Probabilistic safety assessment of dam’s gated spillway systems

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Summary

- What is a gated spillway system ?
  - Function, Description, Complexity of system

- Motivations

- Method foundations
  - Expression of the feared event
  - Collecting trustworthy reliability data
  - Generic modelling
  - Quantification

- Future works in sight

What is a gated spillway system ? [1]

- Function

Dam gated spillway is a subsystem within dams.

It aims to :

- release surplus or flood water which exceeds the allotted storage space in storage and detention dams
- divert water which has a flow rate that exceeds the design limit for diversion dams

Prevents overtopping that may lead to a breach of dam

What is a gated spillway system ? 2

- Description : *Components*

  Gates

  - Three main kinds of gates
    1. hinged flaps or shutters
    2. vertical-lift gates
    3. radial gates

  - Actuated by :
    - The weight of water at a given upstream level
    - External sources of energy (electrical engine, hydraulic)

What is a gated spillway system ? [4]

- Description : *Components*

  Electrical supply

  - National grid
  - Diesel driven generator set

  Several kinds of electrical wiring with different levels of reliability

What is a gated spillway system ? 5

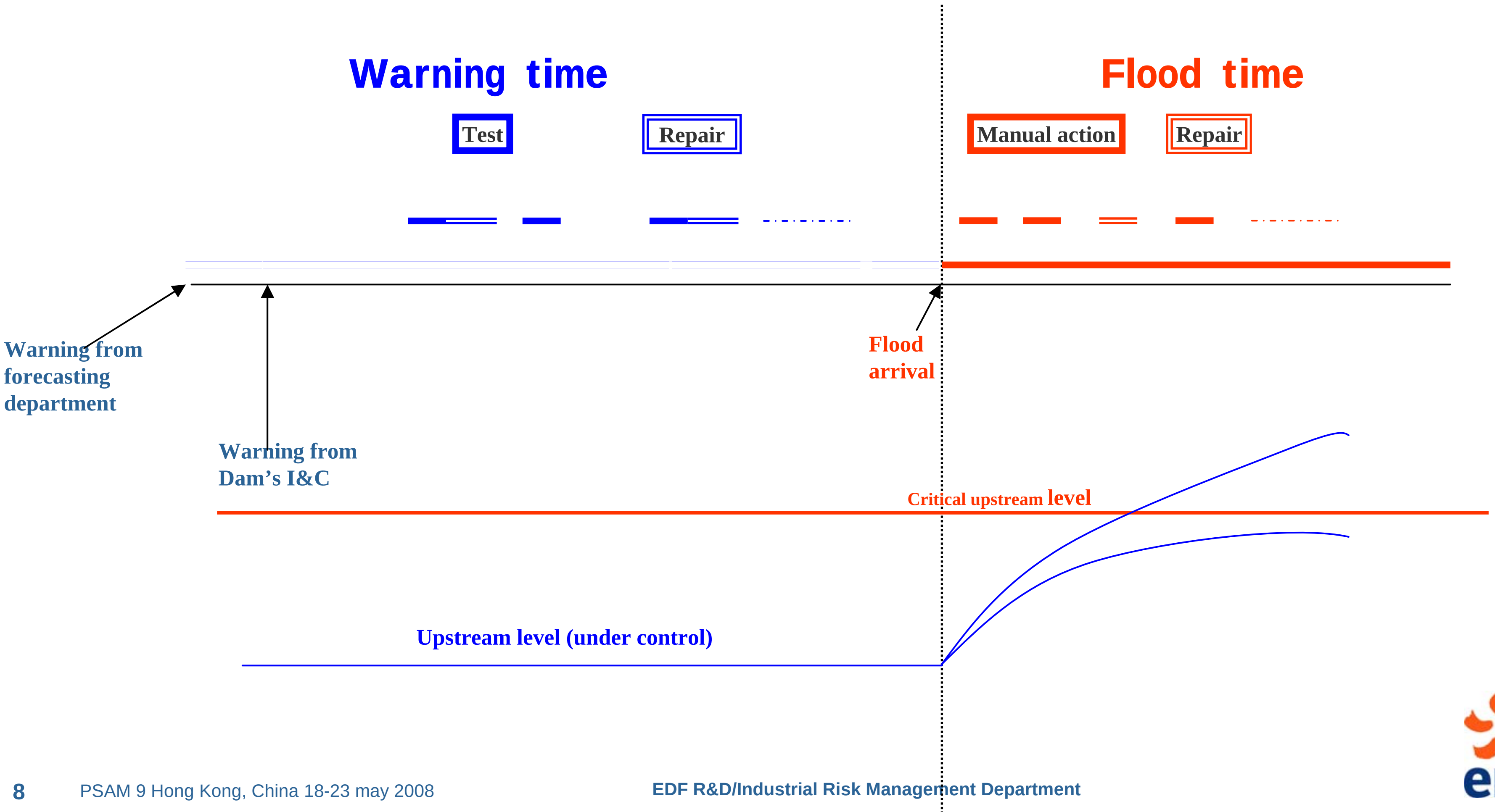
- Description : *Components*

  I&C subsystem

  - Detects flood conditions
  - Detects gate position
  - Detects malfunction
  - Signals alarm to operators
  - Formulates opening/closing instructions
  - Sends opening/closing orders to gate actuators

What is a gated spillway system ? [6]

- Description : *Behaviour*



Motivations

- Statistics

  Overtopping has caused

  49% of embankment dam failures

  43% of masonry dam failures

  9% of concrete dam failures

