Risk Management in Tunneling Projects: Estimation and Planning

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Chair of Session: Dr. John Leander

OBJECTIVES OF THE PHD PROJECT

- To investigate the impact of uncertainty on **project performance**
- To develop a **model** to account for uncertainties in project **time** and **cost** estimation

CONTENTS

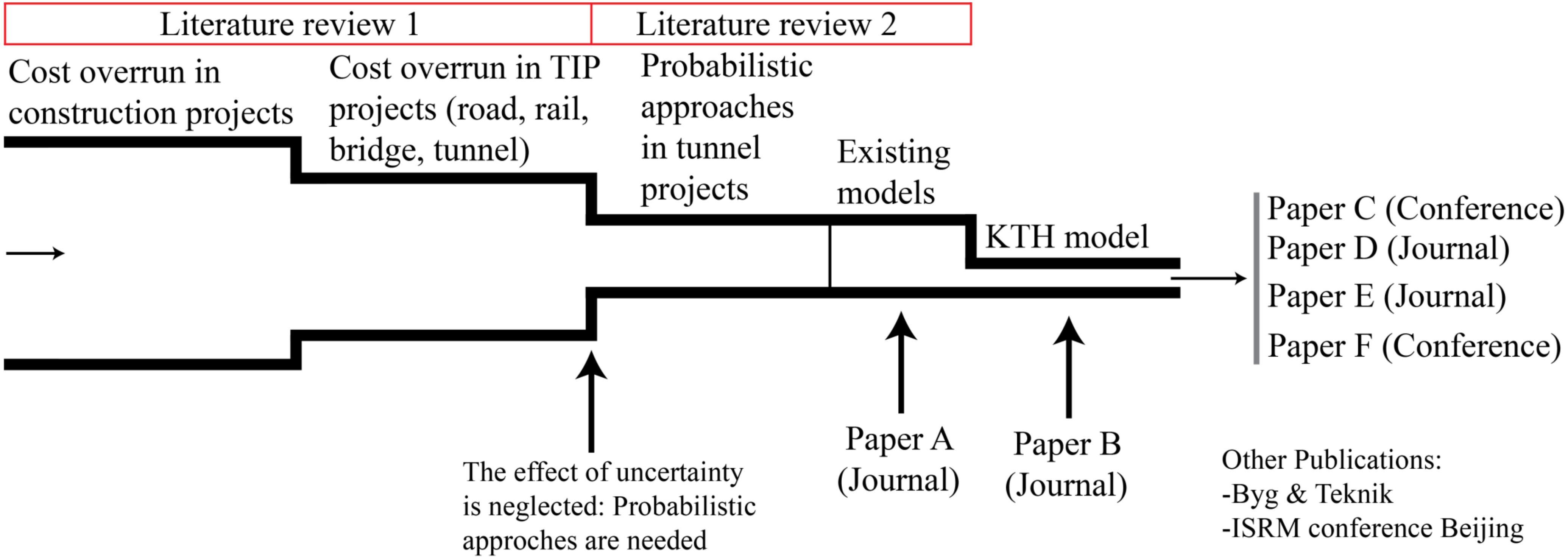
INTRODUCTION : TIME AND COST OVERRUN

Project	Estimated cost (billion SEK)	Actual cost (billion SEK)	Percentage increase **(Overrun)**
Citybanan	7.5 (1994)	20.1 (2017)	105%
Södra länken	4 (1991)	8.4 (2004)	71%
Norra länken	2.1 (1991)	10.4 (2014)	259%
Förbifart Stockholm	19 (1994)	37.7* (2030)	-

Reference: Svenska Dagbladets debattsida 24 januari 2022

**Forecast*

OVERVIEW OF THE THESIS



WHAT ARE THE REASONS OF OVERRUN?

Error

- Technical explanations
- Psychological reasons (bias)

