海上风机运行和维护

Offshore Operations and Maintenance

GARRAD HASSAN

内容Content

- 海上风机运行和维护的综述
  Offshore O&M overview
- 海上风机运行和维护建模分析
  Modelling offshore O&M
- 团队练习
  Team exercise
- 大体趋势，总结
  General trends, summing up

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海上风机运行和维护综述（1）
Offshore O&M overview (1)

- 至今运行和维护的经验

  O&M Experience to date….

	岸上 Onshore	海上 Offshore
长期可利用率 LT Availability	~ 97%	?
运行和维护成本 O&M Costs	~ € 30k （台/年） (machine/annum)	?

- 海上风机运行风险：

  Offshore Operational Risks:

- 可进入性差=> 可利用率低

  Poor accessibility => low availability

- 高成本（与预期相比）

  Higher costs (than anticipated)

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海上风机运行和维护综述（2）
Offshore O&M overview (2)

- 行业需要面对的一些关键问题 Some key questions facing the industry...
  - 银行和业主： Banks and Owners:
    - 担保期故障的概率 *Probability of warranty failure ?*
    - 在担保期之后风电场的可利用率 *Wind farm availability after warranty period ?*
    - 在运行及维护上应投资更多还是更少？ *Is it worth investing more / less in O&M resource ?*
  - 运行和维护承包商/风机制造商 O&M Contractors / Turbine Manufacturers:
    - 运行和维护策略是否满足担保的可利用率水平？
      Is our O&M strategy adequate to meet warranted availability level ?
    - 运行和维护合同的价值是多少？ *What is the value of our O&M contract ?*
  - 怎样分担运行风险？ How should the Operational Risks be divided ?

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海上风机运行和维护活动
Offshore O&M Activities

- 定期维护 Scheduled maintenance
  - 轮班周期为**12**个月（**80**－**120**个工作时）
    Shift towards 12 month frequency (80 - 120 man hours)
  - 检查、清洁等等
    Inspection, cleaning, etc
- 修理安排 Repair operations
  - 一般是在维修时期进行或者等待通知
    Usually conducted on an *ad hoc* or reactive basis
  - 涉及某种程度的故障检修
    Involve some level of trouble shooting
  - 从手动重启到更换主要部件
    From manual restarts to major component change-out
- 备件管理 Spares management

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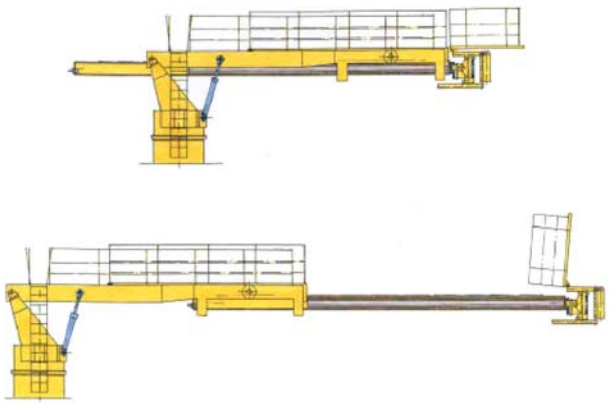
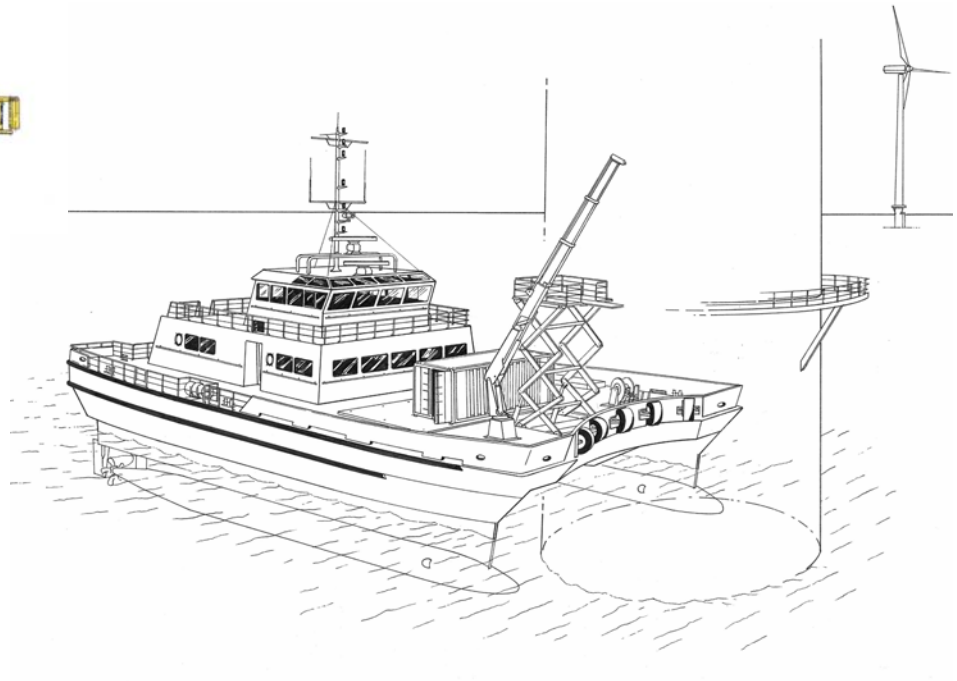
进入方法（1）
Access methods (1)

Copyright: Elsam A/S

进入方法（2）
Access methods (2)





海上风机运行和维护建模分析

Modelling Offshore O&M

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内容
Content

- 背景和动机
  Background and Motivation
- 海上风机运行和维护仿真模拟
  Offshore O&M Simulation
- 应用实例
  Example Applications

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背景和动机
Background and Motivation

- 进入风机成为海上风机运行和维护的一个棘手的问题
  Access makes offshore O&M a tricky problem
- 已开发了一个运行和维护建模分析工具：
  An O&M modelling tool has been developed to:
  - 海上风电场可利用率预算 Predict offshore wind farm availability
  - 优化运行和维护策略 Optimise O&M strategies
  - 改进对运行风险的理解 Improve understanding of operational risks
- 以Bossanyi and Strowbridge 工作为依据
  Closely based on work of Bossanyi and Strowbridge
  (ETSU 1994)
- 工具命名为O2M“运行和维护的优化”
  Model dubbed O2M,“Optimisation of Operations & Maintenance”

