

# Dynamic Bayesian network model for assessment of tunnel excavation risk

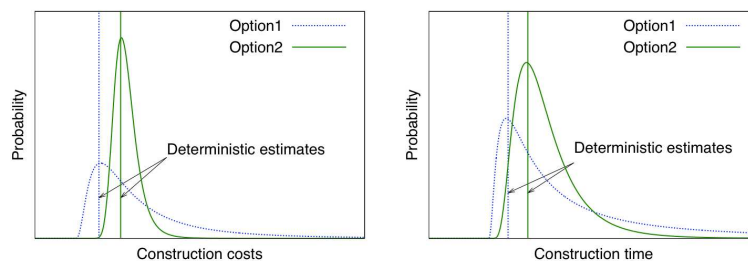
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## Modeling of tunnel construction process Motivation and aims

Average cost escalation of tunnel and bridge projects is 34%, there has been no improvement over past 70 years (Flyvbjerg 2004).

**Provide tools for probabilistic modeling of construction costs and time estimates.**



## **Contents**

- Bayesian networks - basic principles
- DNB model of tunnel excavation
- Algorithm for inference of DBN
- Results, Conclusions

## **Contents**

- **Bayesian networks - basic principles**

### Dynamic BN model of tunnel excavation BN – basic principles

Directed acyclic graphical model which represents probabilistic dependencies of set of random variables

```

    graph TD
      Geology((Geology)) --> Time((Time))
      Geology --> Costs((Costs))
      Time --> Costs
    
```

Geology	$P(G)$
Good	0,6
Poor	0,4

$$p(G, C, T) = p(G)p(T|G)p(C|G, T)$$

$$p(G, T) = p(G)p(T|G) \sum_C p(C|G, T)$$

$$p(T) = \sum_G p(G, T)$$

Time (days)	$P(T)$
0,2	0,36
0,3	0,26
0,4	0,38

$P(T G)$	Geology	
	Good	Poor
0,2	0,6	0
0,3	0,3	0,2
0,4	0,1	0,8

### Dynamic BN model of tunnel excavation BN – basic principles

Dynamic BN

- For modeling of stochastic processes
- Memory through particular time slices

```

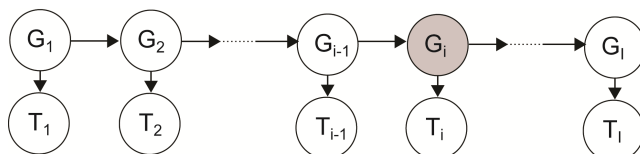
    graph LR
      G1((G1)) --> T1((T1))
      G2((G2)) --> T2((T2))
      Gi_1((Gi-1)) --> Ti_1((Ti-1))
      Gi((Gi)) --> Ti((Ti))
      Gi --> Gi_1((Gi))
      Gi_1 -.-> G2
      G2 -.-> G1
    
```

$$p(g_i, t_i) = \sum_{g_{i-1}} p(g_{i-1})p(g_i|g_{i-1})p(t_i|g_i)$$

$P(G_i G_{i-1})$	$G_{i-1}$	
$G_i$	0,6	0,1
	0,4	0,9

## Dynamic BN model of tunnel excavation BN – basic principles

D-separation (Markov blanket )



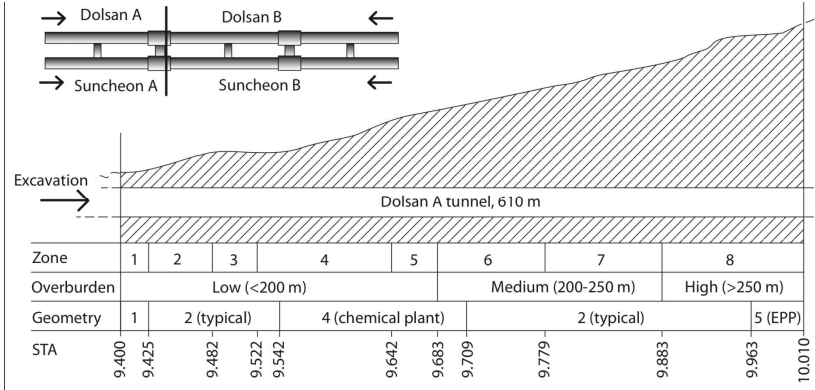
## Contents

- DNB model of tunnel excavation

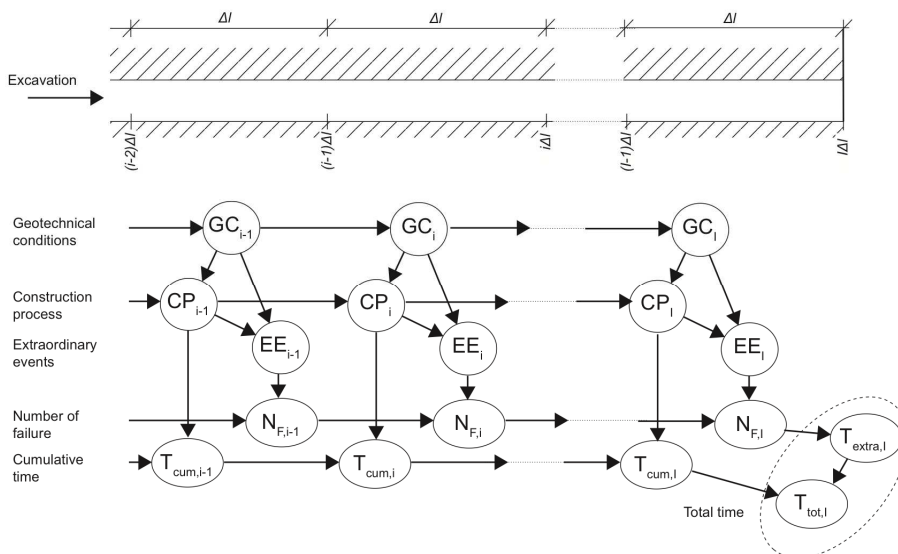
### Dynamic BN model of tunnel excavation