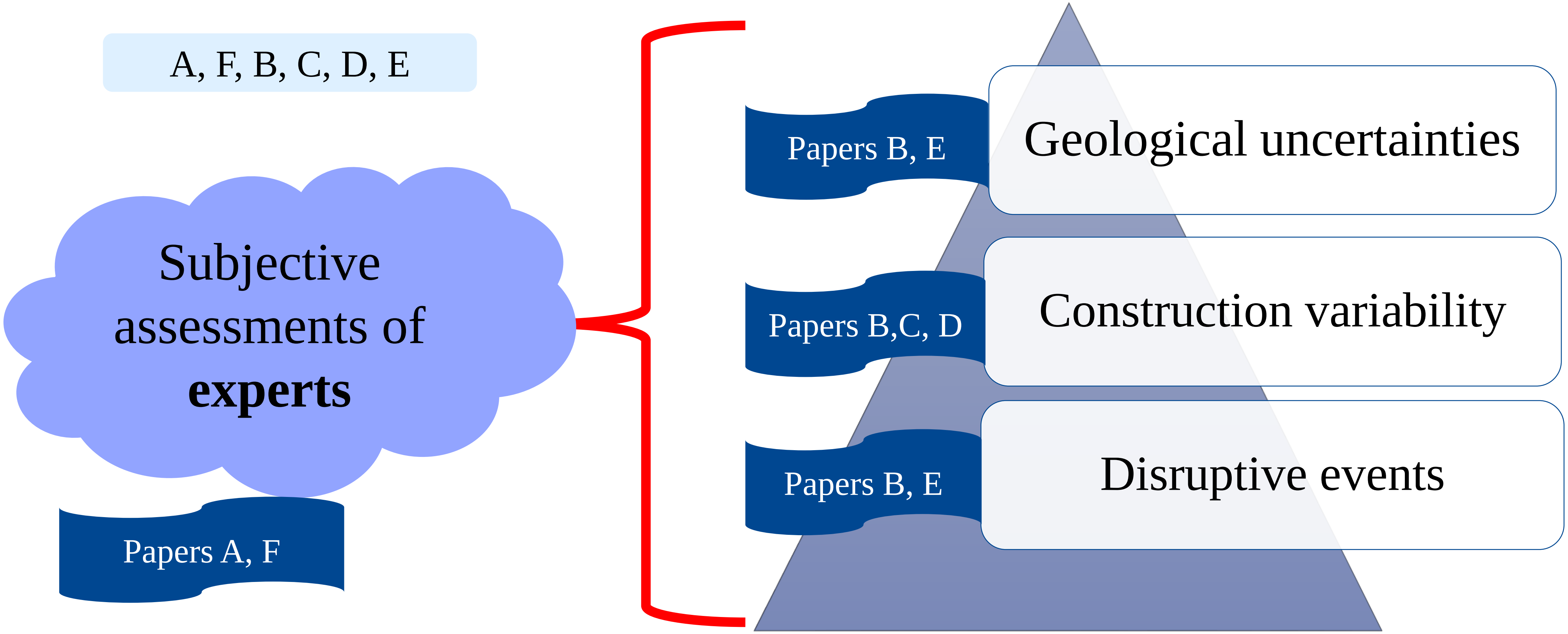
Uncertainty

Deception

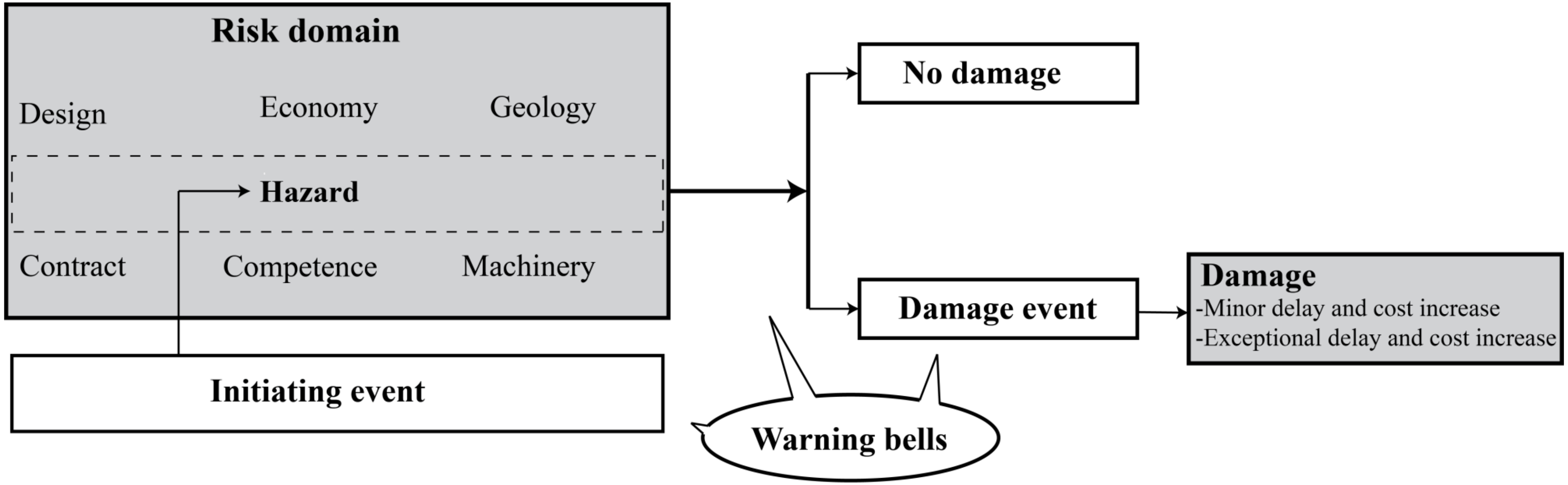
- Economic explanation
- Political explanation

