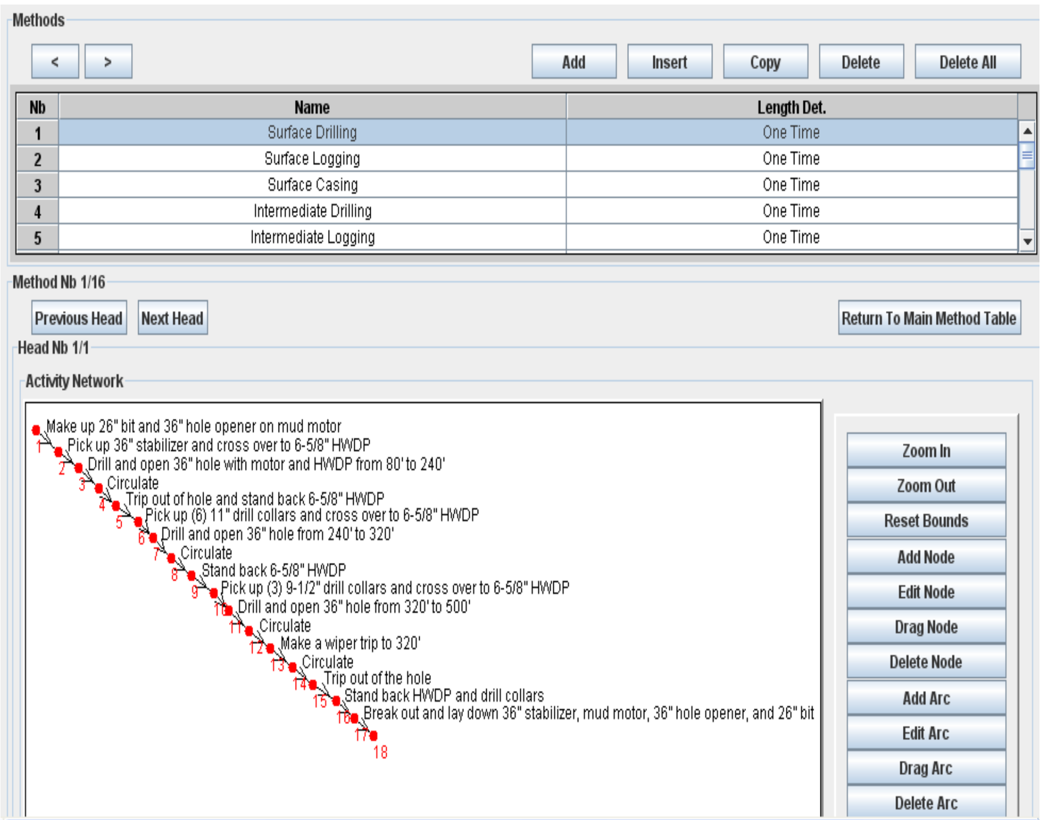
Drill Cost, Time and Cost Model Including Uncertainties
Example application to Sandia (Polsky et al., 2008) Case

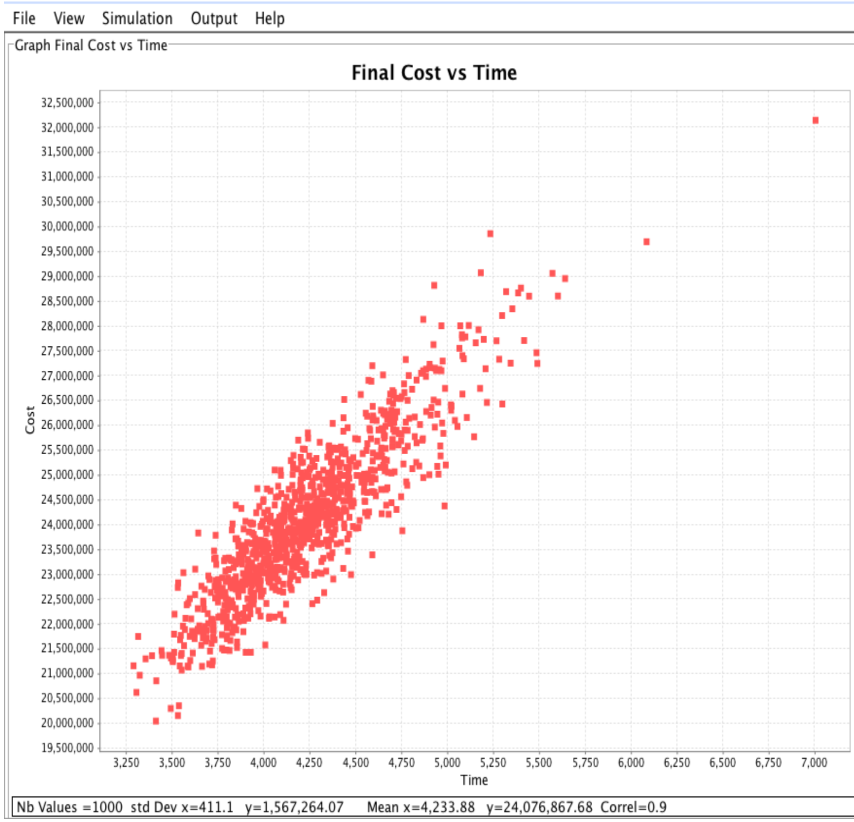




Sandia Well Network

Accomplishments, Results and Progress





Activity Network for the Surface Drilling Method (DAT Screenshot).

Cost-Time Scattergram for Combined Parametric Study. 1000 construction simulations were performed, taking into account component cost uncertainty, trouble events, geological variation, and drilling fluid usage rates.

DECISION ANALYSIS FOR EGS SUMMARY

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SUMMARY OF MAJOR ACHIEVEMENTS

Stochastic Fracture Pattern Model

Circulation (Flow and Heat Exchange) Model

Well Cost/Time Model

All the above have been validated.
All the above consider uncertainties.
All the above are easily useable (Matlab or otherwise available software).

The final steps – exploration and systems model have been started based on the above.

It is thus possible to say that significant impact on the DoE Geothermal Energy Office's mission and goals has been achieved through:

Decision Making Tools for Assessing, Analyzing and eventually Reducing the Time - and Cost Risk of the Subsurface Part of EGS.

Project Management

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Timeline:

Planned Start Date	Planned End Date	Actual Start Date	Current End Date
12/29/2009	01/31/2014	02/01/2010	01/31/2014

Budget:

Federal Share	Cost Share	Planned Expenses to Date	Actual Expenses to Date	Value of Work Completed to Date	Funding needed to Complete Work
549,148	54,487	~480,000	480,000	SAME	~120,000

- Funds used to support:
  - Postdoctoral Associates, Graduate Research Assistants, Undergraduate Research Assistants, PI
  - These participants worked in close day-to-day interaction
- Interaction with other research at MIT
  - Close interaction with EGS mechanics oriented research
- Interaction with Industry:
  - Contacts made to get data.