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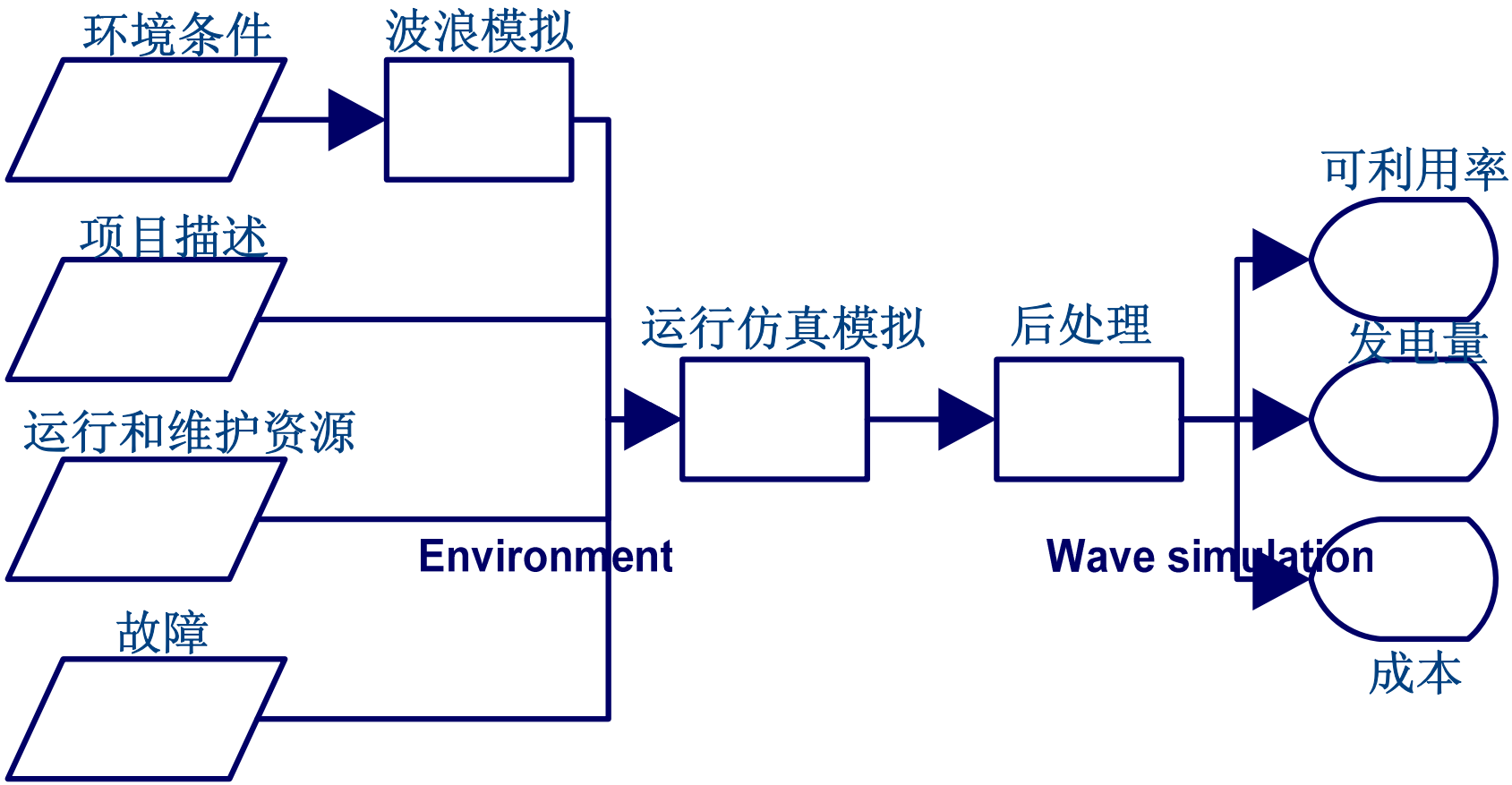
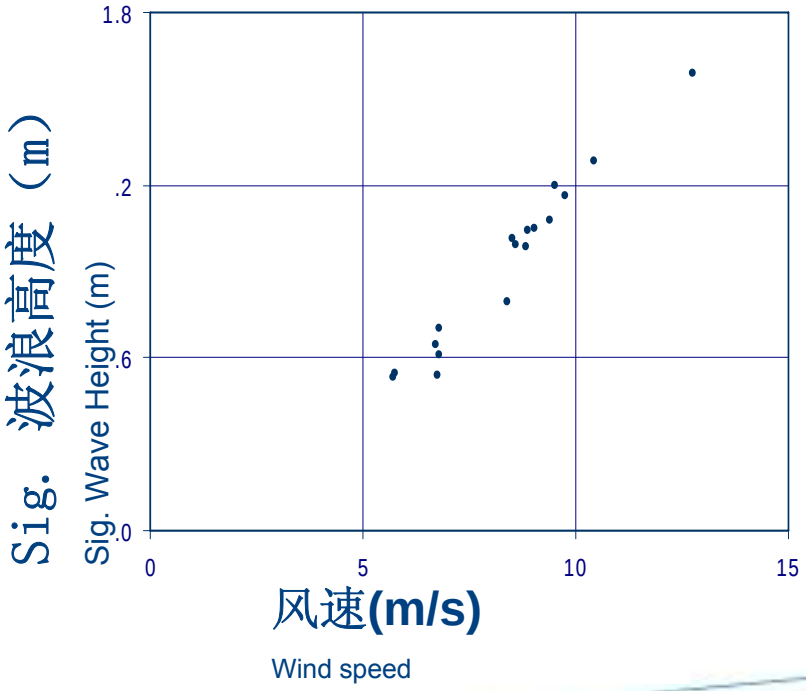
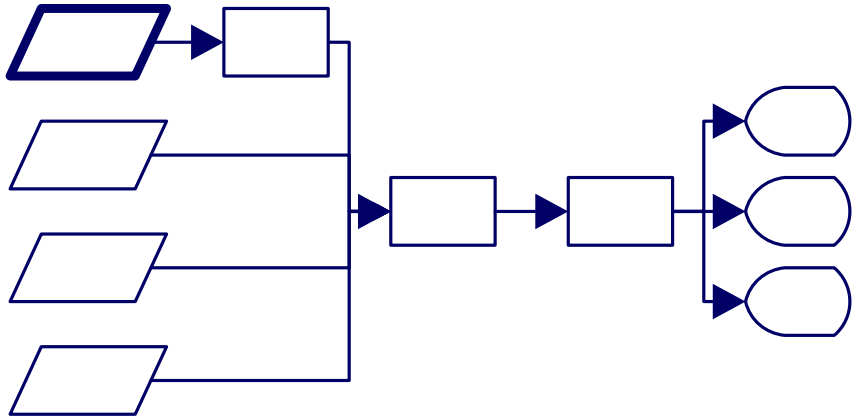
O2M结构
O2M Structure



输入：环境条件
Inputs: Environment

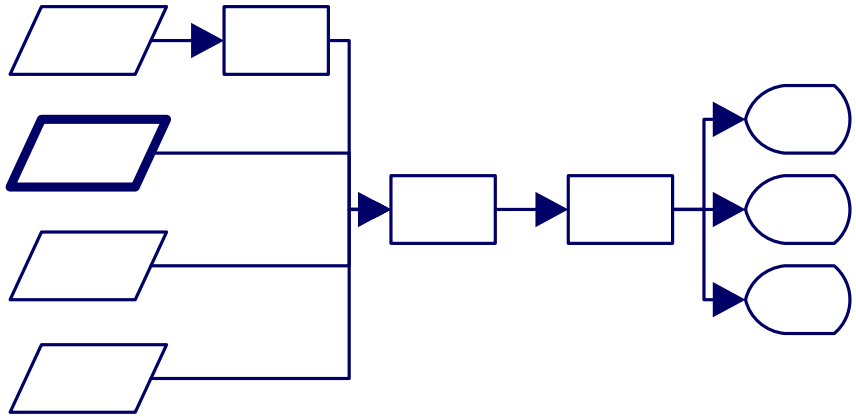
- 波浪时序（如果有的话）
  Wave time series, if available
- 风—浪关系
  Wind – wave relationship





输入：项目描述
Inputs: Project Description

- 风电场数目
  No. of wind farm sites
- 每个场址的风机数目
  No. turbines on each site
- 储存和服务地点
  Stores and service locations
- 机动性＋交通时间
  Mobilisation + Travel times
- LT 风机发电量计算
  LT energy prediction
  - （按季节列出）
    (seasonal breakdown)



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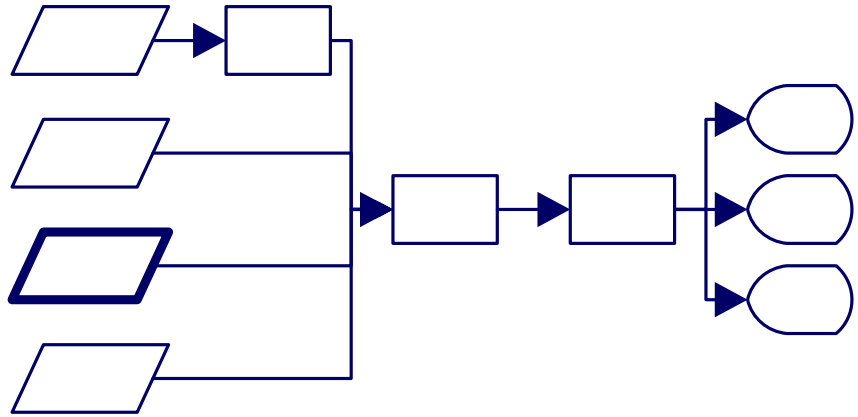
输入：运行和维护资源
Inputs: O&M Resources