Deliberate underestimation

ESTIMATION: SOURCES OF UNCERTAINTY



THE RISK MODEL

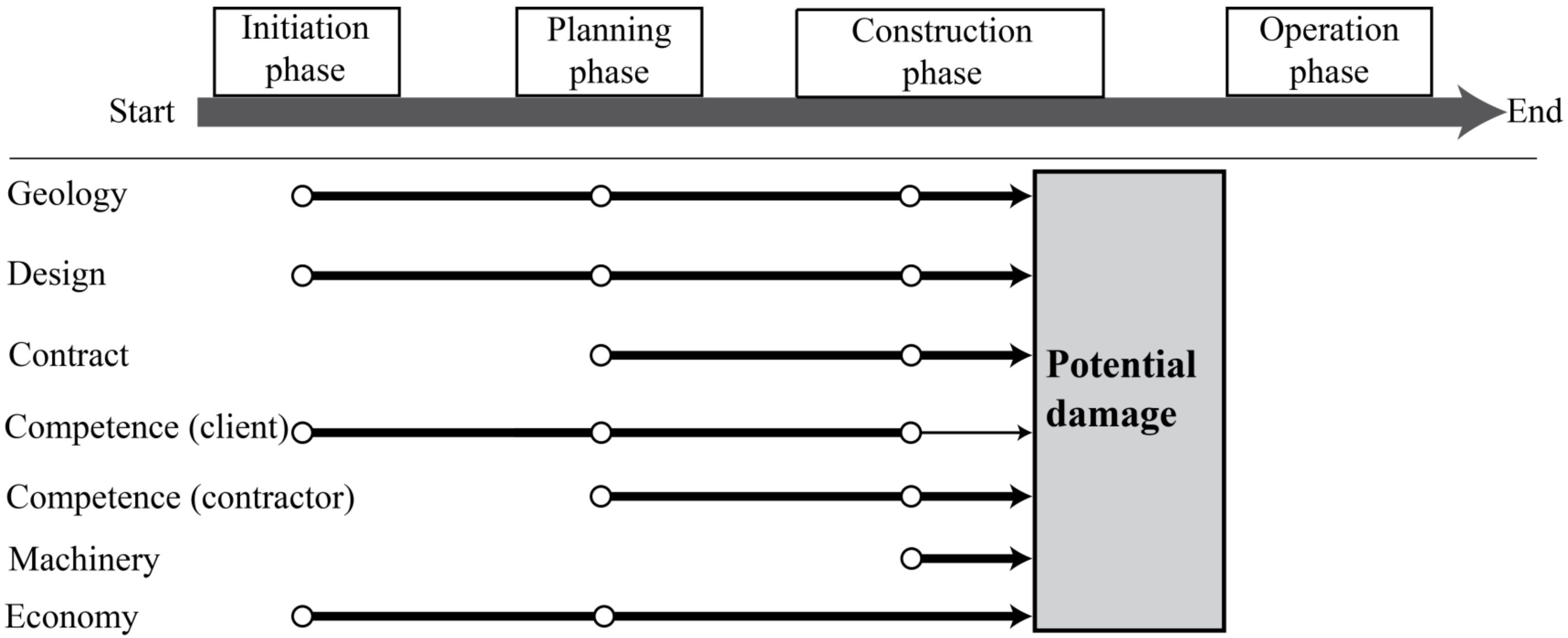


$$T = f(\text{geology, design, contract, competence, machinery, economy})$$

$$C = h(\text{geology, design, contract, competence, machinery, economy})$$

Paper A

THE RISK MODEL IN TUNNELING PHASES



Paper F

THE KTH MODEL: THEORETICAL FRAMEWORK

Probabilistic time and cost estimation:

Isaksson and Stille (Rock Mech Rock Eng, 38:373–398, 2005)

- $T = T_{\mathrm{N}} + T_{\mathrm{E}} = \sum_{u=1}^{n_{\mathrm{zone}}} \int_{L_u} g_u[\mathbf{x}(l)]dl + \sum_{i=1}^{n_{\mathrm{dis}}} T_{\mathrm{E},i}$

- $C = C_{\mathrm{N}} + C_{\mathrm{E}} = \sum_{u=1}^{n_{\mathrm{zone}}} \sum_{\alpha=1}^{n_{\alpha}} \int_{L_u} z_{\alpha} g_{\alpha}[\mathbf{x}(l)]dl + \sum_{i=1}^{n_{\mathrm{dis}}} C_{\mathrm{E},i}$

