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Maintenance Planning of Continuous Production Systems

Illustration in the Case of an Off-shore Platform

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Problem Characteristics and Motivation

- Maintenance activities require **halting production** of the platform, which also include a **fixed cost** for cooling down and starting up.
- Maintenance plans in the oil industry are set **several years in advance** while maintenance volume is partly uncertain.
- Any day without production can represent **$M of lost production**. Customer contracts impose additional penalties for non-production.
- The oil industry has been using sophisticated models for reservoir explorations, but it is **less common in the operations** sector of the industry.
- **Scale and increased interdependence** of platforms have created a need for providing decision support to management.
- Maintenance managers complain about not having tools for estimation of **indirect effects of capital expenditure** projects on losses.

Definitions

- **Turnaround (sometimes called planned shutdown)**
  - Planned stop of the platform
- **Shutdown**
  - Unplanned stop of a platform (after failure of a system)

Picture source : http://en.wikipedia.org/wiki/Image:Oil_platform.jpg

The Objective: Robust Maintenance Plan

Region	Field	Platform	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Europe	Field A	A1	12		12		12		12		12		12
		A2	12		11		11		11		11		11
		A2	14	2	10		10		10		10		10
	Field B	B1	7	7	7	7	7	7	7	7	7	7	7
		B2		13									
	Field C	C1		13	80	11		11		11		11	
		C2	5	20			10	20			10	20	
		C3	21		25	2		25			25		10

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Field A - 2008 plan

Activity type	Number of activities	Man-hours
Corrective maintenance	89	2548
Preventive maintenance	62	3381
Inspections	7	140
Modifications & capital exp.	46	4160
Total	204	10229

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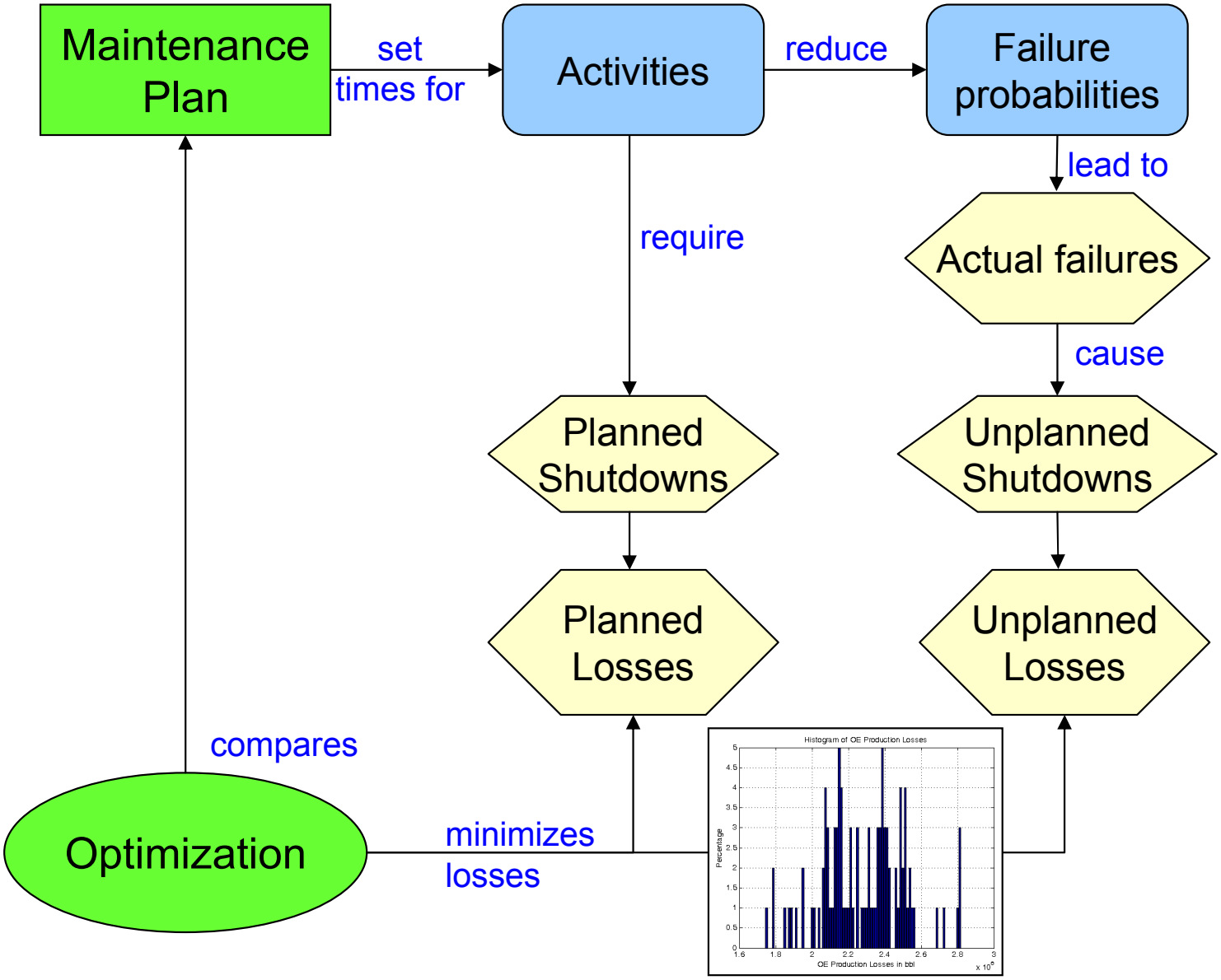
Modeling Considerations