- 人员 Staffing
- 轮班系统 Shift system
- 船只能力 Vessel capability
- 备件库存 Spares holding
- 备件供货期 Spares lead times
- 决策逻辑 Decision logic



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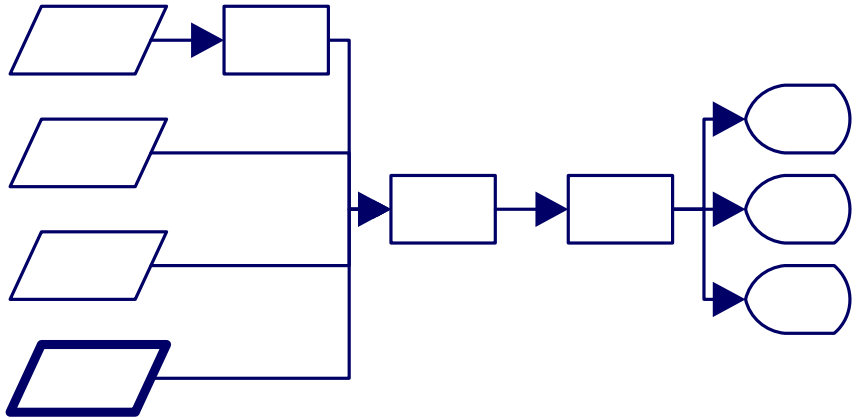
输入：风机的可靠性
Inputs: Turbine Reliability

- 定义故障类别
  Define several failure categories
- 对每个故障类型，定义
  For each category define
  - 故障发生平均间隔(MTBF)
    Mean Time Between Failure (MTBF)
  - 平均修复时间(MTTR)
    Mean Time To Repair (MTTR)
  - 备件的要求
    Spares requirement
- 故障输入的例子
  Example schedule of faults:



	描述 DESCRIPTION	MTBF (HRS)	MTTR (HRS)
1	手动重启 Manual restart	4000	2
2	更换小的部件 Small component change-out	2500	8
3	主要部件的修理 Major component repair	15000	30
4	主要部件的更换 Major component change-out	50000	45

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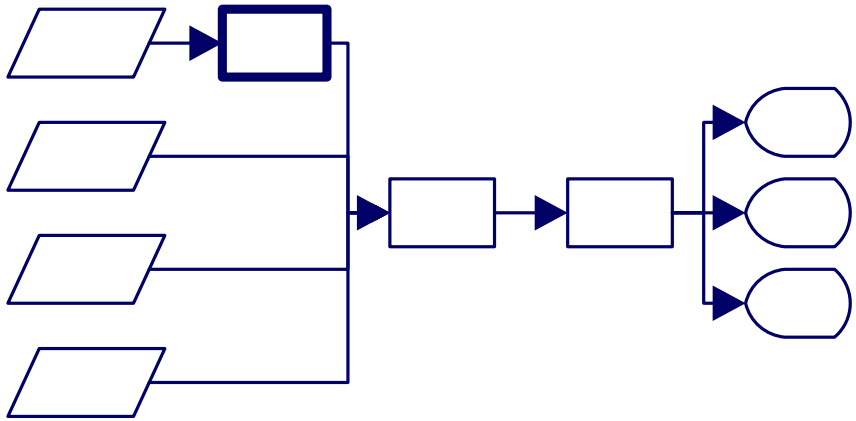
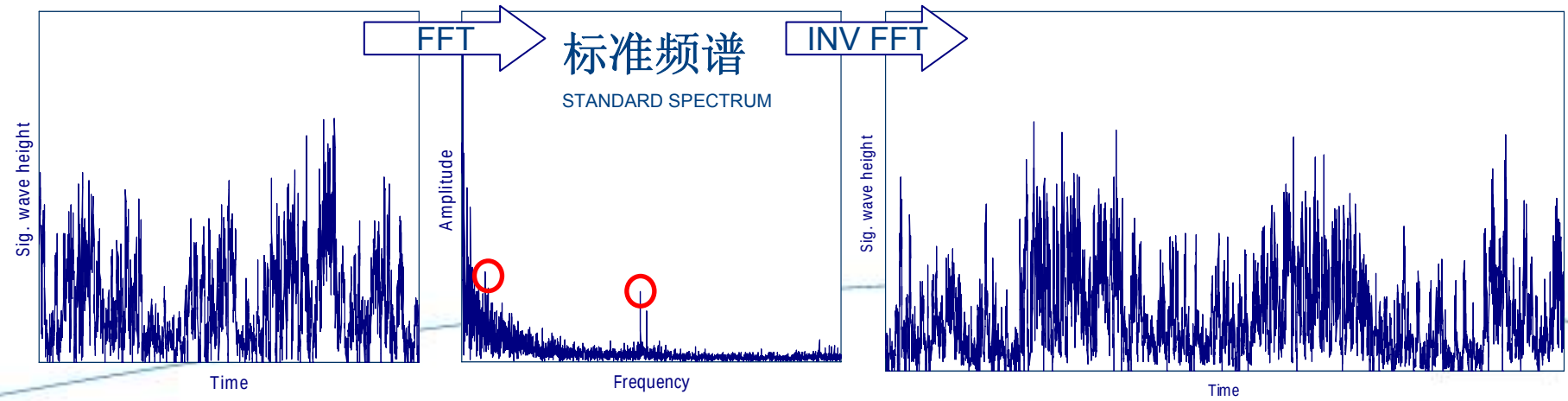
波浪合成 Wave Synthesis

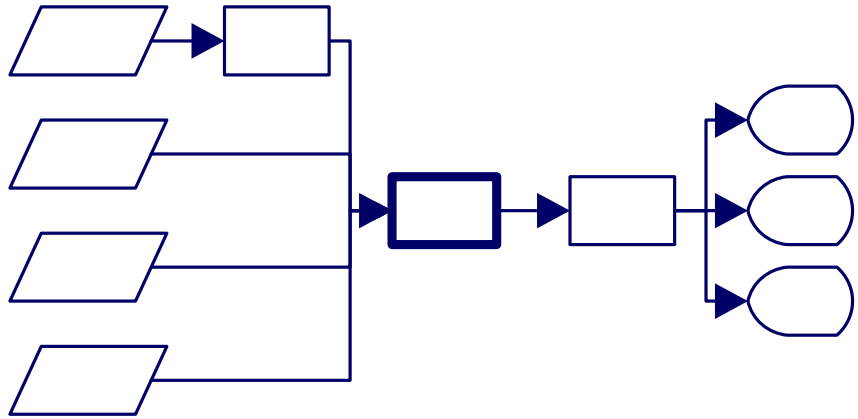
- 输入时序 Input time series
- 快速傅立叶变换 Fast Fourier Transform (FFT)
- 波谱，包括 Wave Spectrum, includes
  - 季节性相位调整 Seasonal phasing
  - 潮汐相位调整 Tidal phasing
- 逆傅立叶变换 Inverse FFT
- 合成所需的时序长度 Synthesised time series of desired length