T_{N} = Normal time, T_{E} = Exceptional time

x = Geological parameters that affect tunneling time and cost

n_{zone} : Number of geotechnical (geological) zones along tunnel route

n_{dis}: Number of types of disruptive events

Obtaining $g_u[\mathbf{x}(l)]$ is very challenging in practical application

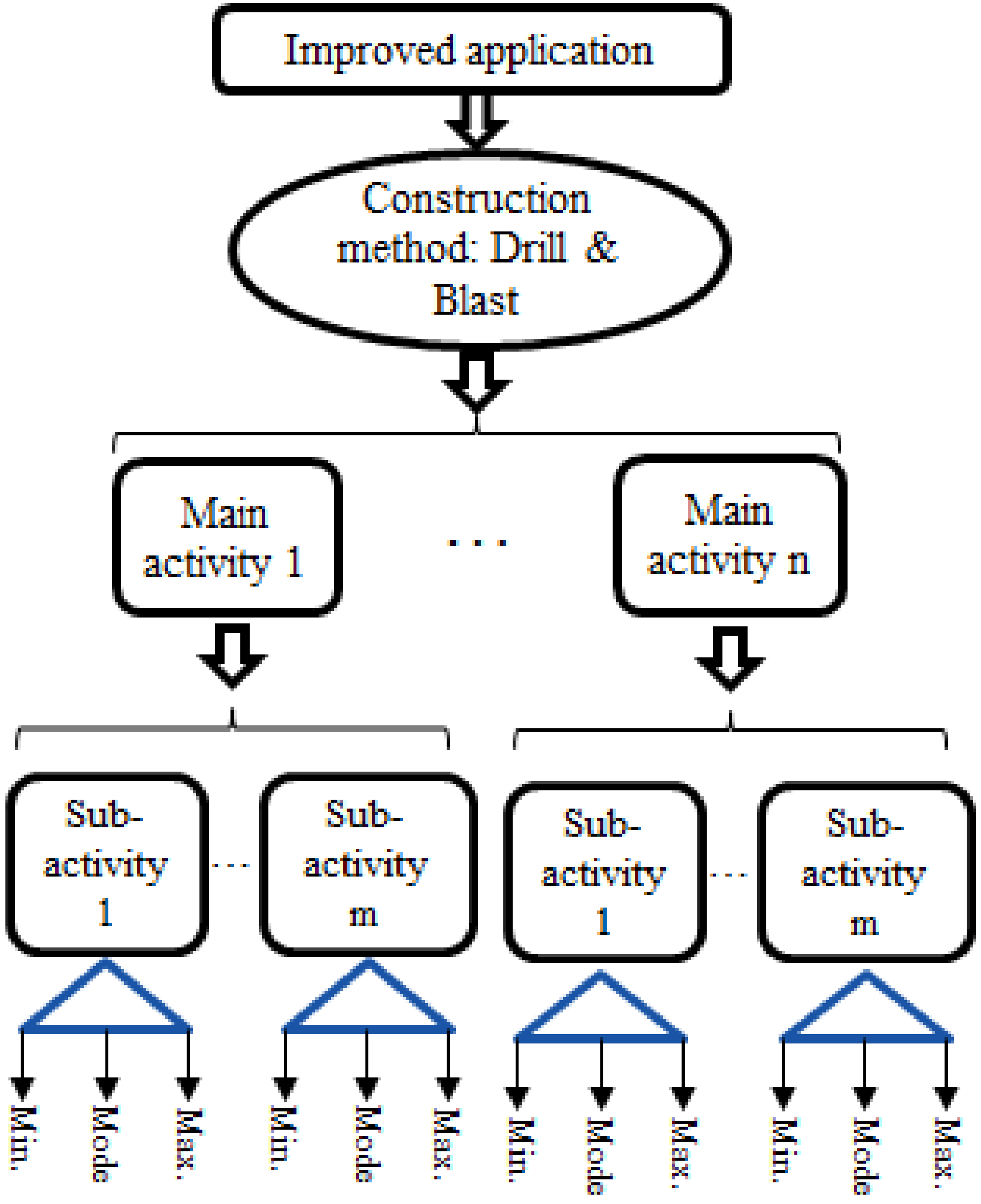
THE KTH MODEL: PRACTICAL

Production effort (Q): Time per unit length.

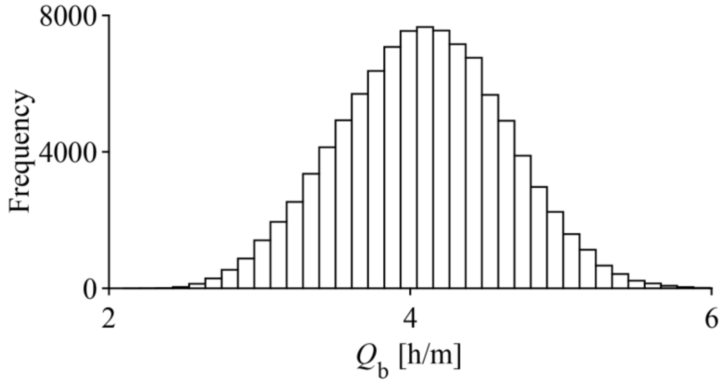
$$Q = g_u[\mathbf{X}(l)]$$

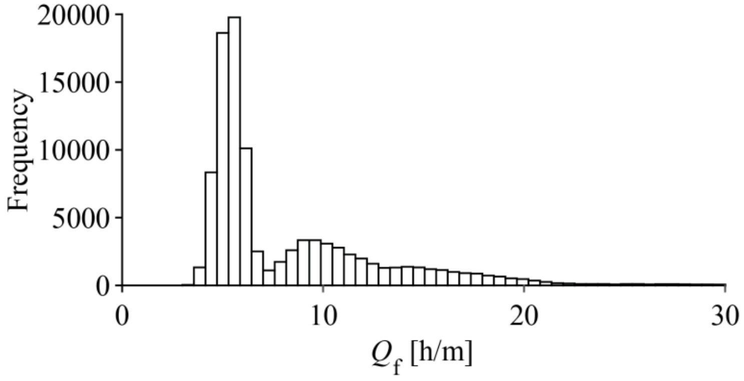
$Q = \sum_{a=1}^{n_a} Q_a$	Production effort
$Q_a = \sum_{k=1}^{n_k} p_{a,k} Q_{a,k}$	Production effort of the a^{th} production activity
$Q_{a,k} = \sum_{j=1}^{n_q^a} q_{j,a}$	Production effort of the a^{th} production activity in its k^{th} class

Paper B



THE KTH MODEL: PRACTICAL APPLICATION





$$\mathbf{Q} = [Q_1, Q_l, \ldots, Q_L]$$

$$T'_{\mathrm{N}} = \sum_{l=1}^{L} Q_l$$

Normal Time (T'_{N})

$$T'_{\mathrm{N}} \rightarrow \mathcal{N}(\mu_{T',\mathrm{N}}, \sigma_{T',\mathrm{N}})$$

$$\mu_{T',\mathrm{N}} = L\mu_Q$$

$$\sigma_{T',\mathrm{N}} = \Gamma L \sigma_Q$$

$$\Gamma = \sqrt{\frac{\delta}{\delta + L}}$$

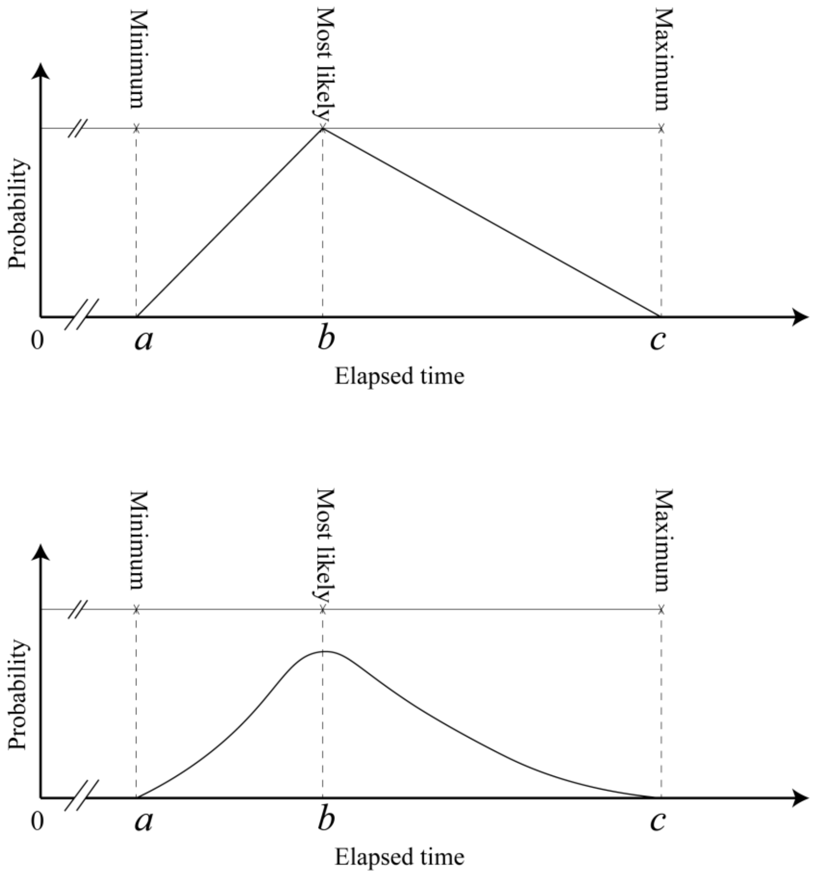
L = Tunnel length (m)

