



# Probabilistic maintenance and asset management on moveable storm surge barriers

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# The Netherlands

Below sea level!



Probabil

Rijkswaterstaat

# To prevent...

The Netherlands  
1953



# To prevent...

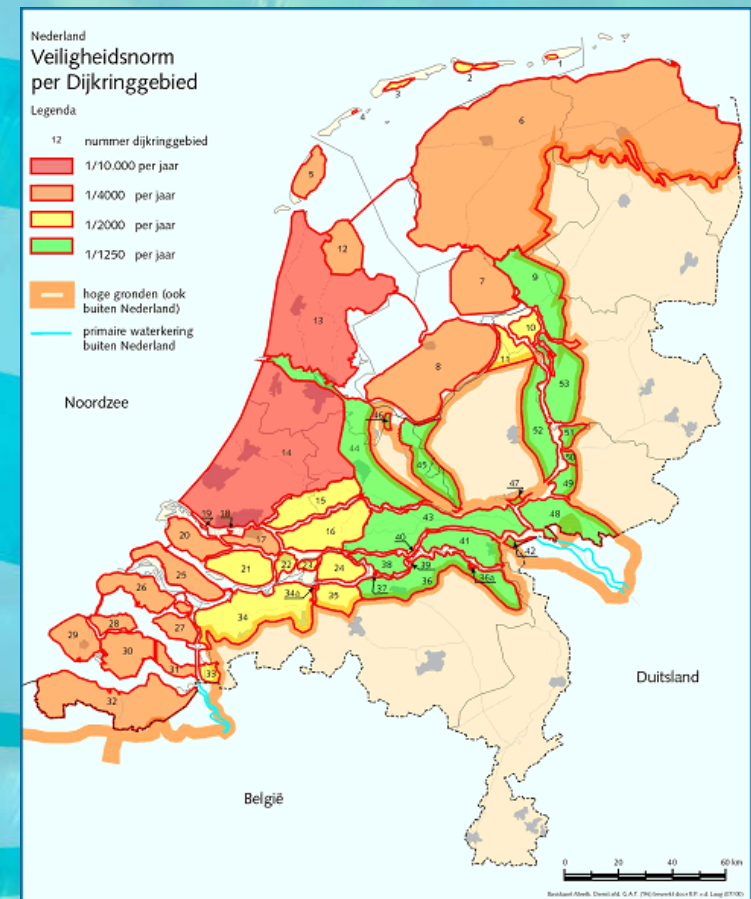
New Orleans  
2005



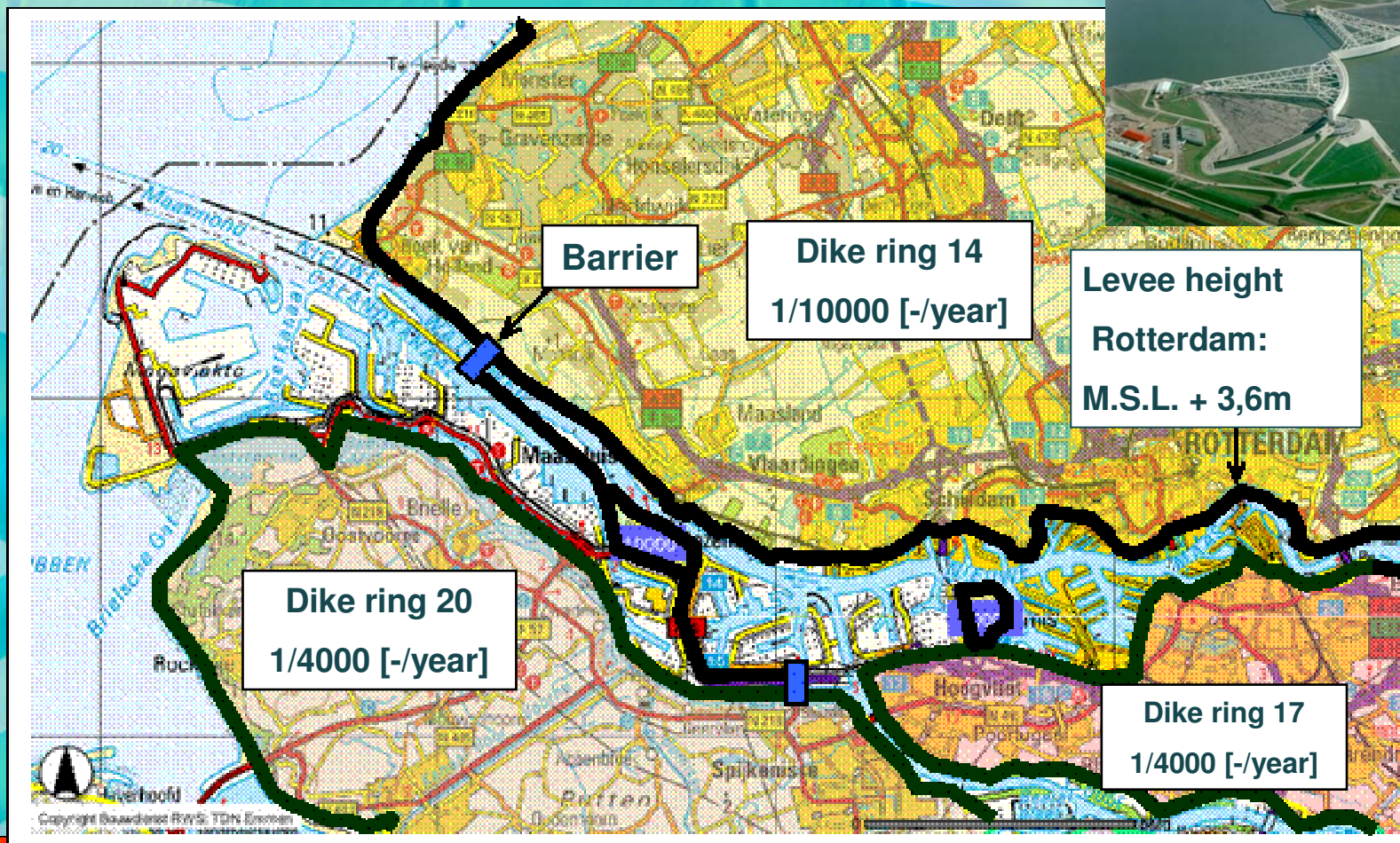