- **Maintenance models typically do not consider the need for shutting off production to perform maintenance:**
  - Existing models consider multiple systems independently (for the planning aspect) and focus on determining maintenance activity rates.
  - Existing models (even multiple heterogeneous units) consider either replacement or inspection strategies.
  - Existing models are often limited to two-state deterioration processes (OK and Fail).

- **Maintenance planning problem involves discrete and continuous variables:**
  - When to have a planned production stop for maintenance (“turnaround”)?
  - Which activities to include in each turnaround?
  - How much time should be allocated to the turnaround?
  - How much slack should be built into the schedule?

High-level Structure of our Model



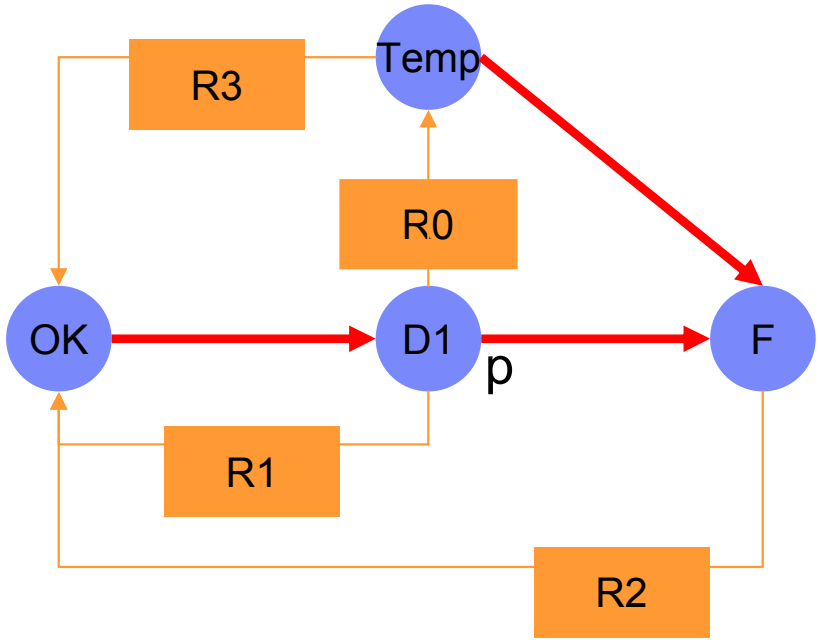
Decisions included in a Maintenance Plan