  22 % of overtopping cases caused by underestimated spillway systems

  17 % of overtopping cases caused by malfunction of spillway systems

- Possible need of increasing spillway discharging capacity due to a re-evaluation of flood extreme levels

  ➔ Meet actual requirements for individual dams :

  How to measure risk level?

  ➔ Coordinate and prioritize investments according to actual risk level :

  Standardize risk analysis method

  Common references for every spillway risk analysis

  Help and support method for approximately 200 analyses

Method foundations [1]

- Expression of the feared event

$$P(z > C) = \sum_{F} P(z > C \mid Flood_F) * P(Flood_F)$$

z : upstream water level

C : critical water level (before overtopping)

$Flood_F$: A potential flood

z is a continuous variable which varies over time and governs the occurrence of the feared event

Method foundations ²

- Collecting trustworthy reliability data for equipment

  National failure record system But great equipment disparity in the EDF operated dams

  - Highlighting common equipment characteristics

    ➔ New classification of equipment

  - Collecting and processing recorded data according to the new classification

Usage of produced data as a starting point that has to be refined by experts and operators for each specific dam gated spillway system

Method foundations [3]

- Collecting trustworthy reliability data for human factor
  - At the reception of warning time signal
    - If present in the dam
      - operator must acknowledge awareness of alarm signal
    - If absent
      - operator must acknowledge awareness of alarm signal and go to the dam
  - Operator may be requested for
    - Test And Repair in warning Time
    - Normal manual operating in flood Time
    - Backup manual operating in flood Time
    - Repair in flood Time