# Dutch Flood Defense Act

Dutch Flood Defense Act (1996) states:

- For every primary dike ring: Maximum acceptable probability of overtopping
- at the Rotterdam area: Probability of overtopping should be at most: 1/10,000 [-/year] (once in 10,000 years on average)
- This should be proven every 5 years



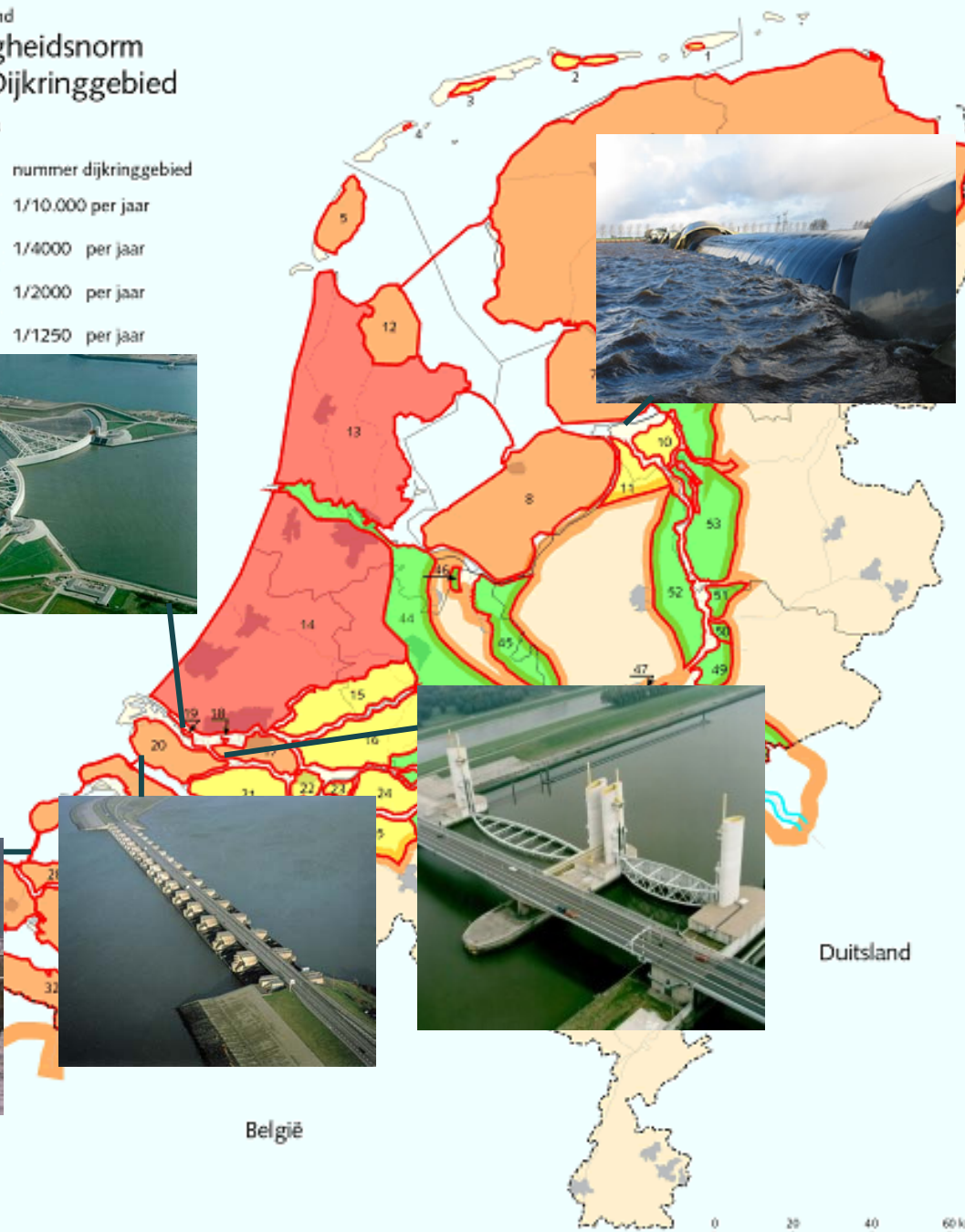
# Reliability requirements moveable storm surge barrier