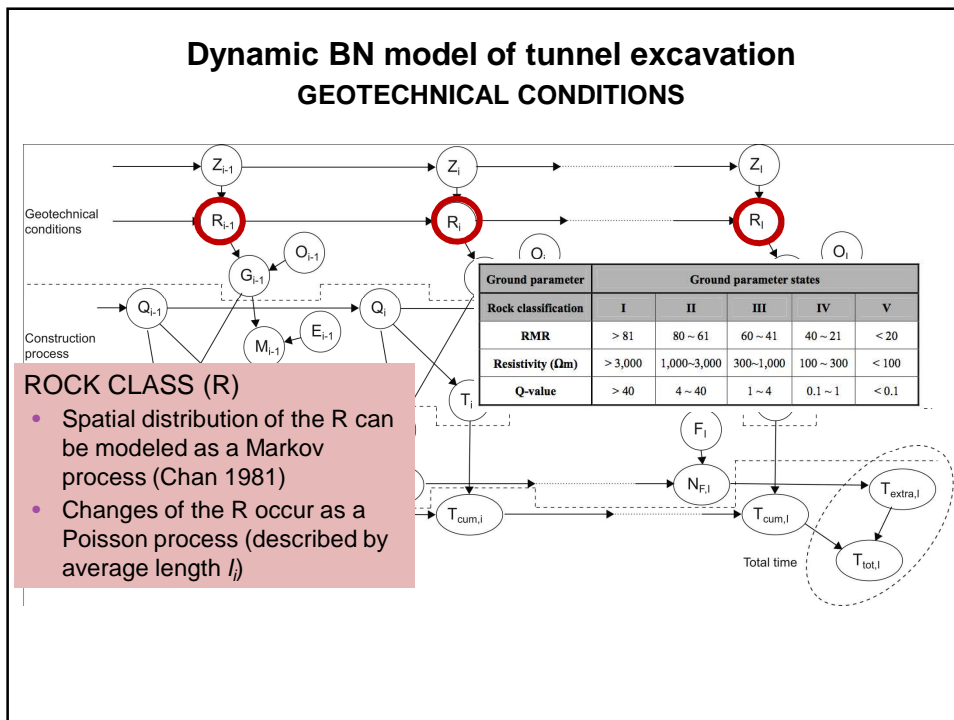
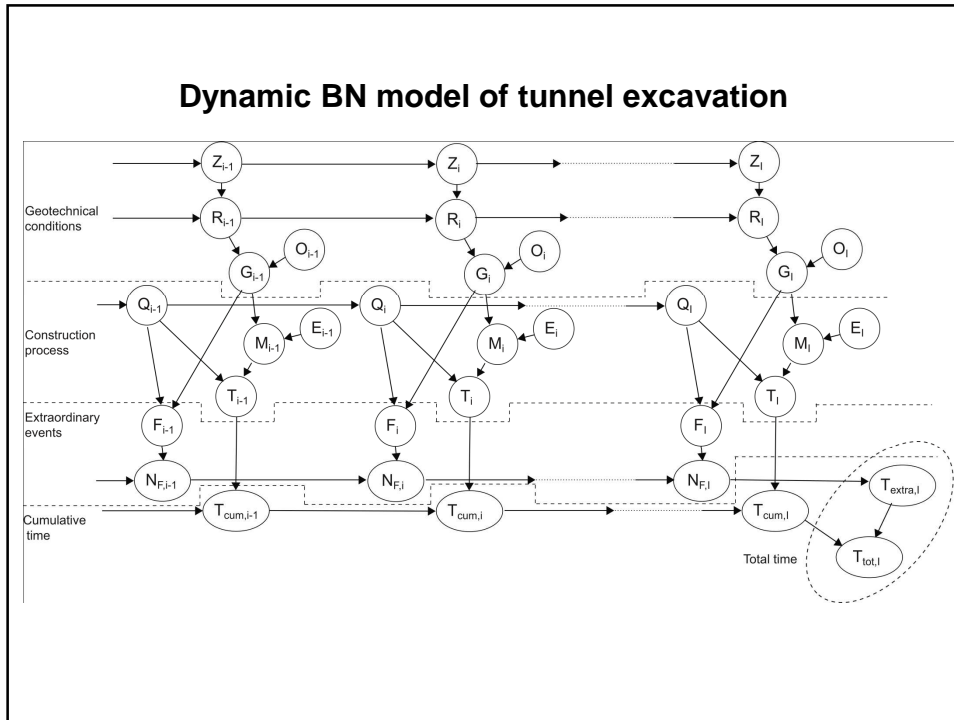
Modeled tunnel (Min 2003) - cca 610 m long