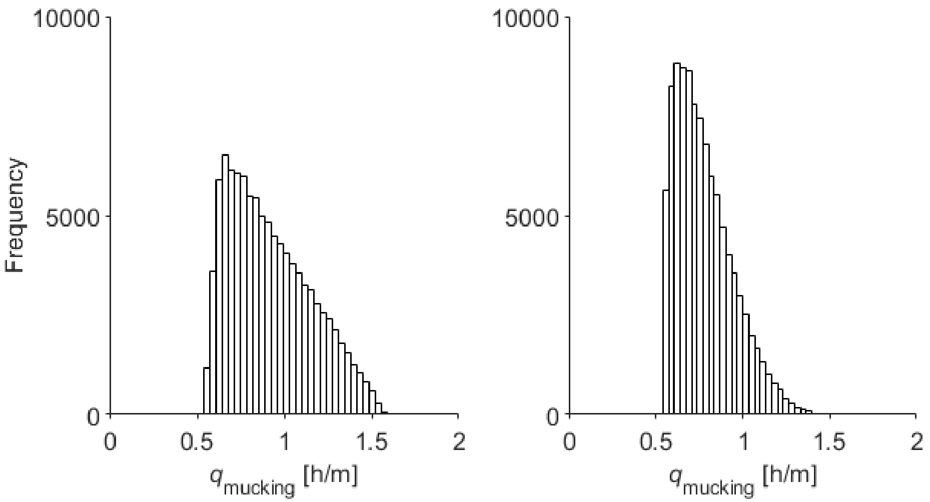
δ = Scale of fluctuation

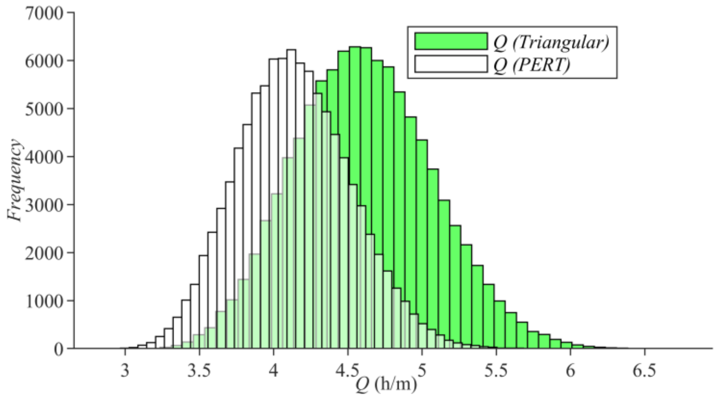
$L \gg \delta$

Paper B, C

THE KTH MODEL: ACTIVITY DURATION



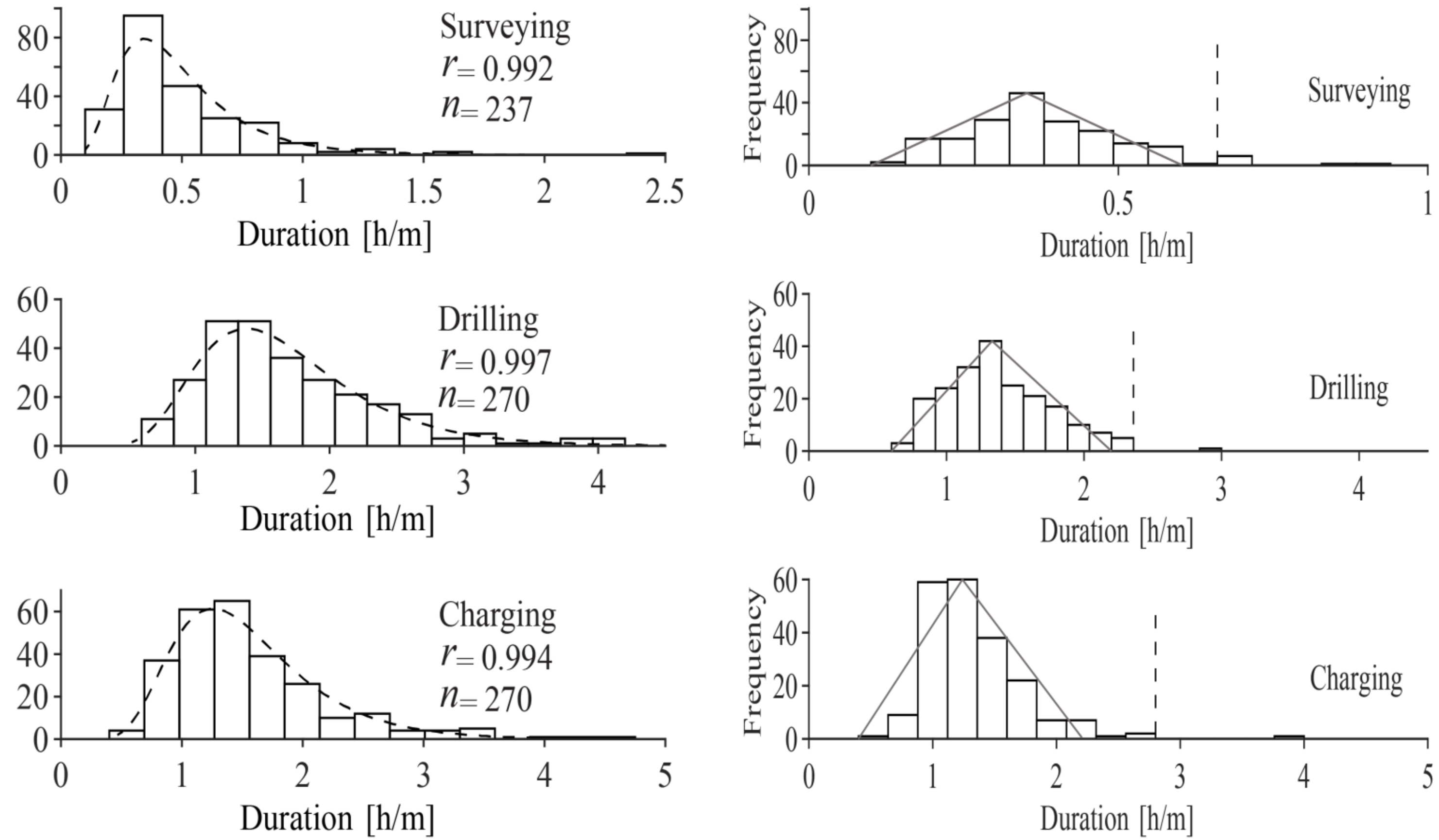




	Mean T_N (Std)
PERT	8276 h (229)
Triangle	9216 h (280)

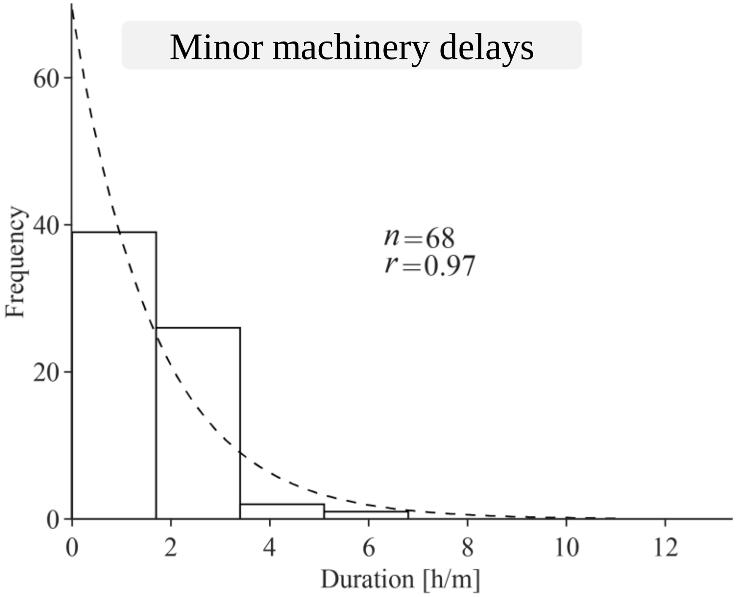
Paper C

THE KTH MODEL: MINOR DELAYS



The tails represent **minor machinery delays** (mmd) and **minor performance delays** (mpd)