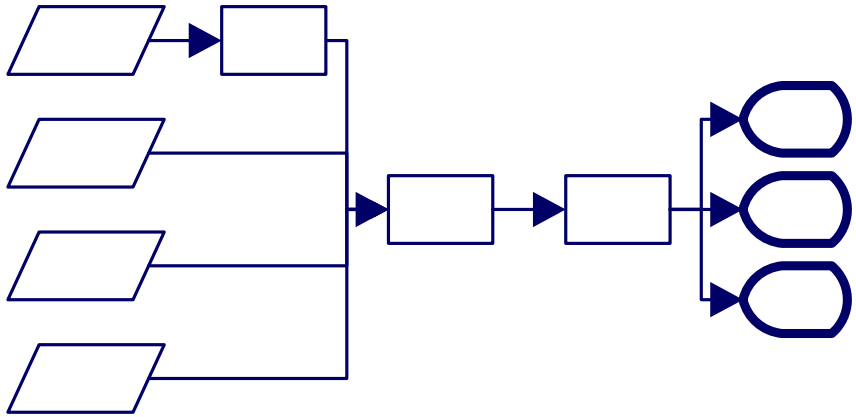
运行仿真模拟
Operations Simulation

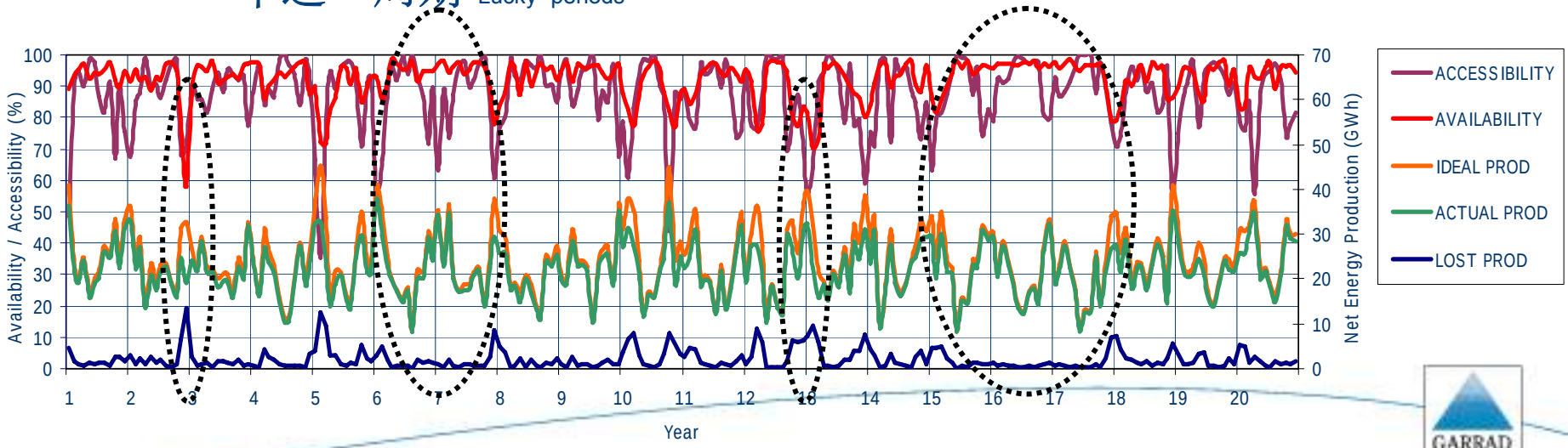
- 以小时为时间步长，运行N年
  Hourly time step, run for N years
- 在每个时间步长：
  At each time step:
  - 故障发生（蒙特卡洛） Failures (Monte Carlo)
  - 相应动作 Actions
  - 状态更新 Status updated
    - 风机 Turbines
    - 工作组 Crews
    - 部件 Parts
  - 结果输出 Results recorded



输出 Outputs

- 可利用率 Availability
- 发电量和损失的发电量
  Production and Lost Production
- 成本、资源及备件的使用
  Costs, resource and spares usage
- 输出的图形例子
  Example output plot
  - 进入困难时的厄运 Access double-whammy
  - “幸运”周期 “Lucky” periods





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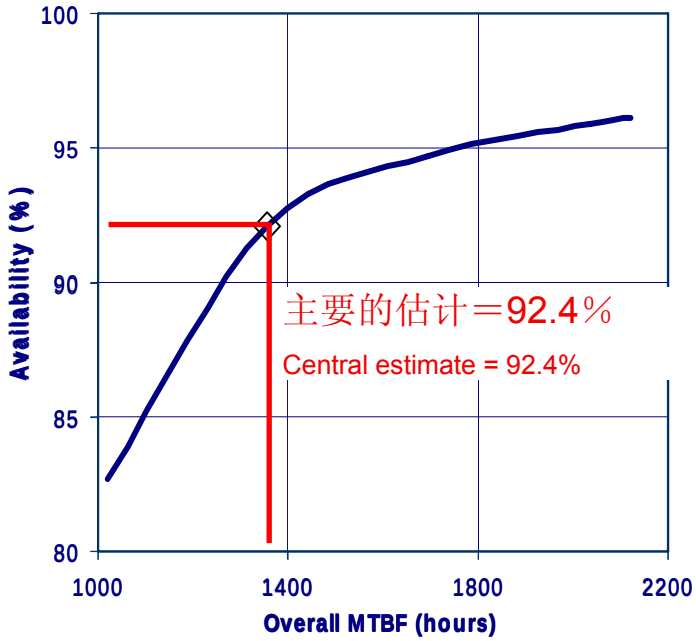
应用实例Example Applications （1）

- LT 可利用率 预计＋明感性分析 LT Availability Estimation + Sensitivity Study
- 输入假定值 Input Assumptions
  - 100个风机 x 3MW @ 36% 容量系数 (~9m/s)
    100 turbines x 3MW @ 36% cap factor (~9m/s)
  - 6 工作组，8 小时轮班，5 天/周
    6 crews, 8 hour shift, 5 days/week
  - 运行＋运输 时间＝2小时
    mobilisation + transit time = 2 hours
  - 到达能力：Hs<2.0m,风速<15m/s
    Access capability: Hs < 2.0m, wind speed < 15 m/s
  - 适中的波浪气候（可到达性＝81%）
    Moderate wave climate (accessibility = 81 %)
  - 全部主要的MTBF＝1357小时
    Central overall MTBF = 1357 hours

	描述DESCRIPTION	MTBF (HRS)	MTTR (HRS)
1	手动重启Manual restart	4000	2
2	更换小的部件 Small component change-out	2500	8
3	修理主要的部件 Major component repair	15000	30
4	更换主要的部件 Major component change-out	50000	45

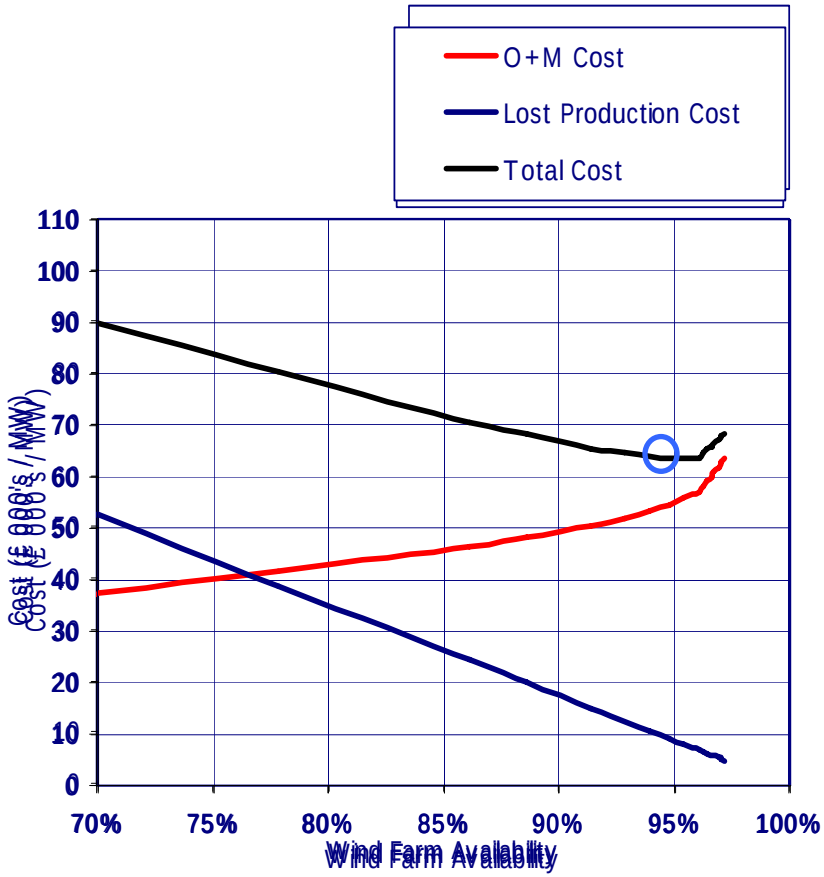


应用实例（2）
Example Applications (2)