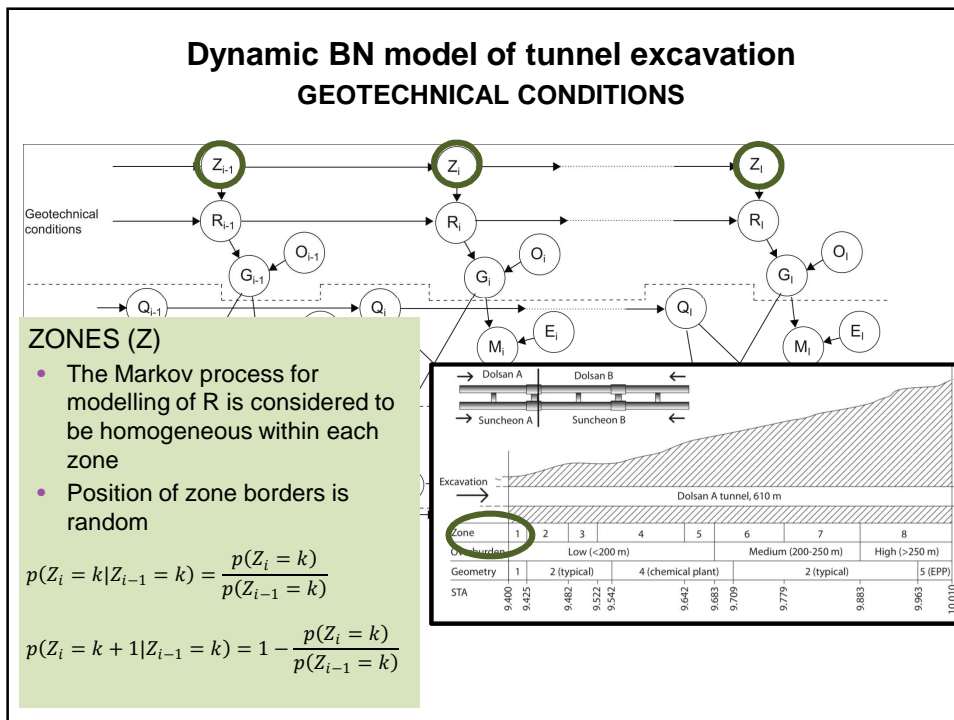
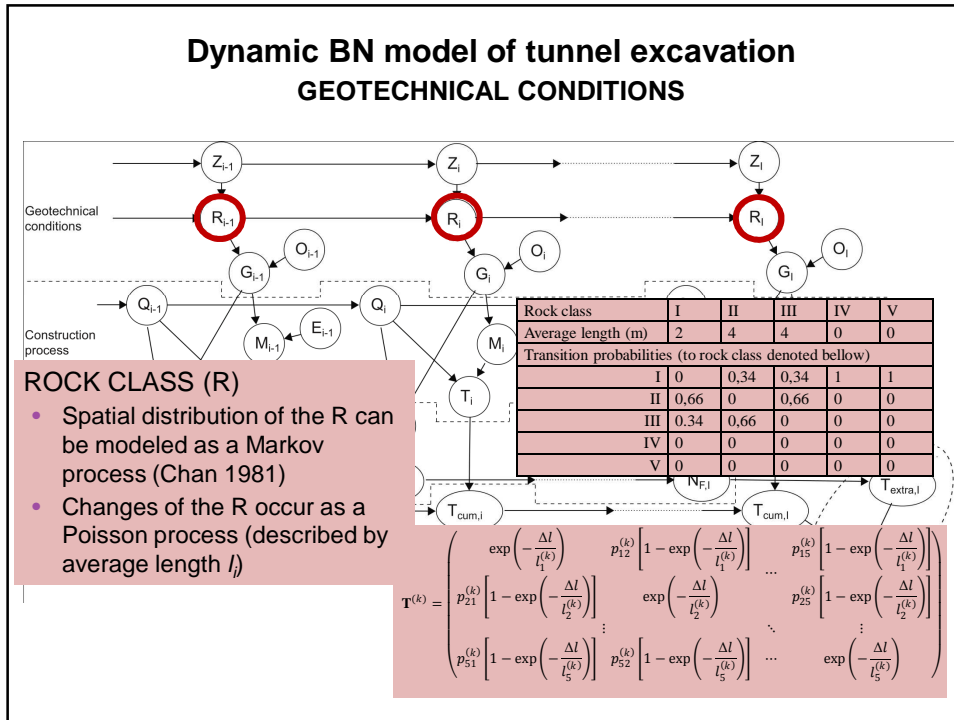
- Excavation technology: NATM
- 8 geological zones
- 2 tunnel tubes (only one modelled)
- Emergency parking places, chemical plant, begin/end

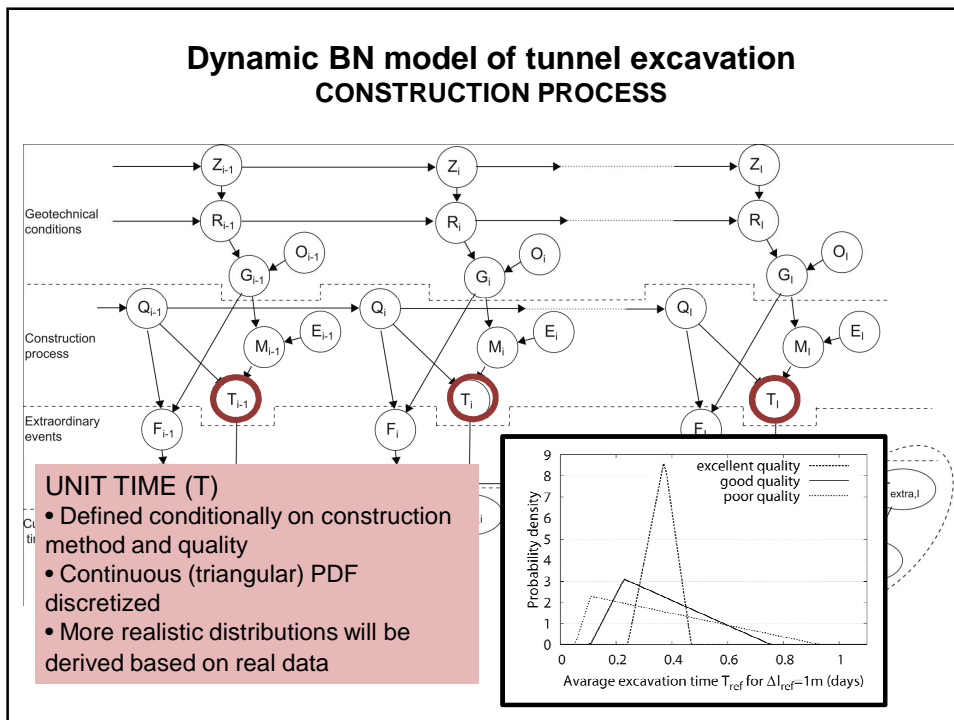
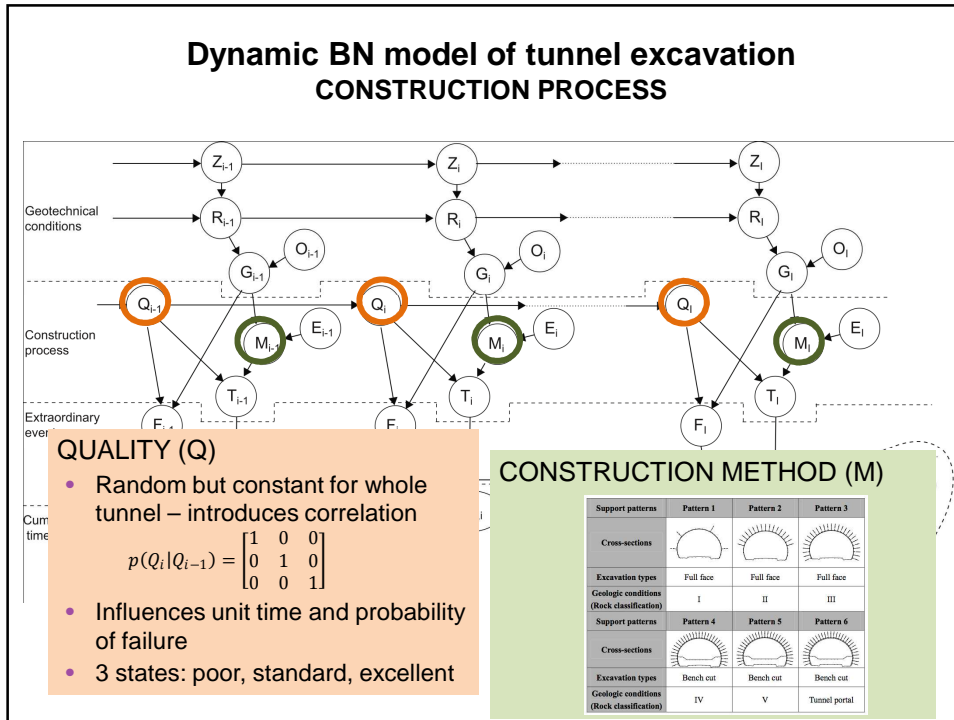