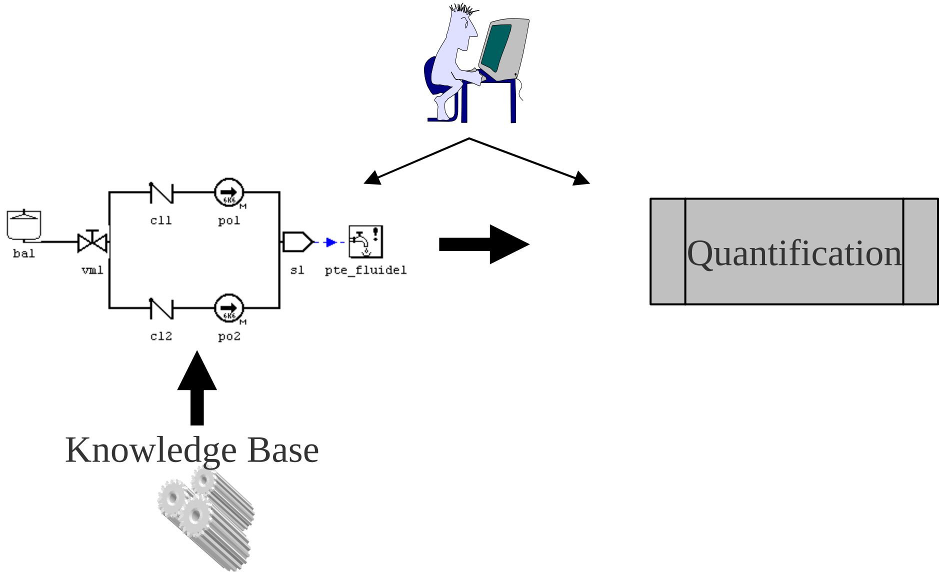
Method foundations [4]

- Generic modelling

Set up a tool that aims, for every individual gated spillway system, to estimate the probability that the water in the upstream dam basin will reach critical level.

➔ Usage Of KB3

Multi-domain software platform for system dependability evaluation



Method foundations 4

```
CLASS Gate KIND_OF component;
    INTERFACE
        Actuator                         KIND_OF ACTUATOR
                                         CARDINAL 1 TO 2;
    CONSTANT
        MaxFlowrate                      DOMAIN REAL
                                         DEFAULT 200;
        GammaFailureOnOpeningDemand      DOMAIN REAL
                                         DEFAULT 0.001;
        OpeningDuration                  DOMAIN REAL
                                         DEFAULT 0.15;

    ATTRIBUTE
        State                            DOMAIN 'opened' 'closed'
                                         DEGFAULT 'closed';
        CurrentFlowrate                  DOMAIN REAL
                                         DEFAULT 0;
        toOpen                           DOMAIN BOOLEAN
                                         DEFAULT FALSE;
        orderReceived                    DOMAIN BOOLEAN
                                         DEFAULT FALSE;

    INTERACTION
        IF    State = 'opened'
        THEN  CurrentFlowRate ← MaxFlowrate
        ELSE  CurrentFlowRate ← 0.;
```

```
OCCURRENCE
    receivingOrder
    IF State = 'closed' AND NOT orderReceived
        MAY_OCCUR FAULT ROO
        DIST INS (GammaFailureOnOpeningDemand)
        INDUCING
                orderReceived ← TRUE
    OTHERWISE TRANSITION NON_ROO
        INDUCING
                toOpen ← TRUE,
                orderReceived ← TRUE;

    openingGate
    IF orderReceived AND toOpen
      MAY_OCCUR TRANSITION OPENING
        DIST T_C (OpeningDuration)
        INDUCING
                state ← 'opened'
```

Method foundations [5]

- Principles of modelling : Equipment

For every component : One failure mode → γ

For some components : Two failure variants

a non repairable variant → γ

a repairable variant → γ & ***mean time to repair***

Some components are testable in warning time → *mean time to test*

Some components must be operated manually → *mean time to operate*

Some components may be operated manually in impaired situation → *mean time to operate*