- **Scheduling of Planned Maintenance**
  - Number, dates and durations of planned maintenance periods (turnarounds)
  - Which activities are to be included in each maintenance period
  - What level of slack to allow in planned maintenance periods for the unplanned repairs

- **Management of Corrective Maintenance**
  - How to prioritize between immediate or postponed repairs after deterioration
  - How to decide between full or temporary repairs
  - How to decide what repair activities are included in a planned maintenance period given the time budget

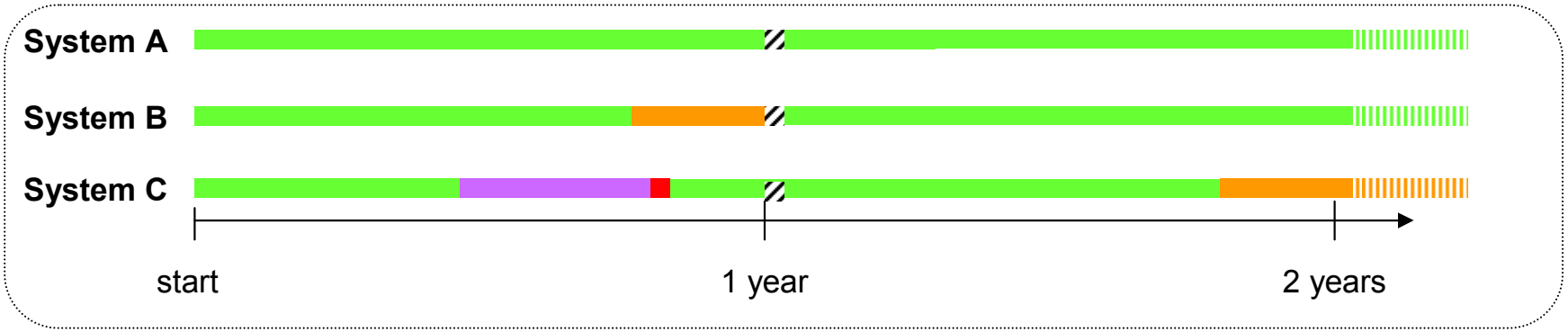
Model of System Deterioration

- **4 states, characterized by a possible penalty on production**
  - OK (as good as new)
  - Deteriorated
  - Failed
  - Temporarily repaired
- **3 types of deterioration distributions**
  - Time from OK to deteriorated
  - Time from deteriorated to fail
  - Time from Temp to fail
- **4 repairs**
- **Probability of correctly observing given the system is in D1**



Further Assumptions about Platform Evolution

- **The evolution of a system follows a semi-Markov model, where not all states are observed.**
- **Maintenance activities intervene in the evolution of the system:**
  - By changing the state of the system (repair)
  - By enabling observation of the state of the system (inspection)
- **We assume systems on the platform evolve independently, yet their evolution is made dependent by the maintenance periods.**
- **We model the evolution of the platform as a Generalized Semi Markov Process.**