### Dynamic BN model of tunnel excavation

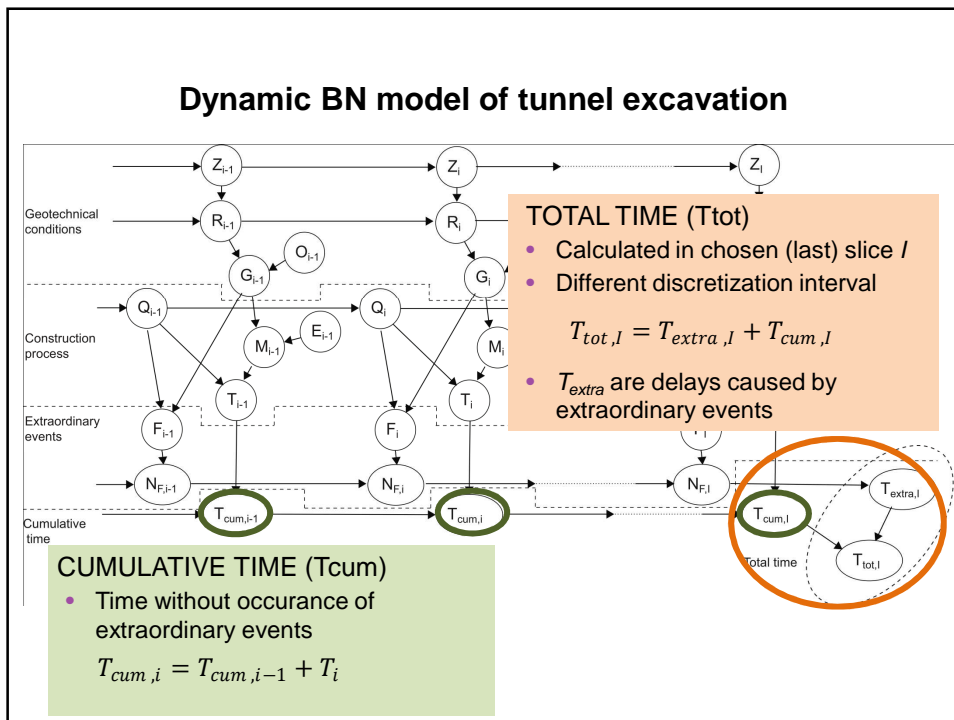
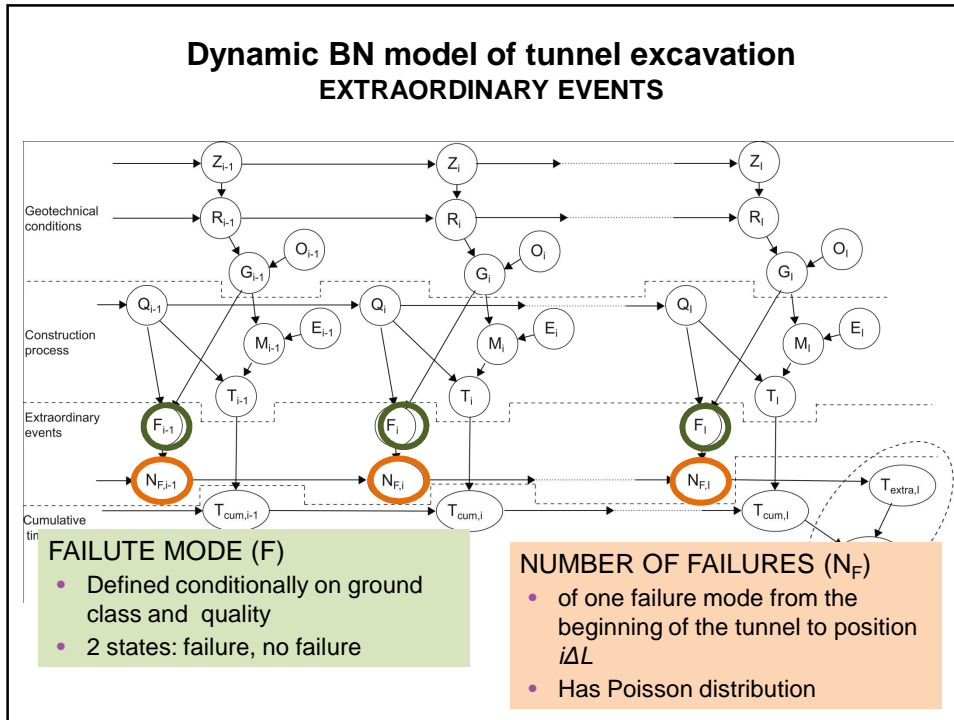