- 运行和维护的优化
  O&M Optimisation

  运行和维护的直接成本
  ＋损失的发电量
  ＝总成本

  O&M Direct Costs
  + Lost Production Cost
  = Total Cost



总结
Recap

- 海上风场运行和维护风险：可进入性＋成本
  Offshore O&M Risks: Access + Costs
- O2M结构：时域， Monte Carlo，等等
  O2M Structure: Time domain, Monte Carlo, etc
- 应用实例
  Example Applications
  - LT 可利用率 LT Availability
  - 敏感性分析 Sensitivity Studies
  - 季节性分析 Seasonal Analyses
  - 情景模拟 Scenario Modelling
  - 成本利益分析/运行和维护的优化 Cost Benefit Analyses / O&M Optimisation

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海上风场运行和维护建模分析

Offshore Operations and Maintenance Modelling Exercise

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介绍
Introduction

练习 The Game

- “O&M运行和维护优化挑战”
  “O&M Optimisation challenge”
- 带有奖励性的练习
  A team exercise (with prizes at stake!)
- 目标：优化某风电场运行和维护的成本
  Aim: Optimise O&M costs for Wind Farm X
- 5 次优化循环－多重选择
  5 rounds of optimisation – multiple choice
- 以仿真结果作为成绩
  Results based on modelled results

规则 The Rules

- 提供了风电场的描述
  Wind farm description provided
- 给出了每次循环开始时的战略选择
  Strategic options outlined at the start of each round
- 非优化选择会带来财政处罚
  Financial penalties accrued for non optimal choices
- 被处罚最少的队伍获胜
  Team with least penalties wins !

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X风场介绍
Introducing Wind Farm X

- 100×3MW风机
  100 x 3 MW turbines
- 5个工作组，8小时轮班
  5 crews, 8hr (day) shift
- 每组3个技师
  3 technicians per crew
- 6.5个故障/风机/年
  6.5 failures / turbine / year
- 中等波浪气候(进入 = 77% @ Hs < 1.2m)
  Moderate wave climate
  (access = 77% @ Hs < 1.2m)

Wind Farm X

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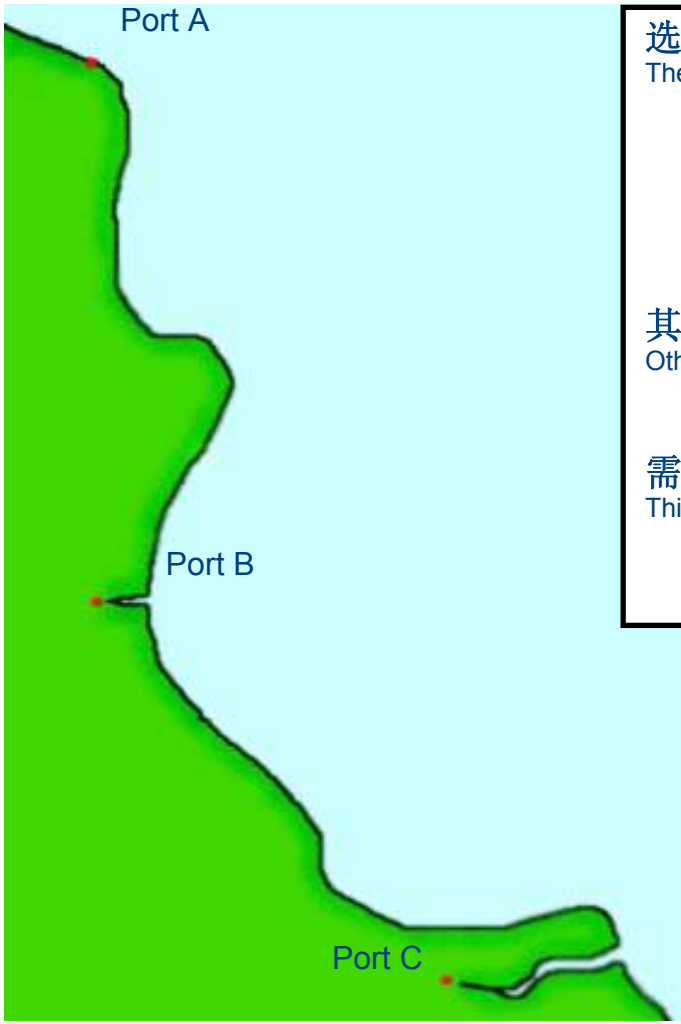
循环1：哪个港口
Round 1: Which Port ?



选项
The Options

- 港口A：2小时路程，无潮汐限制
  Port A: 2 hours transit, no tidal constraints
- 港口B：1.5小时路程，21.6小时/日 潮汐限制
  Port B: 1.5 hours transit, 21.6 hrs / day tidal access
- 港口C:1小时路程，19.3小时/日 潮汐限制
  Port C: 1 hour transit, 19.3 hrs / day tidal access

其他信息
Other information

- 3个港口在其他方面都是相同的
  All 3 ports are equal in all other respects

需考虑的事情
Things to consider

- 路程和潮汐限制哪个影响更大？
  Is distance to site more crucial than tidal constraints ?

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循环1：结果
Round 1: Results

AV = 可用性Availability
DC = 直接成本Direct Costs
LP = 发电量损失Lost Production
TC = 总成本Total Cost (DC+LP)
总成本欧元
All costs in Euro 000s / turb / annum

R1 Port

基本假设BASIC ASSUMPTIONS

A: 2hrs transit, 24hr tidal access	B: 1.5hrs transit, 21.6hr tidal access	C: 1hr transit, 19.3hr tidal access
AV = 95.6 % DC = 121.6	AV = 95.1 % DC = 121.5	AV = 95.9 % DC = 121.7
LP = 555.1 TC = 676.7	LP = 626.5 TC = 748.0	LP = 528.5 TC = 650.2
罚款 = 26.5	罚款 = 97.8	
2个小时路程 24小时潮汐	1.5个小时路程 21.6小时潮汐	1个小时路程 19.3小时潮汐

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循环2：多少个工作组
Round 2: How many crews ?

选项 The Options

- **4**个工作组 4 crews
- **5**个工作组（与前面的循环一样）5 crews (same as previous round)
- **6**个工作组 6 crews
- **7**个工作组 7 crews

其他信息 Other information

- 所有的工作组在相同的轮班制度下工作（白班）
  All crews are working on same (day) shift
- 每个工作组费用**540，000**欧元**/**年
  Each crew costs € 540,000 / annum

需要考虑的事情 Things to consider

- 加快修理速度需要增加多少工作人员？
  How much will additional crews increase repair rates ?
- 加快修理速度值得增加的成本吗？
  Is the increased repair rate worth additional costs ?