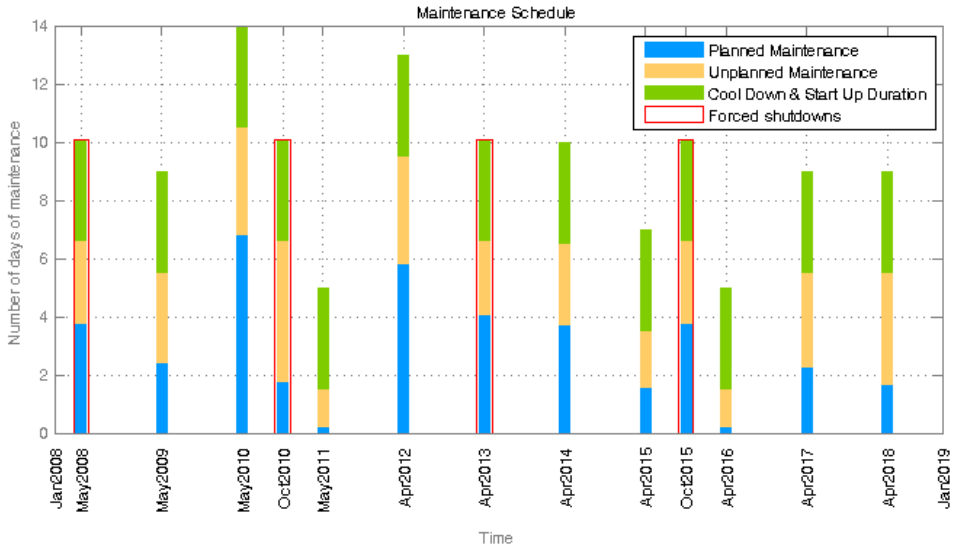


Results

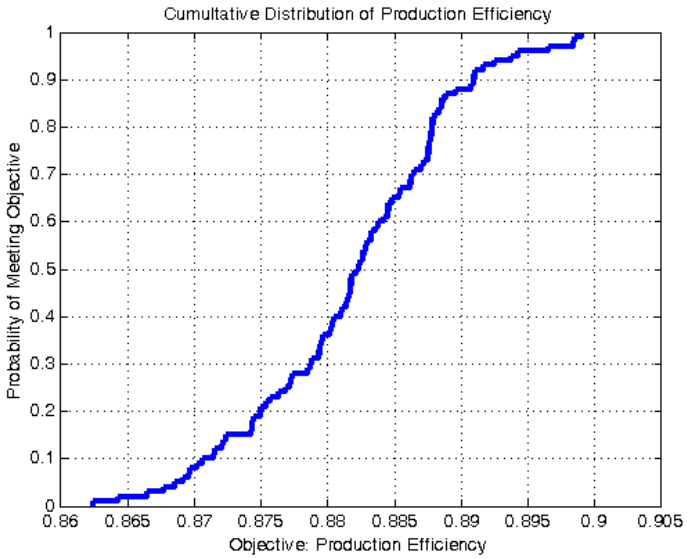
Projected Maintenance Plan

About 10% of the Planned Maintenance periods take longer than planned (on average 4% of the planned time

About 90% of the Planned Maintenance periods are shorter than planned (on average 40% of the planned time