# Nederland Veiligheidsnorm per Dijkkringgebied

## Legenda

- 12 nummer dijkkringgebied
- 1/10.000 per jaar
- 1/4000 per jaar
- 1/2000 per jaar
- 1/1250 per jaar



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Beeldart Alreb. Dienstltd. G.A.T. (P)©overst door R.F. v.d. Laag (2008)













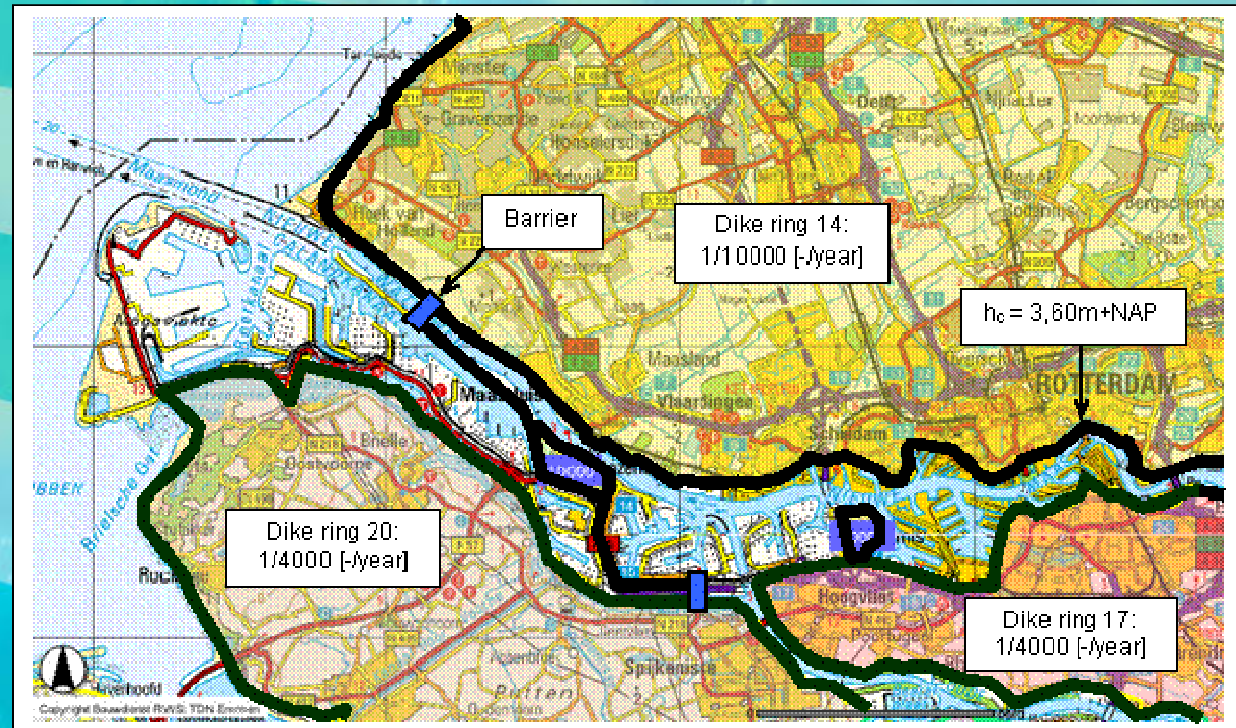


# Requirements for barrier performance

Overtopping requirements dike rings behind the barrier



Maximum probability of failure closing the barrier on demand (when needed)