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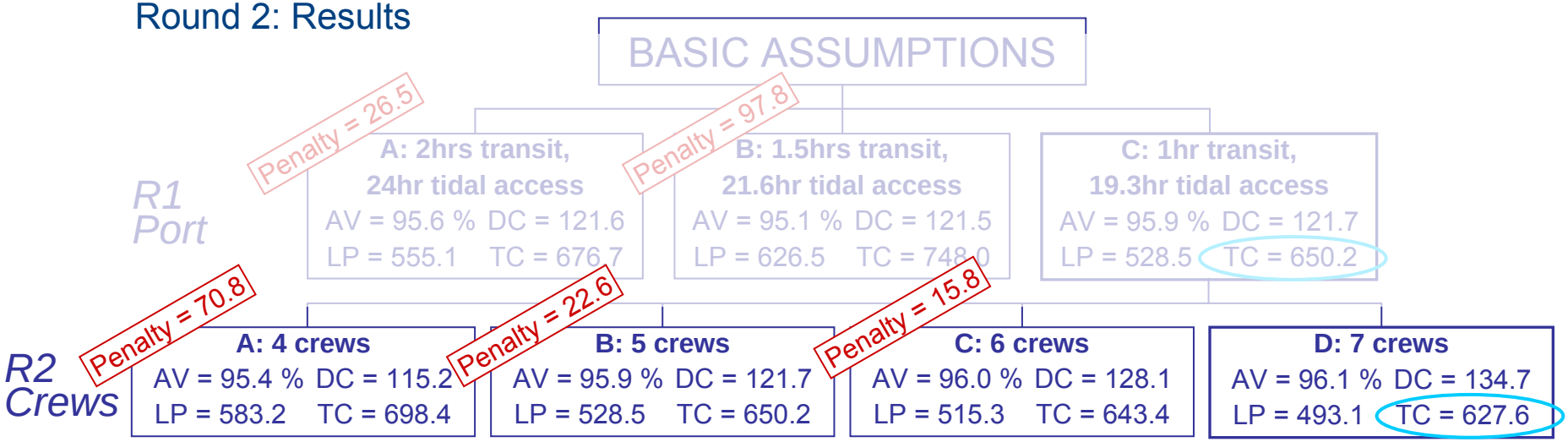
AV = Availability
DC = Direct Costs
LP = Lost Production
TC = Total Cost (DC+LP)
All costs in Euro 000s / turb / annum

循环2：结果
Round 2: Results



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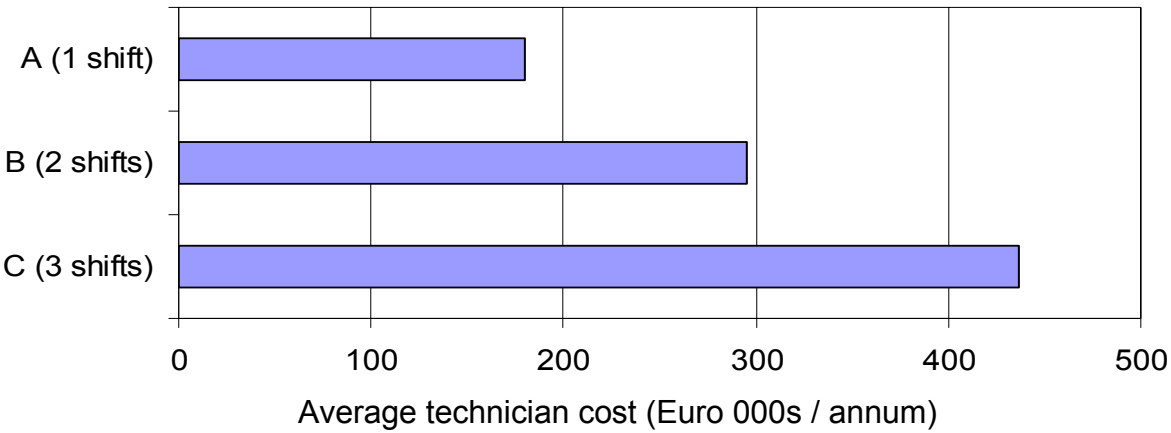
循环3：轮班模式？
Round 3: Shift pattern ?

选项 The Options

- A：所有工作人员白天值班（与从前的模式一样）
  A: All crews on day shift (same as previous round)
- B：4个工作人员是白班，3个是夜班
  B: 4 crews on day shift, 3 crews on late shift
- C：2个在早班，3个在白班，2个在夜班
  C: 2 on early shift, 3 on day shift, 2 on late shift



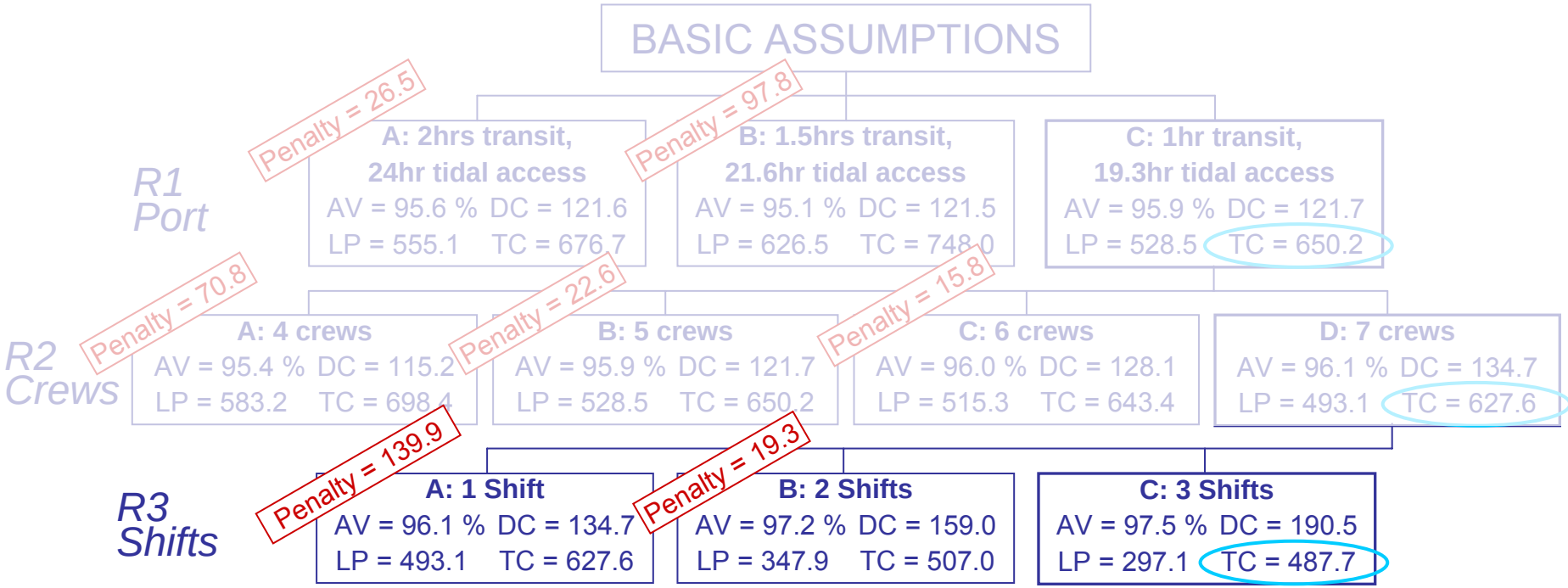
其他信息
Other information

需要考虑的事情
Things to consider

- 增加的班次能更好的利用天气条件吗？
  Do additional shifts allow better utilisation of weather windows ?

循环3：结果
Round 3: Results

AV = Availability
DC = Direct Costs
LP = Lost Production
TC = Total Cost (DC+LP)
All costs in Euro 000s / turb / annum



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循环4：哪种船只？
Round 4: Which vessels ?