Some components are activated at a specified level

of upstream water → *level*

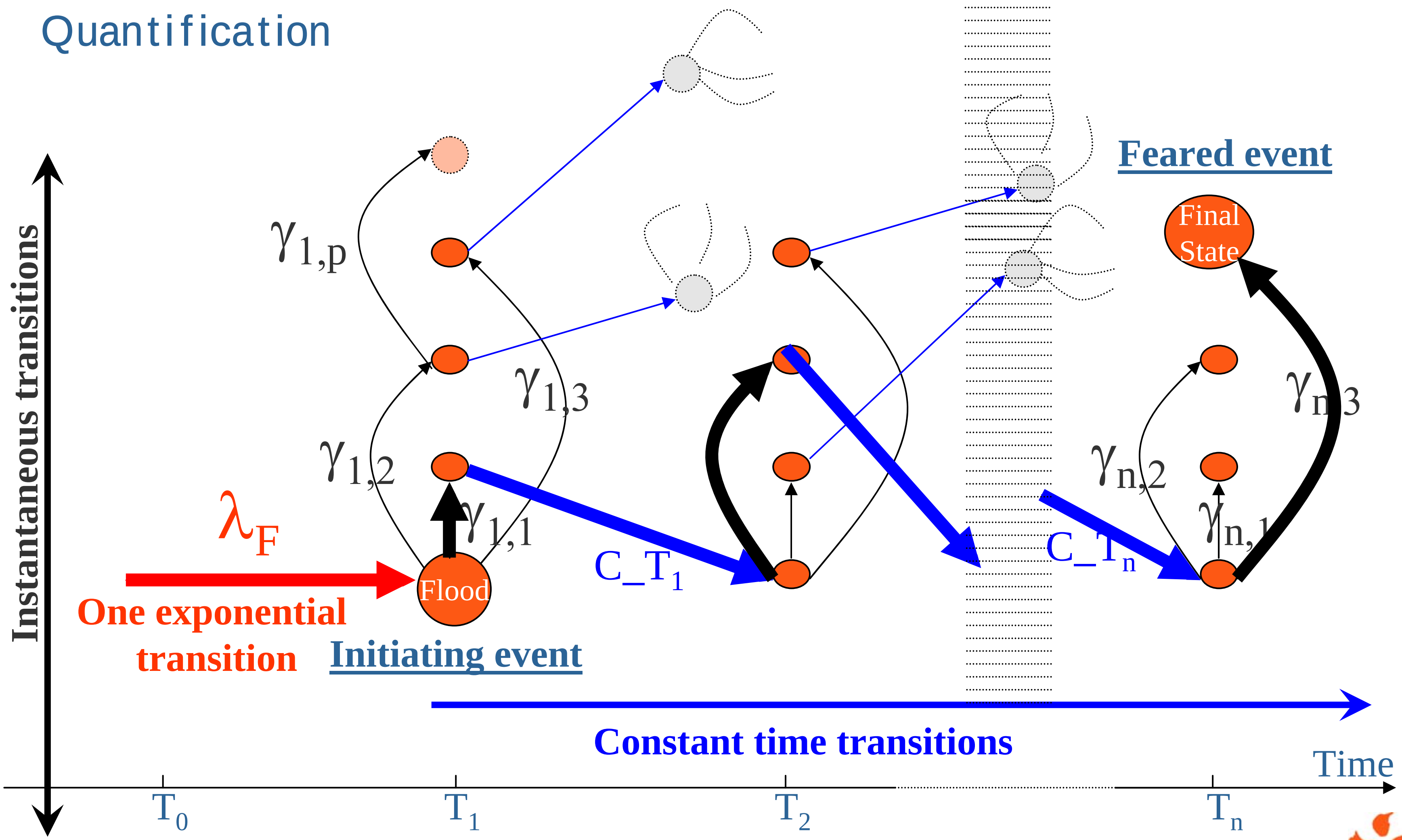
Gates have a discharging capacity that depend on the level of upstream water → *level*$_1$, *level*$_2$, ..

Level of upstream water varies over time

$Z_{t+\delta t} = Z_t + \alpha.(Q_{in} - Q_{out}).\ \delta t$ → α

Method foundations 6

- Quantification



Method foundations [7]

- Quantification

$$P(S_n^F) = \left(\prod_{t_{ij} \in S_n^F} \gamma_{t_{ij}}\right).(1 - e^{-\lambda_F T}).$$

$$P_F(FearedEvent) = \left(\sum P(S_n^F)\right) = (1 - e^{-\lambda_F T}).\sum\left(\prod_{t_{ij} \in S_n^F} \gamma_{t_{ij}}\right)$$

$$\downarrow \qquad \downarrow$$

$$P(Flood_F).P(z > C | Flood_F)$$

$$P(FearedEvent) = \sum_F P_F(FearedEvent) = \sum_F P(z > C | Flood_F) * P(Flood_F)$$

$$\boxed{= P(z > C)}$$

Method foundations 8

- Quantification output example

	Freq(TO)	nb seq.	Cible n°	Expression booleenne :
	2.4245764e-007	1842	1	realise(EvenementRedoute)
	2.4245764e-007	**1842**		