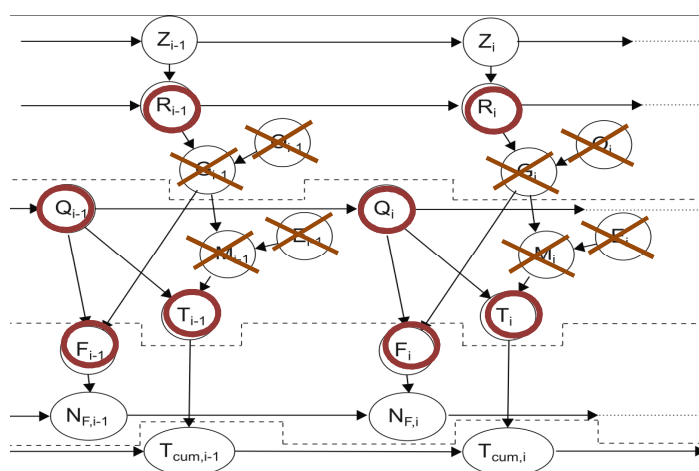


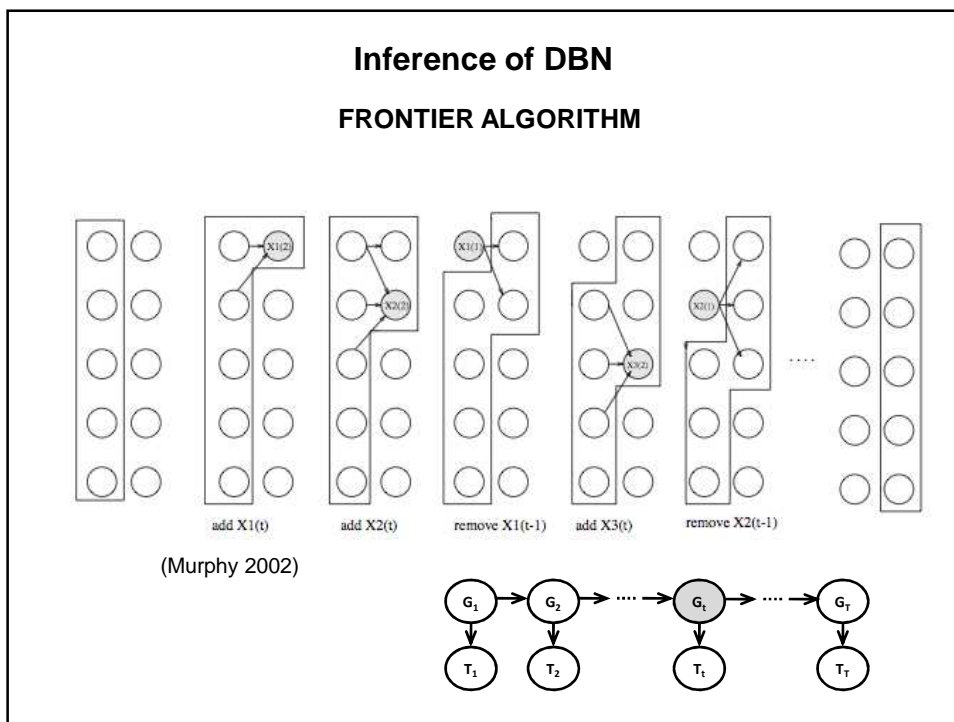
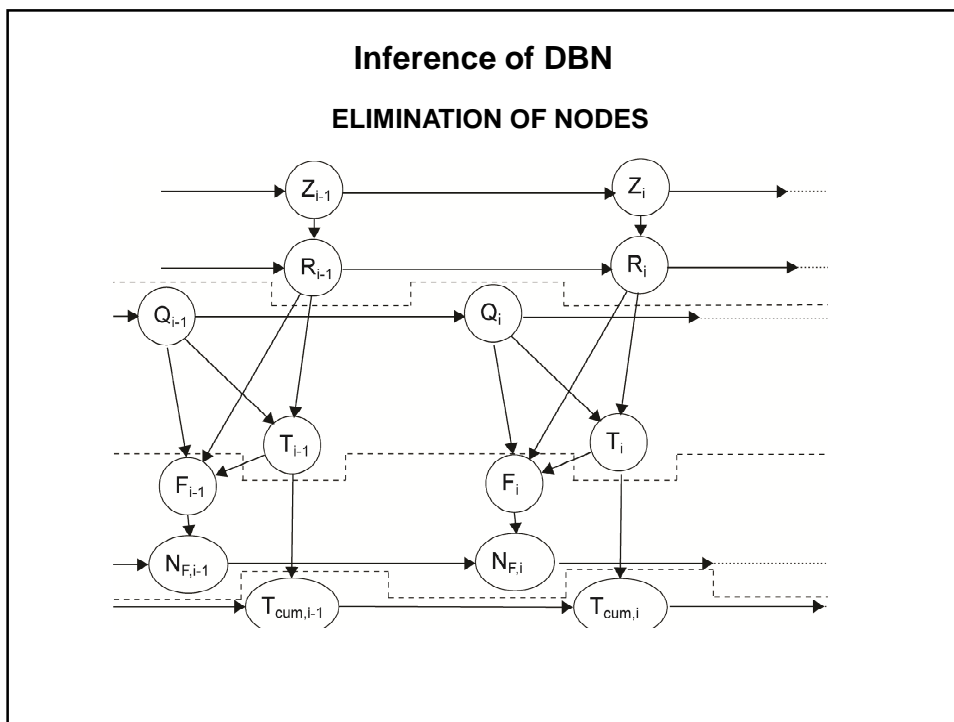