Both mmd and mpd are modeled with **exponential** distributions



Paper D

THE KTH MODEL: MINOR DELAYS

Minor machinery delays (mmd)

$$\kappa_{\mathrm{m},i} = (\lambda_{\mathrm{m}}^{a}) e^{(-\lambda_{\mathrm{m}}^{a} n_{\mathrm{r}}^{a})}$$

$$\kappa_{\mathrm{m},a} = \sum_{i=1}^{n_{\mathrm{r}}^{a}} \kappa_{\mathrm{m},i}$$

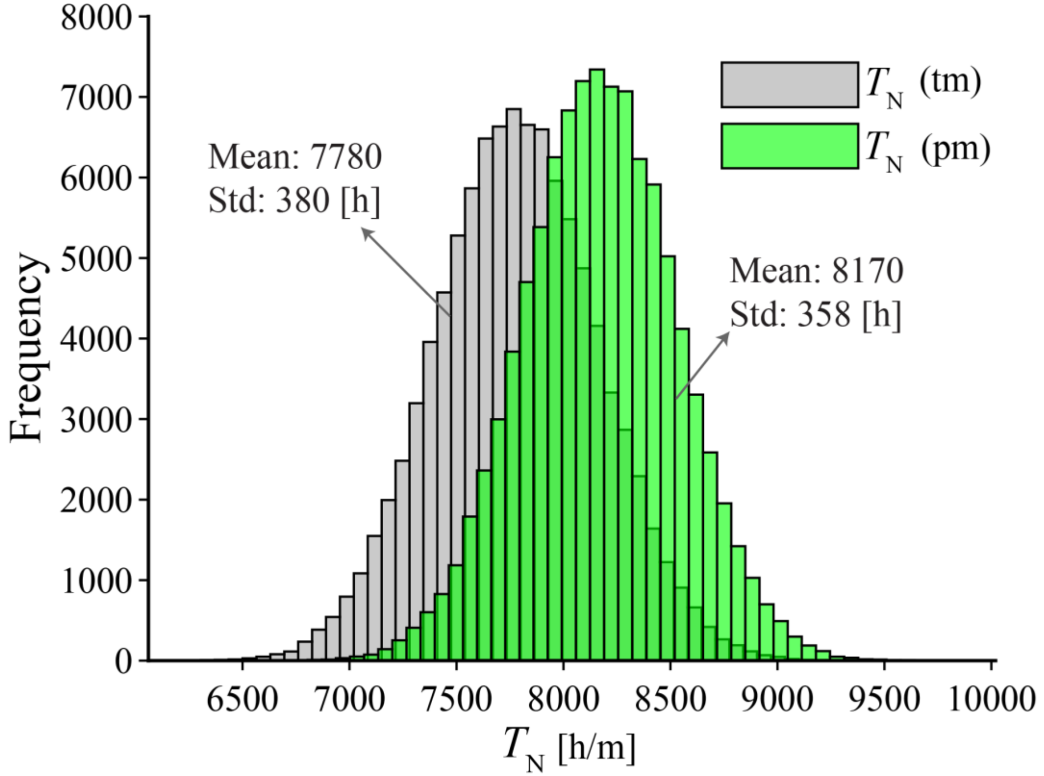
$$\kappa_{\mathrm{m}} = \sum_{a=1}^{n_a} \kappa_{\mathrm{m},a}$$