Production Performance



Production Efficiency

88.18%

Average Oil Equivalent Losses

2.29 Mbbl per year

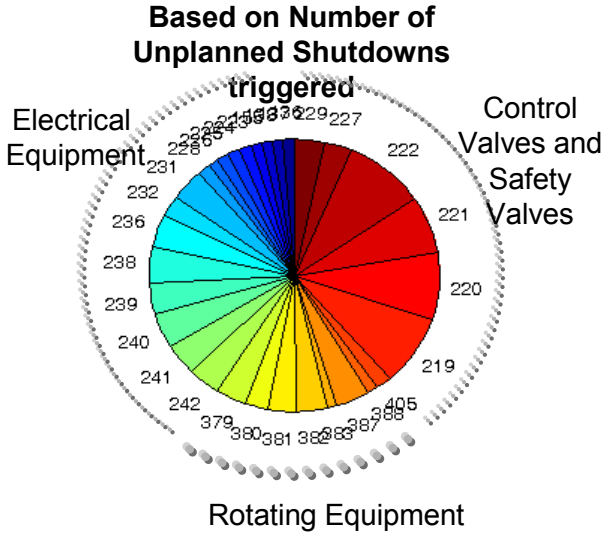
Average Oil Losses per year

1.17 Mbbl per year

Average Gas Losses per year

173 msm3 per year

Unplanned Shutdown Drivers



ILLUSTRATIVE DATA

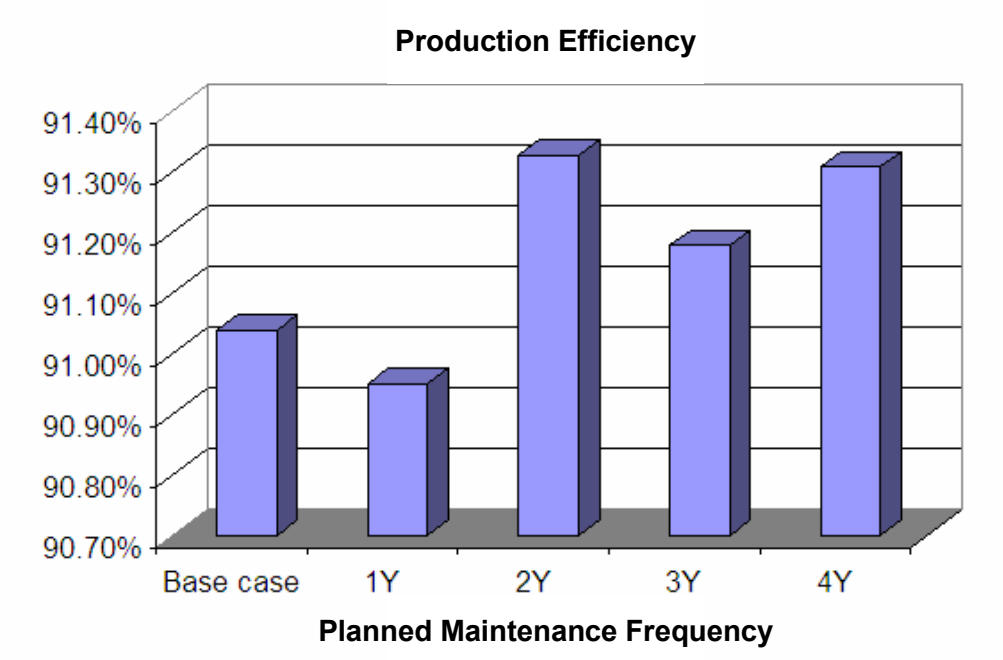
Results

	Average	Std. Dev.	Minimum	Maximum
Proportion of Oil Losses from Planned Stops	**16.24%**	1.68%	13.00%	20.85%
Proportion of Oil Losses from Unplanned Stops	**69.47%**	4.16%	60.42%	80.04%

Production Statistics

	Average	Std. Dev.	Minimum	Maximum
Number of Turnarounds	**4**	0	4	4
Number of Shutdowns	**51**	5	38	65
Number of Days of Turnaround per year	**6**	0	6	6
Number of Days of Shutdown per Year	**34**	4	25	43
Average Duration of Turnarounds	**16**	0	15	16
Average Duration of Shutdowns	**7**	0	6	8

Scenario Analysis



Optimization of Maintenance Plan based on Simulation model

- **Objective**
  - Minimize expected production losses (planned and unplanned)
- **Decision Variables:**
  - Start dates of the planned maintenance periods
  - Duration for the planned maintenance periods
  - Thresholds parameters
  - Discrete variables such as whether activity i is to be planned for maintenance period j are determined through a scheduling heuristic.
- **Constraints**
  - Maximum inter-maintenance time for some activities

- **Derivative-free optimization methods are necessary in this setting.**
  - The simulation model serves as a black box engine which one can query with solution candidates
- **Two main approaches in derivative-free optimization**
  - Lattice approaches (local searches)
  - Interpolation approaches (model approximation)
- **Given characteristics of value function (non-continuous and noisy) , we have chosen a state-of-the-art lattice approach.**

Upcoming Challenges

- **Scalability of the simulation model into multi-platform estimation**
- **Improvement robustness of scheduling heuristic**
- **Modeling of the dependencies among systems in terms of deterioration and maintenance activities**
- **Assessment of the probabilistic inputs and of the objective function (multi-criteria, utility)**

Closing Comments

- **Our current model is able to quantitatively evaluate the consequences of a given maintenance plan in particular:**
  - Losses from Planned Maintenance
  - Losses from Unplanned Maintenance.
- **In addition, we provide** insights **into the activities driving unplanned losses, thereby informing risk mitigation strategies.**
- **The evaluation model is designed to be integrated with an optimization algorithm that explores optimal maintenance plans.**
- **The approach is being implemented within a European Oil Producer.**
- **A similar model could be employed in other industries with continuous production systems such as electricity generation.**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Thank you
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