# Characteristics of moveable storm surge barriers

- Low frequency of closure ('sleeping giants')
- Complex systems of many components, including complex interactions
- Huge moveable storm surge barriers are one of a kind (unique)



# PRA storm surge barriers

## How to prove the reliability of the barrier?

- Perform a PRA / QRA
- Fault Tree Technique (also Event Trees)
- Specify Top Event: e.g. failure of closing the barrier on demand (when needed)

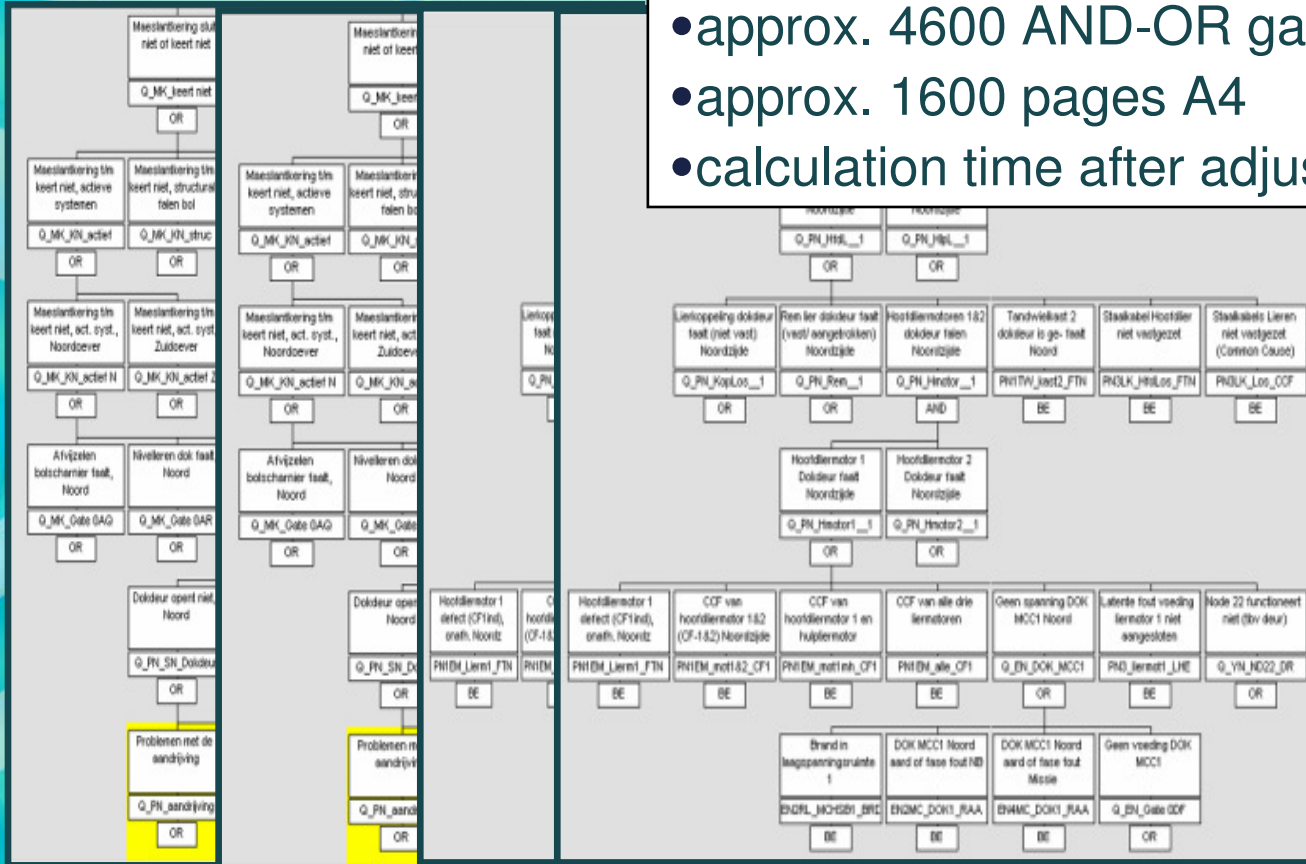




# PRA storm surge barriers

Statistics PRA Maeslant barrier:

- approx. 6200 Basic Events
- approx. 4600 AND-OR gates
- approx. 1600 pages A4
- calculation time after adjustments: 15 minutes



# PRA storm surge barriers

The models are also containing:

- Failure of basic components (failure rate; maintenance strategies, test and repair duration, maintenance intervals et cetera)
- Human error (in operation and in maintenance)
- Dependent Failure (Common Cause, Common Mode)
- Unavailability of (sub-)systems by internal fire or lightning
- Software Failure



# Probabilistic Maintenance and Asset Management (PMAM)

## What is PMAM?

- The framework for the process to obtain, maintain and optimize the reliability level
- Deming-circle Principle (plan-do-check-act)
- Complete mix of in-depth knowledge of maintenance, technical systems and reliability analysis



# Probabilistic Maintenance and Asset Management (PMAM)

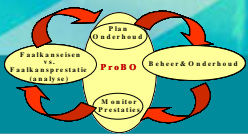
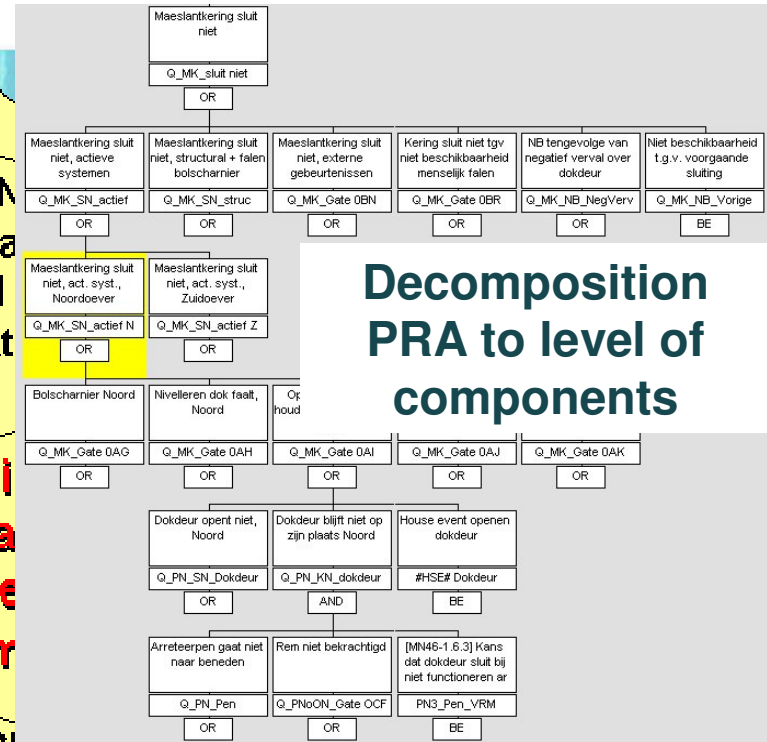
Reliability requirements barrier