选项：
The Options

- **A: OPEX = € 200,000 / 年, Hs 限制: < 1.2m**
  A: OPEX = € 200,000 / annum, Hs limit: < 1.2m
- **B: OPEX = € 500,000 / 年, Hs 限制: < 1.5m**
  B: OPEX = € 500,000 / annum, Hs limit: < 1.5m
- **C: OPEX = € 1,000,000 / 年, Hs 限制: < 1.8m**
  C: OPEX = € 1,000,000 / annum, Hs limit: < 1.8m

其他信息
Other information

- 可进入性：**A = 77%, B = 85%, C = 91%**
  Accessibility: A = 77%, B = 85%, C = 91%

需要考虑的事情
Things to consider

- 一个额外的可进入性的百分点的价值是多少？
  How much is an extra few % of accessibility worth ?

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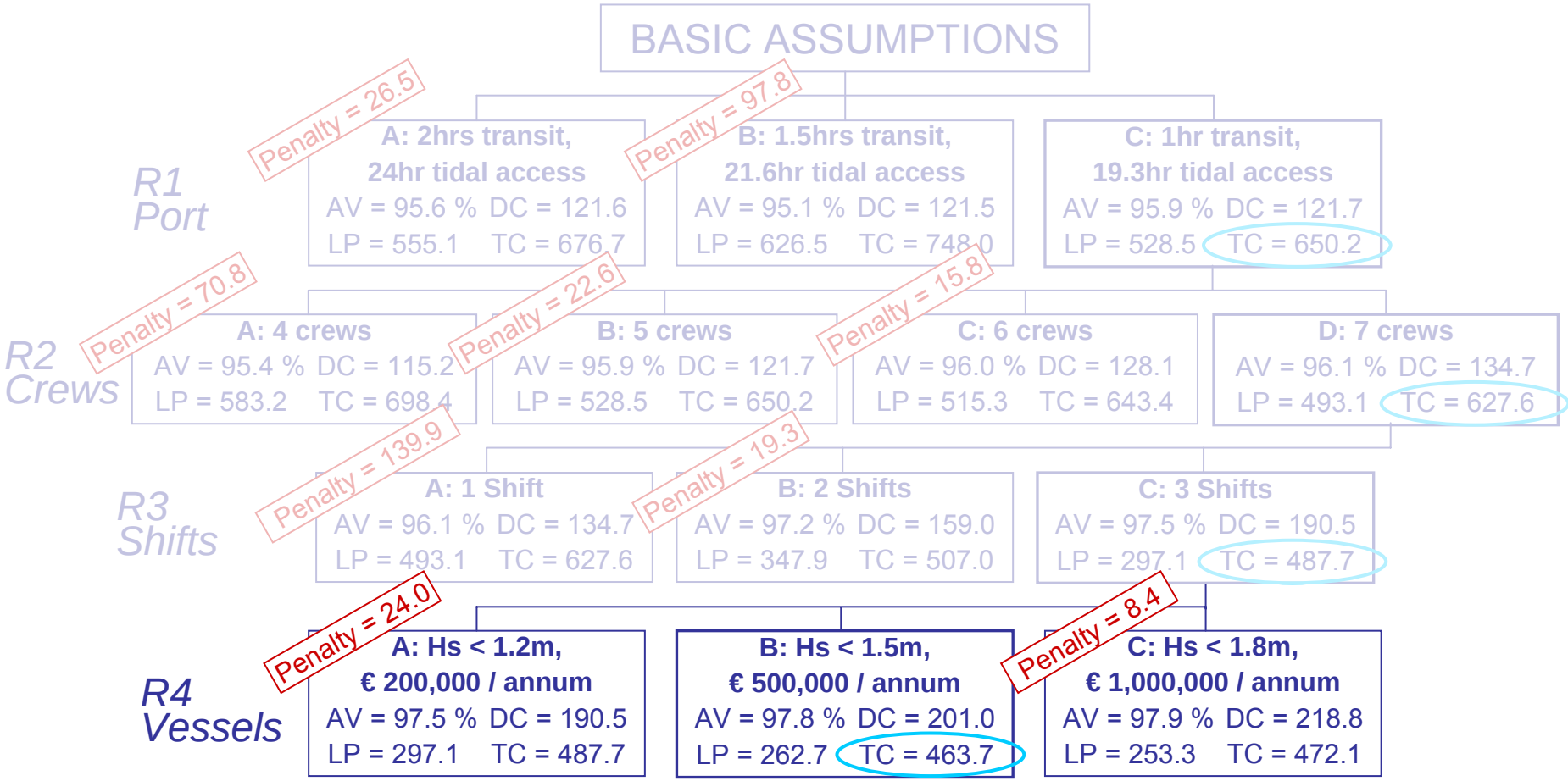
循环4：结果
Round 4: Results

AV = Availability
DC = Direct Costs
LP = Lost Production
TC = Total Cost (DC+LP)
All costs in Euro 000s / turb / annum



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循环5：风机可靠性的影响（风机选型）
Round 5: Reliability profile (turbine choice) ?

选项
The Options

- **A**：排除手动重启
  A: Elimination of manual restarts
- **B**：排除主要部件更换
  B: Elimination of major component change-out

其他信息
Other information

- 你现在从两个候选供应商处得到更多的信息
  You now have better info from 2 candidate suppliers
- 一个提供冗余远程再启动
  One offers improved redundancy and remote restarts
- 其他的对主要部件的更换提供寿命保证
  The other offers life-time guarantee on major change-outs

需要考虑的事情
Things to consider

- 哪个是更昂贵的；经常发生小问题？
  Which are more costly overall; small frequent problems ?
- 或者大的罕见问题？
  …or large infrequent problems ?

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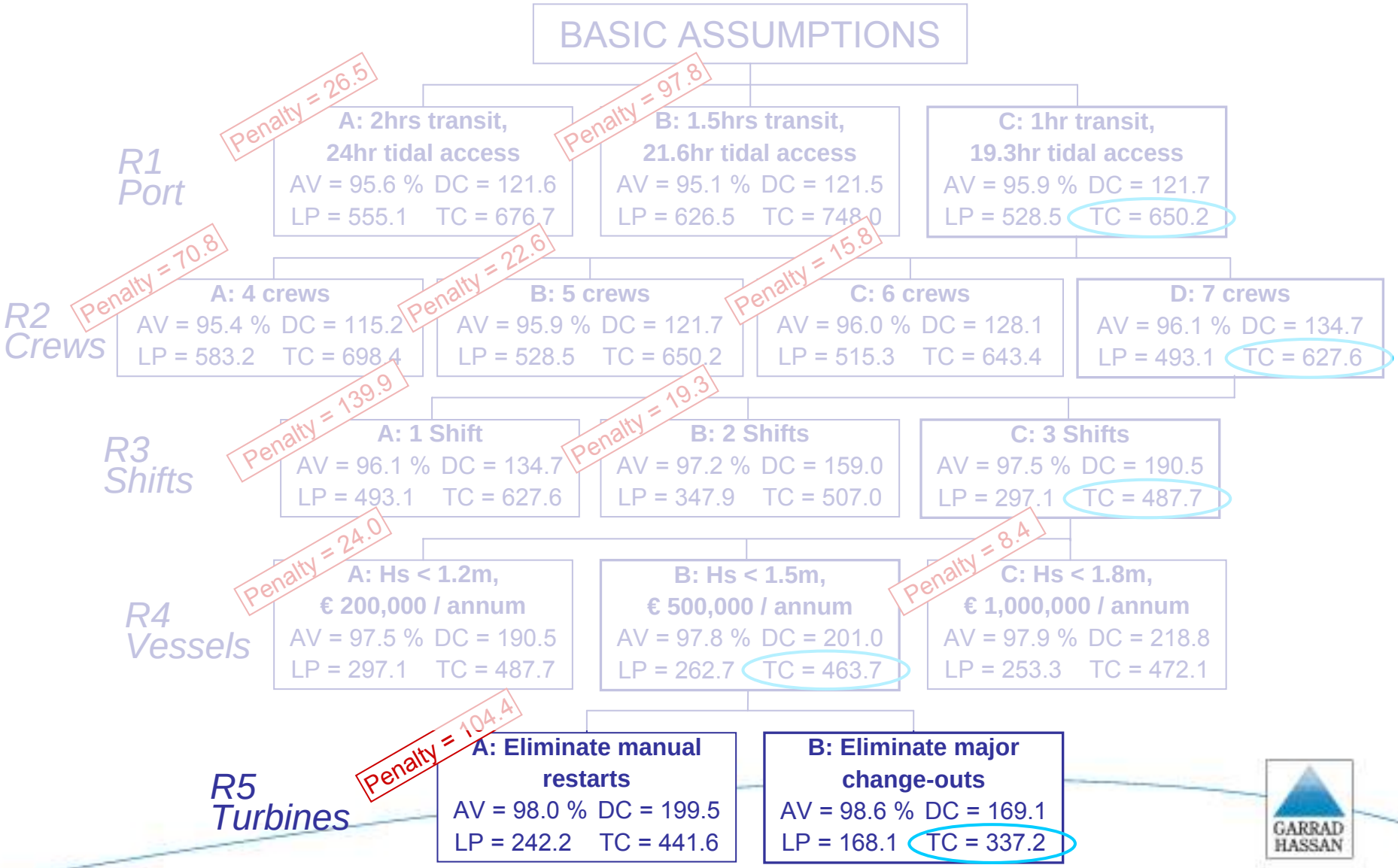
Round 5: Results