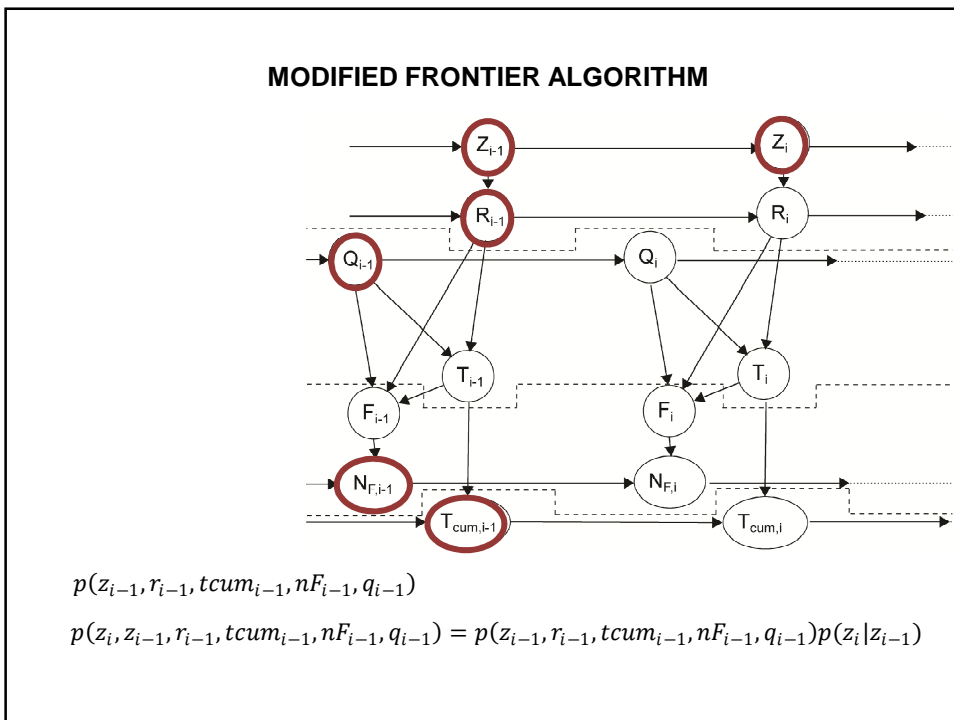
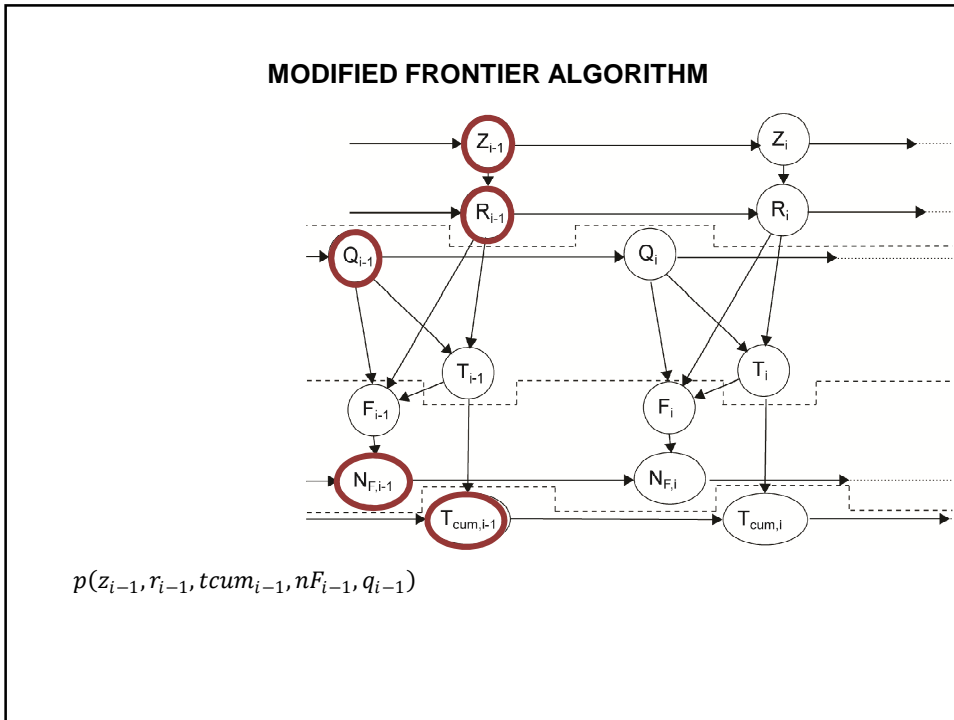
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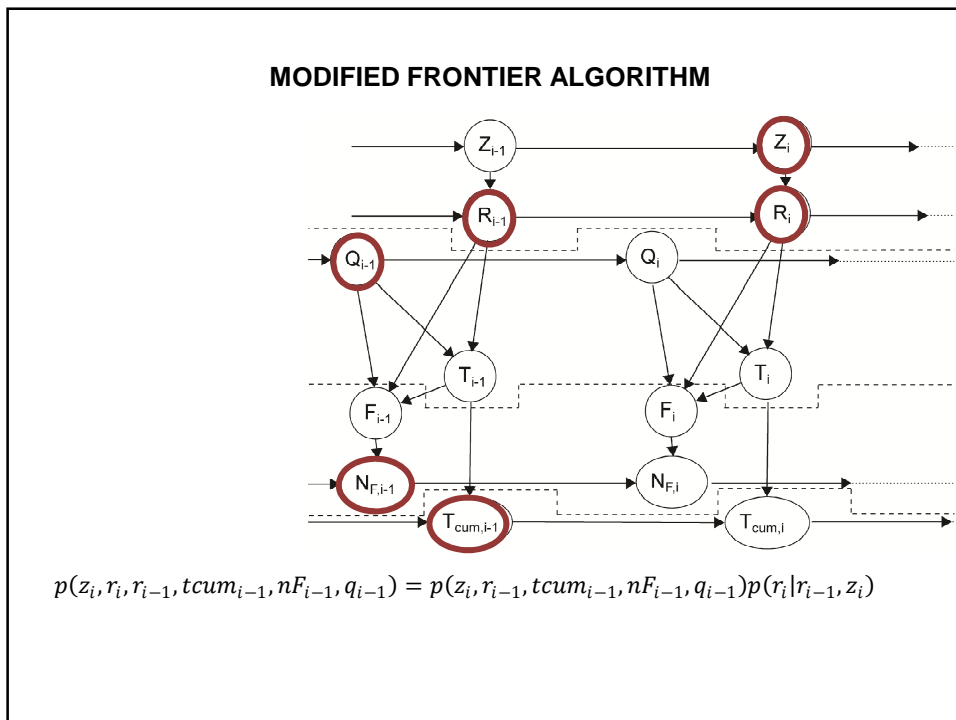
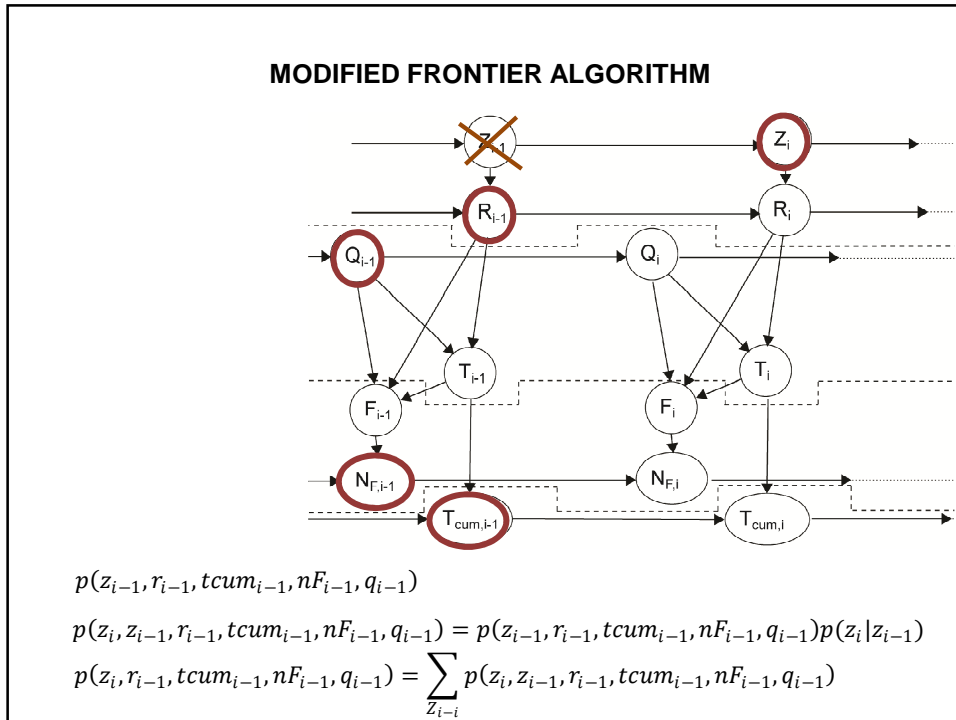
- Algorithm for inference of DBN