**ACT**  
Check Targets and Design Modifications

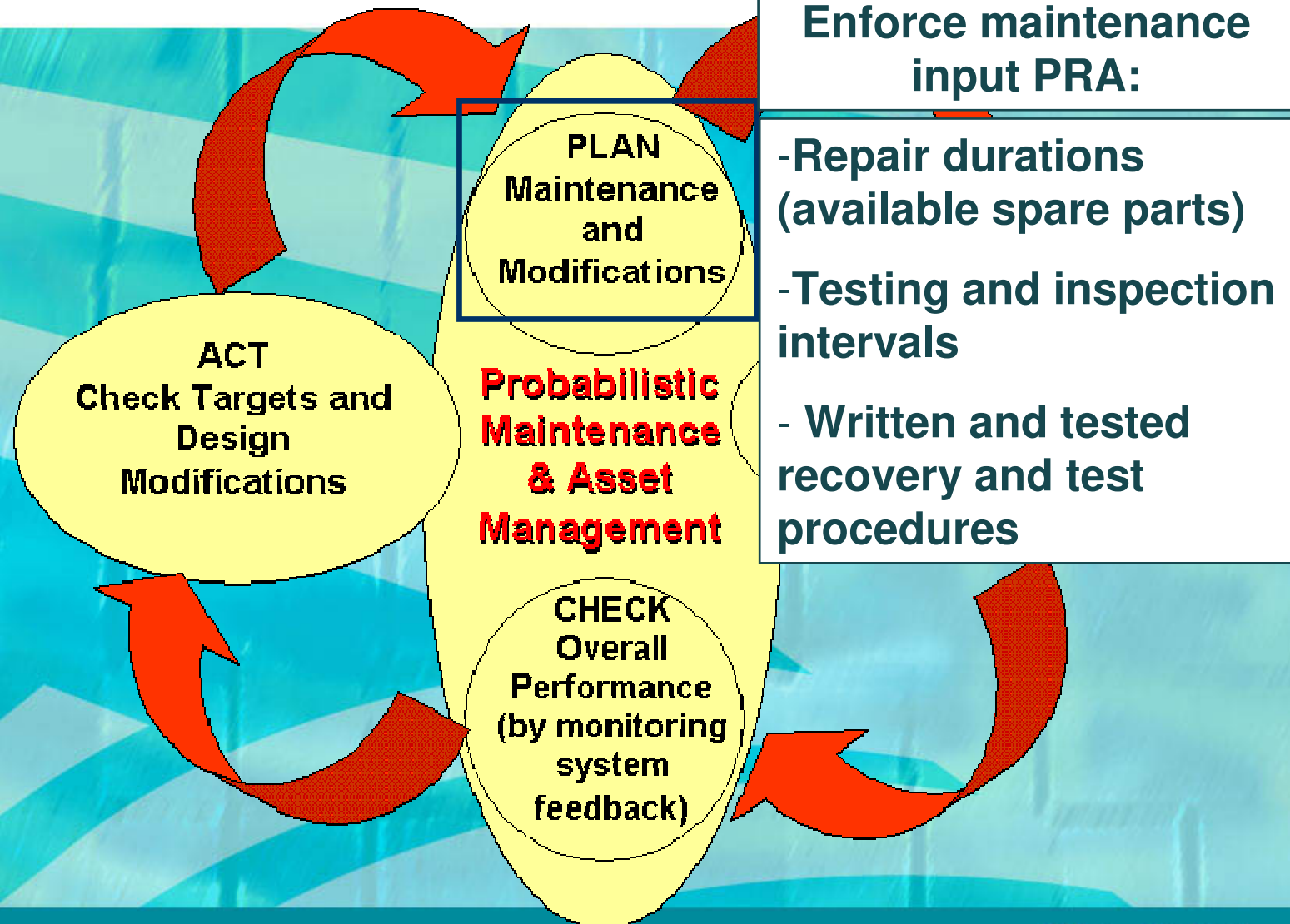
**PLAN**  
Maintenance and Modifications