Minor performance delays (mpd)

$$\kappa_{\mathrm{p},i} = (\lambda_{\mathrm{p}}^{a}) e^{(-\lambda_{\mathrm{p}}^{a} n_{\mathrm{r}}^{a})}$$

$$\kappa_{\mathrm{p},a} = \sum_{i=1}^{n_{\mathrm{r}}^{a}} \kappa_{\mathrm{p},i}$$

$$\kappa_{\mathrm{p}} = \sum_{a=1}^{n_a} \kappa_{\mathrm{p},a}$$



$$T_{\mathrm{N}} = T'_{\mathrm{N}} + \kappa_{\mathrm{m}} + \kappa_{\mathrm{p}}$$

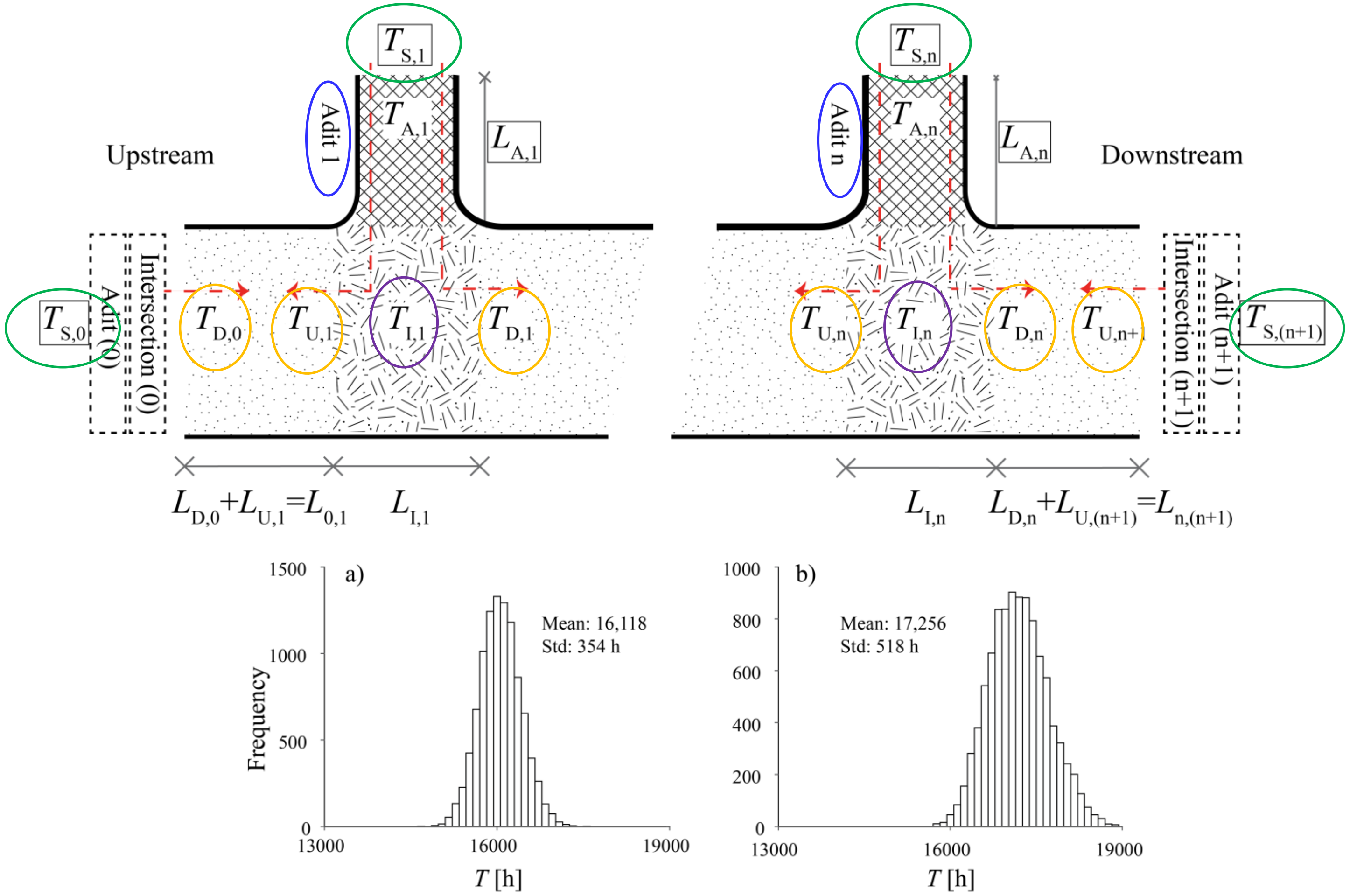
Paper D

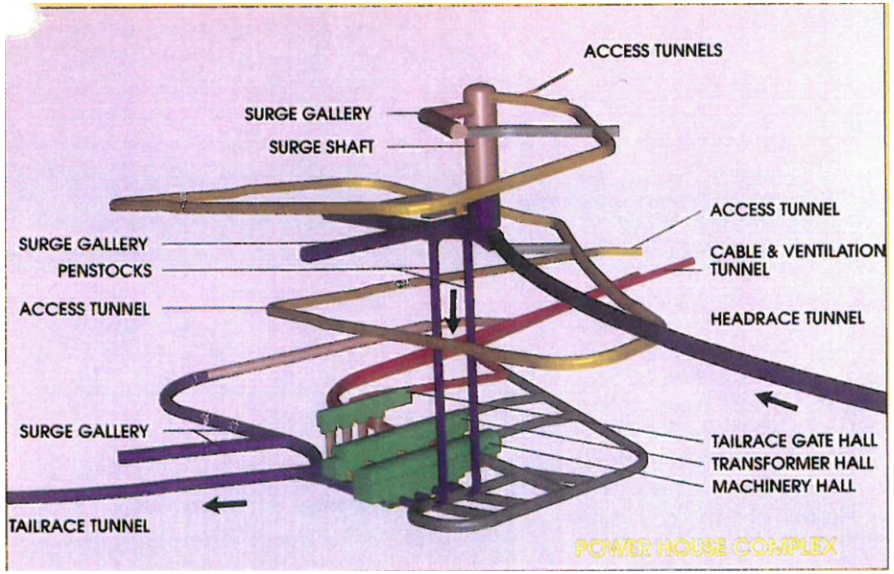
THE KTH MODEL: GEOLOGICAL UNCERTAINTIES

- Using **proportions** of various **ground classes** instead of ground class profiles.
- Modeling geological uncertainty through **user-identified geological setting** of the area (paper B)
- Using **Metropolis-Hastings** (MH) algorithm within the framework of Markov Chain Monte Carlo (MCMC) simulation for modelling geological uncertainties: Paper E
  - ✓ Enabling time estimation for shorter tunnels ($L \gg \delta$)
  - ✓ Round-by-round simulation of tunneling process

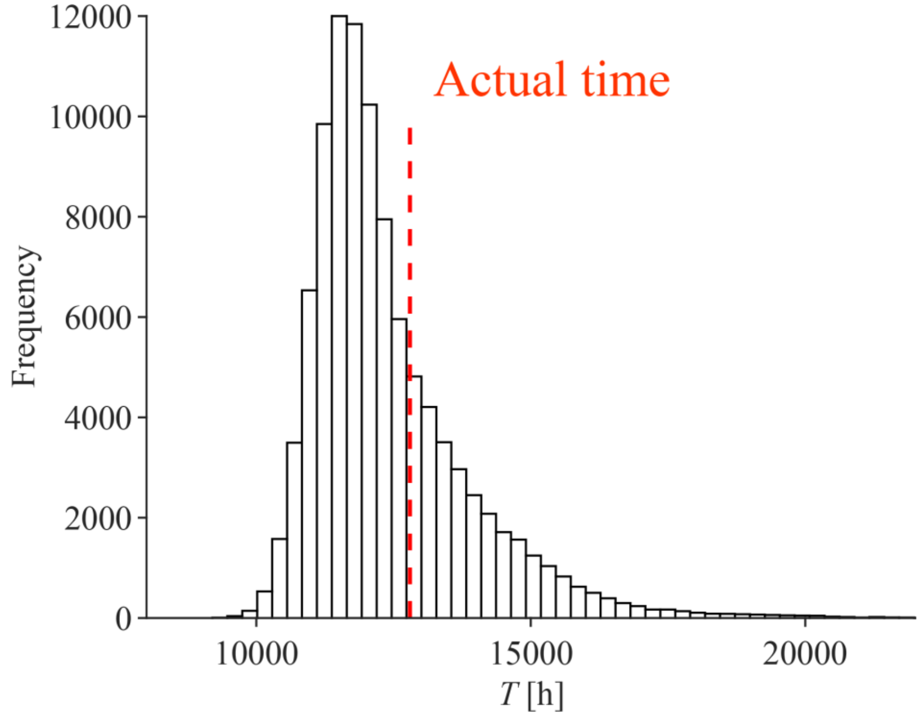
THE KTH MODEL

Round-by-round simulation:
Uncertainty in complex project's critical path





OVERRUN



In this context, the primary concern becomes the decision-making regarding **risk tolerance** or aversion by the involved parties, along with the project's financial circumstances.

Adopting probabilistic estimation provides a more realistic perspective, making the **traditional** concept of cost **overrun less relevant**.

CONCLUSIONS

- Modeling the construction process is achieved through **work breakdown structure** (WBS).
- **PERT** distributions are utilized to represent the uncertainty in the duration of unit activities.
- The main components of **construction performance variability** are:
  - ✓ Typical performance variability
  - ✓ Minor machinery delays
  - ✓ Minor performance delays
- Geological uncertainties are modeled using **Metropolis-Hastings algorithm** within the framework of Markov Chain Monte Carlo (MCMC) simulation.
- **Disruptive events** and their consequences are represented as **stochastic** variables.

FUTURE WORK

- Modeling the **proportions** of different classes of production activities ($p_{a,k}$) as **stochastic** variables.
- Further research on the effect of **spatial correlation** (selection of δ or r) on the accuracy of the results
- The variability in **construction performance** for tunneling methods **other** than drill & blast.
- Adjusting the model for **cost** estimation and analyzing the effect of various scenarios on project performance

Thank you for your attendance