### Inference of DBN ELIMINATION OF NODES

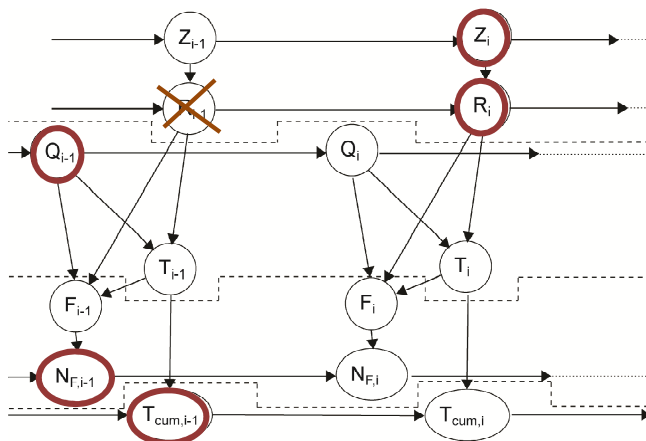








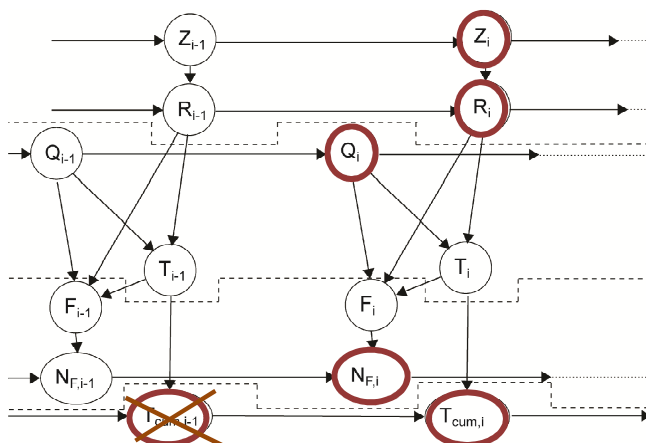
### MODIFIED FRONTIER ALGORITHM



$$p(z_i, r_i, r_{i-1}, tcum_{i-1}, nF_{i-1}, q_{i-1}) = p(z_i, r_{i-1}, tcum_{i-1}, nF_{i-1}, q_{i-1})p(r_i|r_{i-1}, z_i)$$

$$p(z_i, r_i, tcum_{i-1}, nF_{i-1}, q_{i-1}) = \sum_{R_{i-1}} p(z_i, r_i, r_{i-1}, tcum_{i-1}, nF_{i-1}, q_{i-1})$$

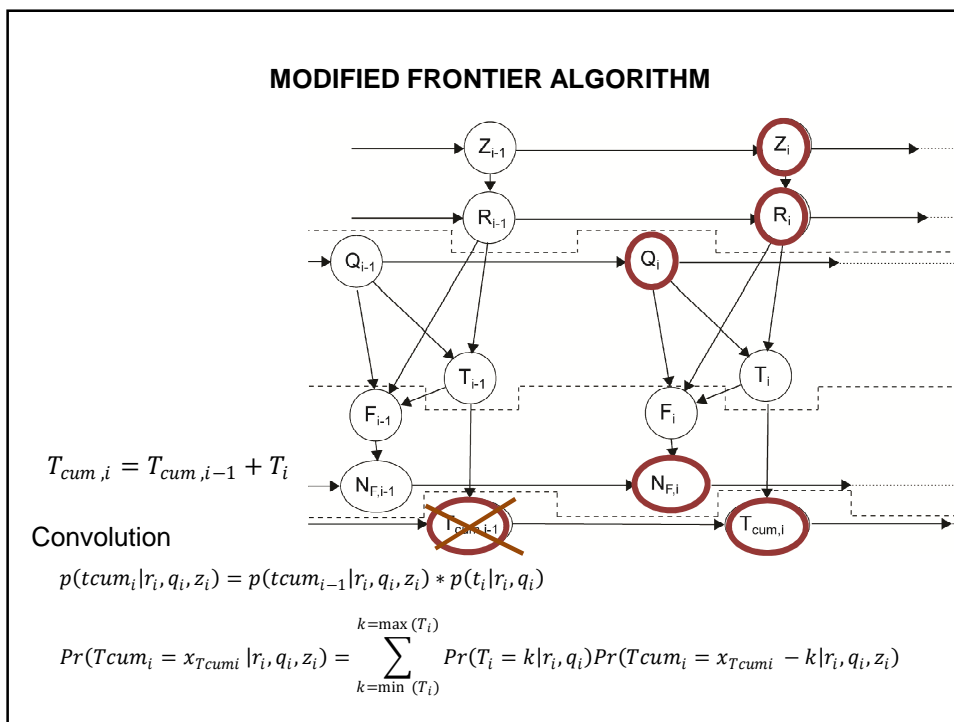
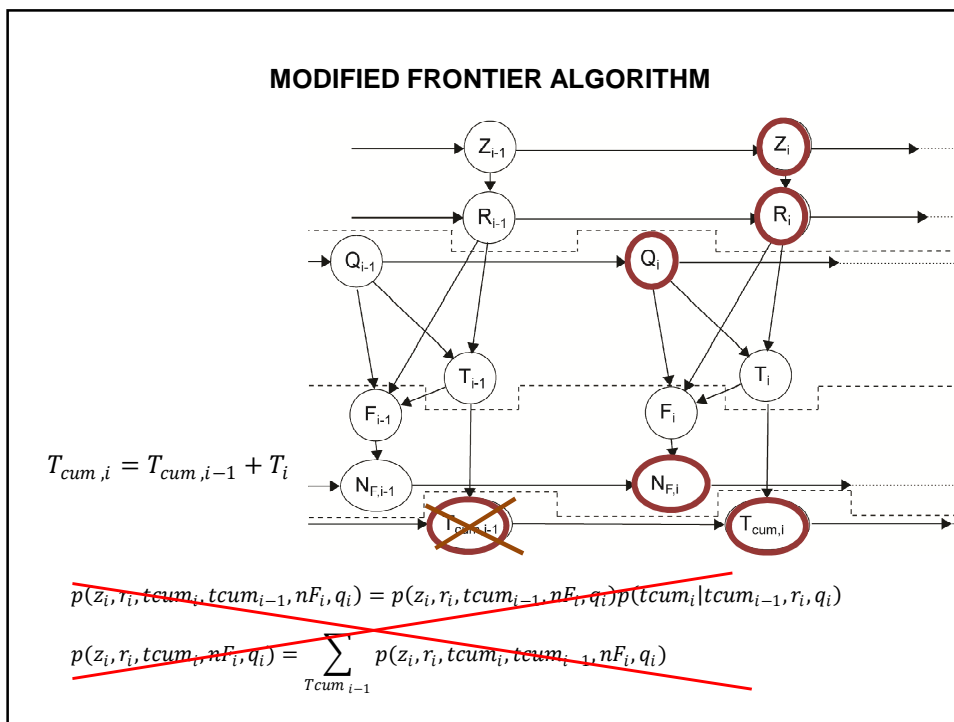
### MODIFIED FRONTIER ALGORITHM