**Probabilistic Maintenance & Asset Management**

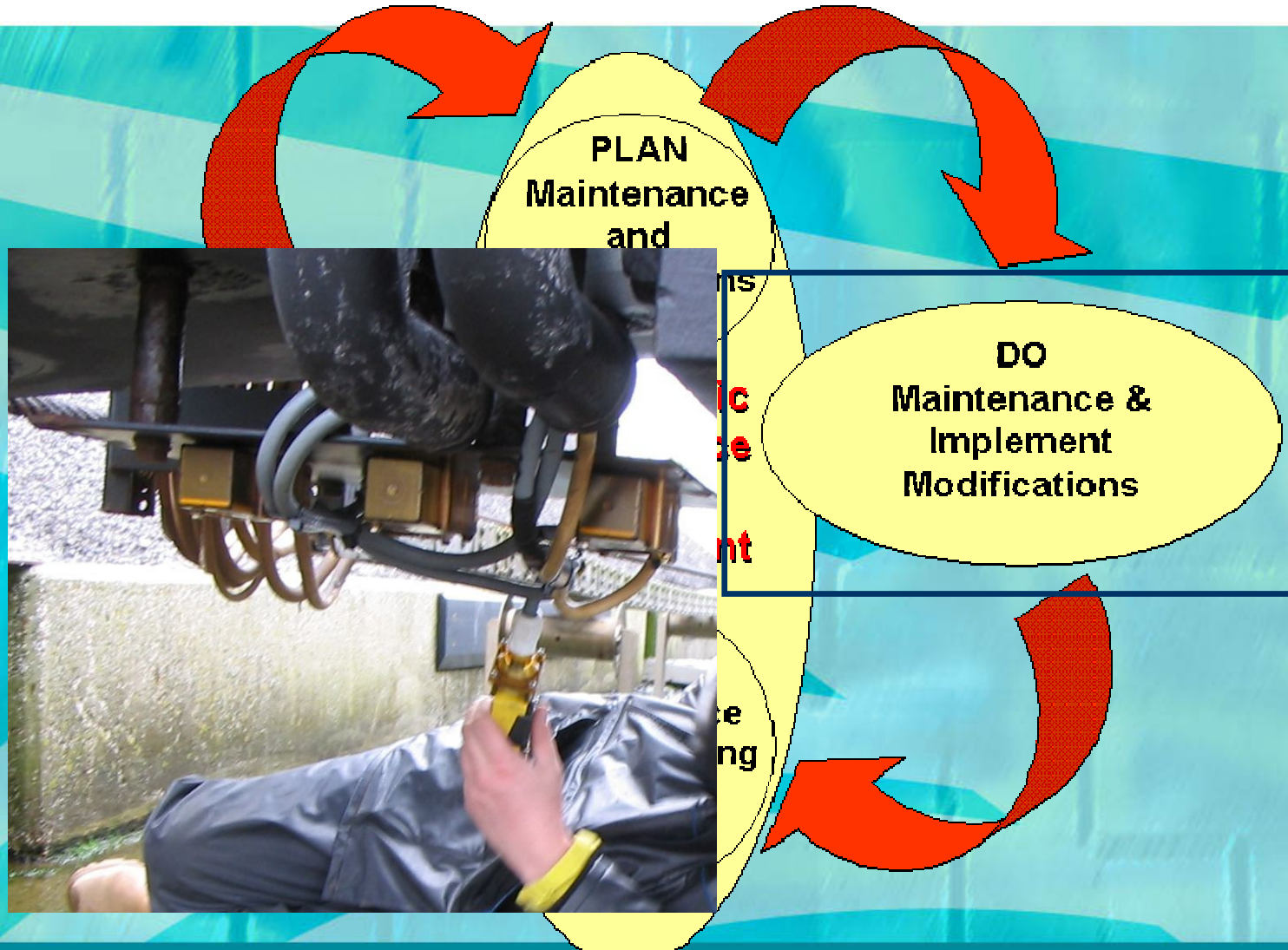
**CHECK**  
Overall Performance (by monitoring system feedback)



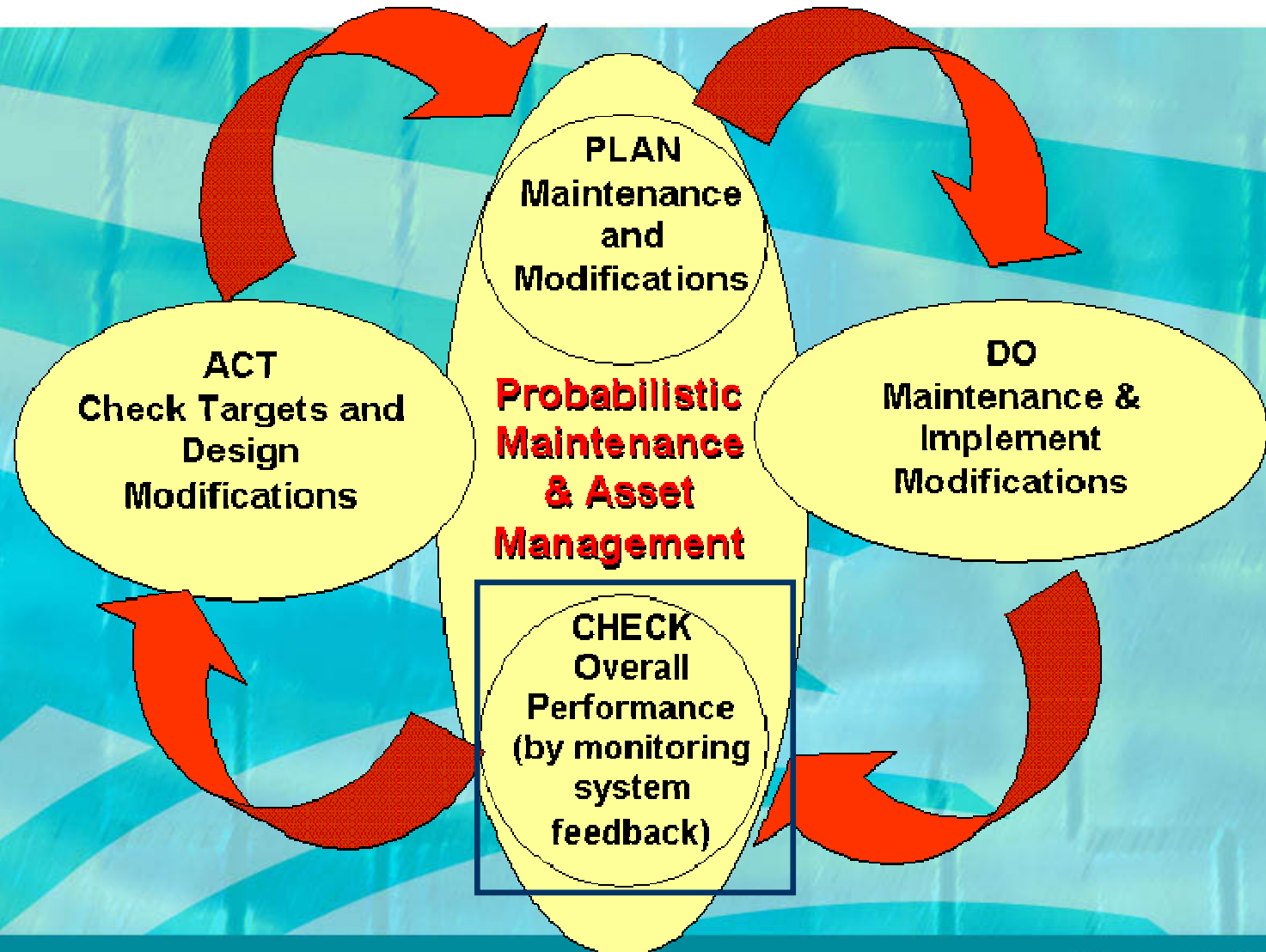
# Probabilistic Maintenance and Asset Management (PMAM)