AV = Availability
DC = Direct Costs
LP = Lost Production
TC = Total Cost (DC+LP)
All costs in Euro 000s / turb / annum



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推出某风电场的运行和维护的策略
Resultant O&M strategy for Wind Farm X

- 港口C作为服务基地 Port C as service base
  - 最近（尽管受潮汐限制） Closest, albeit with tidal constraints
- 7个工作小组 7 Crews
  - 最大的调查选项－如果有更多的人会发生什么？
    Maximum of options examined – what about more crews ?
- 3班制系统 3 Shift system
  - 当有潮汐限制时更多的轮班制度是必要的
    More shifts makes sense when you have tidal constraints
- 进入船只 ：中等价钱，中等性能
  Access vessel: medium expenditure, medium capability
  - 在中等的波浪气候下没必要投资太多
    In moderate wave climates further investment is not required
- 风机可靠性：排除主要部件的更换
  Turbine reliability: elimination of major change-outs
  - 在中等波浪气候条件下是有意义的
    This makes sense in a moderate wave climates
  - 现实中是否可行？
    Is this an option in reality ?

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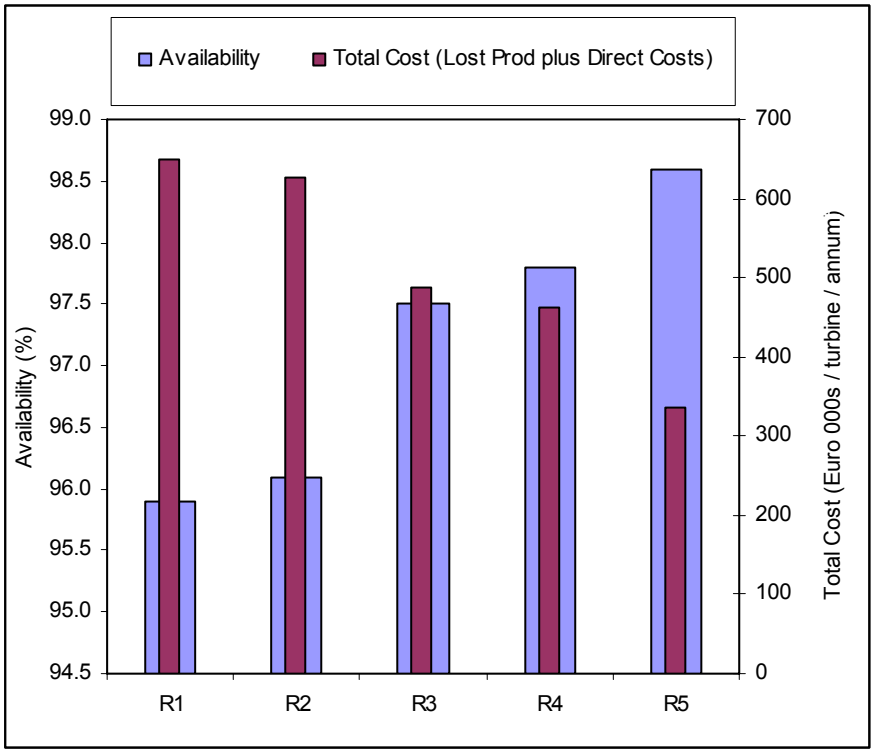
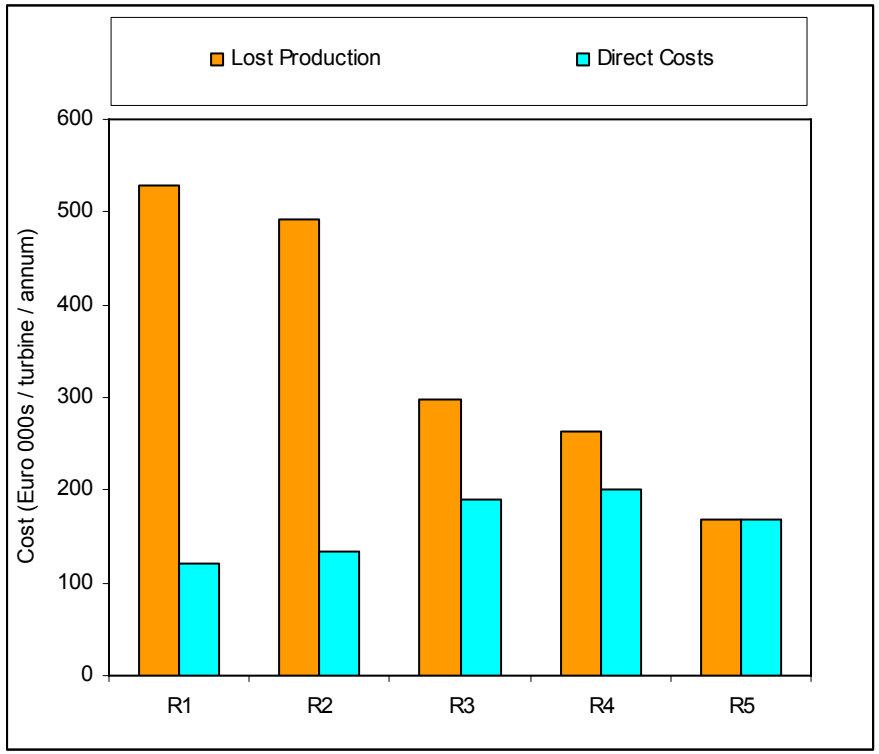
有意思的趋势
Interesting trends





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结论
Conclusions

- 这个练习是分步优化的……一个完整的同步优化分析会更好
  The game was a stage-by-stage optimisation……..
  ……..a full multi-dimensional analysis would be better
- 更大的运行和维护投入获得海上风场更高的回报……但到一个程度！
  Greater O&M investment pays-off for offshore projects……..
  ……up to a point !
- 运行和维护的问题是很难用手算来评估
  O&M issues are difficult to predict “on the back of an envelope”
- 为了了解风险必须建模分析
  Modelling is required to understand the risks
- 优化是为了寻求减少停工期与运行和维护的费用之间的平衡
  Optimisation is about balancing O&M spend against downtime
- 所有的结果都依赖场址特定的条件
  All results are highly site-specific
- 气候条件和风机可靠性支配整体性能
  Climatic conditions and turbine reliability drive performance

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