$$T_{cum,i} = T_{cum,i-1} + T_i$$

$$p(z_i, r_i, tcum_i, tcum_{i-1}, nF_i, q_i) = p(z_i, r_i, tcum_{i-1}, nF_i, q_i)p(tcum_i|tcum_{i-1}, r_i, q_i)$$

$$p(z_i, r_i, tcum_i, nF_i, q_i) = \sum_{T_{cum_{i-1}}} p(z_i, r_i, tcum_i, tcum_{i-1}, nF_i, q_i)$$

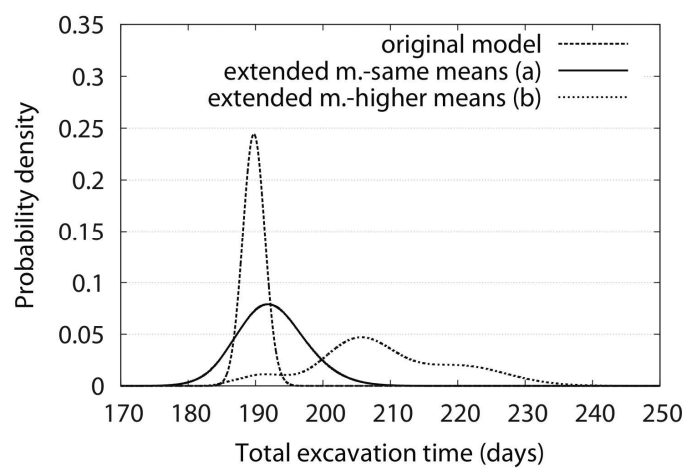


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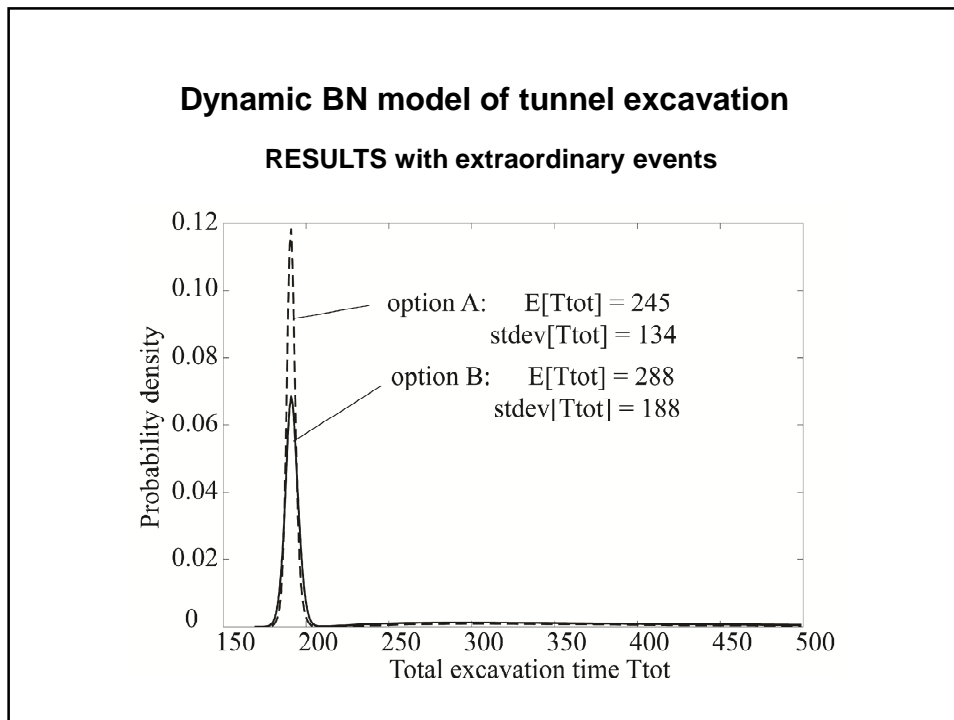
- Results, Conclusions

### Dynamic BN model of tunnel excavation

#### RESULTS without extraordinary events







## Conclusions

Suggested approach enables

- full probabilistic estimation of construction time (cost)
- consideration of both types of risks
- involvement of hardly measurable influence of human factor
- updating of estimates during the on-going project
- systematic learning from past projects (requires generalized description of geotechnical conditions, definition of failures etc. ... and data)

**Thank you for your attention**