	Maj. erreur	nb seq.	Valeur critere tronc.	Critere troncature
	2.2786876e-008	1788828	1e-012	probabilite min
	2.2786876e-008	**1788828**		

Method foundations 8

- Quantification output example

Transitions			Frequences :		Contrib.
Nom	Date	Type	Unite T.	T. Observ.	
[DUREE_2 DE CRueDicennale,		INS			
fonctionneme DE ServicePrevisionCrues]		INS			
[fonctionnement DE TelecomEntrant]		INS			
[fonctionnement DE AlarmeBarrage,		INS			
fonctionnement DE TelecomSortant]		INS			
[fonctionnement DE Dap,		INS			
attente DE OP_1]		INS			
[attente DE OP_2]		INS			
[REUSSITE_DEPLACEMENT DE OP_2]		INS			
[DEPLACEMENT DE OP_2]	2.0000e+00	TC			
[ETABLISSEMENT_CRUE DE CRueDicennale]	4.8000e+01	TC			
[OKabs_signal DE MesureNiveau,		INS			
OKsig_errone DE MesureNiveau]		INS			
[OKdef_soll DE egs_1]		INS			
[OKdef_soll DE DJ_1]		INS			
[OKdef_soll DE Bascule_1]		INS			
[OKdef_soll DE Barre_1]		INS			
[OKdef_soll DE Bascule_6]		INS			
[OKdef_soll DE Redresseur]		INS			
[OKdef_soll DE CCBarrage]		INS			
[OKdef_soll DE CCLocal_1,		INS			
def_sollCourte DE CCLocal_2,		INS			
OKdef_soll DE CCLocal_3]		INS			
[OKdef_soll DE Bascule_2,		INS			
OKdef_soll DE Bascule_4]		INS			
[OKperte_alim DE Coffret_1,		INS			
OKperte_alim DE Coffret_3]		INS			
[OKperte_alim DE MELECTRIQUE_1,		INS			
OKperte_alim DE MELECTRIQUE_3]		INS			
[OKp_c_h DE Chaine_1,		INS			
OKp_c_m DE Chaine_1,		INS			
OKp_c_h DE Chaine_3,		INS			
OKp_c_m DE Chaine_3]		INS			
[OKp_c_m DE VSTONEY_1,		INS			
OKp_c_m DE VSTONEY_3]		INS			
[enclenchementReparations DE moniteur]	4.8001e+01	TC			
[ECHEC_REPARATION DE OP_1]		INS			
[def_sollReparation DE CCLocal_2]	4.8101e+01	TC			
[atteinteNivRN DE moniteur]	4.8154e+01	TC			
[atteinteNivRN DE moniteur]	4.8221e+01	TC			
[atteinteNivPHE DE moniteur,	4.9692e+01	TC			
atteinteNiveauANe DE EvenementRedoute]	4.9692e+01	TC			
[atteinteNivSurete DE moniteur]	5.0000e+01	TC			
[atteinteNivPHE DE moniteur,	5.0572e+01	TC			
atteinteNiveauANe DE EvenementRedoute]	5.0572e+01	TC			
[atteinteNivPHE DE moniteur,	5.0592e+01	TC			
atteinteNiveauANe DE EvenementRedoute]	5.0592e+01	TC	2.0150e-11	8.0601e-09	3.3243e-02

Future works in sight

- Finalising method for data estimation of human action efficiency
- Taking external and physical Common Cause Failure into account
- Making pilot risk analysis
- Improving the clarity of the quantification results
- Transferring tools to engineering departments