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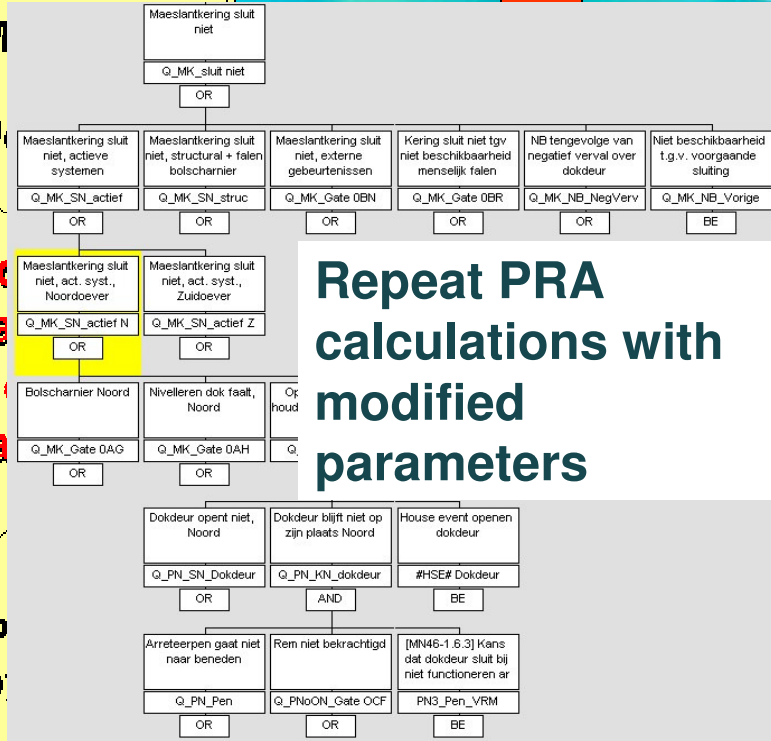


# Probabilistic Maintenance and Asset Management (PMAM)

Performance meets the requirements?

**ACT**  
Check Targets and Design Modifications

## PLAN



Repeat PRA calculations with modified parameters

feedback)





# Some conclusions

- Awareness of the large impact of the Flood Defence Act increases.
- The reliability requirements for moveable storm surge barriers, originating from the Law, appear to be strict. (substantial effort is needed).



# Future challenges

Further research is planned on:

- Ageing and lifetime models in Fault Tree Analysis
- Dependent failure (Common Cause/ Common mode)
- Intelligent maintenance strategies
- Data management/ tools
- Software reliability
- Accuracy of databases and input data
- Bayesian updating methods



**Thank you for your attention!**

