# Série dos Seminários de Acompanhamento à Pesquisa

DEI DEPARTAMENTO DE ENGENHARIA INDUSTRIAL

Número 20 | 09 2021

# Data-driven joint chance-constrained optimization for the workover rig scheduling problem

Autor:

Iuri Martins Santos

PUC RIO

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Autor:

Iuri Martins Santos

Orientador: Prof. Silvio Hamacher
Coorientador: Prof. Fabricio Oliveira (Aalto University)

**CRÉDITOS:**

**SISTEMA MAXWELL / LAMBDA**
https://www.maxwell.vrac.puc-rio.br/

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**Layout da Capa**: Aline Magalhães dos Santos

# Agenda

Personal presentation

Introduction

Systematic Literature Review

Workover Rig Scheduling Problem

- Deterministic model
- Data preparation and prediction
- Chance-constrained model

Next steps

# Personal presentation

# Iuri Santos – PhD Candidate at PUC-Rio

## Academic Background

- Bachelor and Master in Industrial Engineering (PUC-Rio).
- PhD Candidate in Industrial Engineering (PUC-Rio) – 4th year
- Visiting Researcher at Aalto University

## Professional Background

- Researcher and Intern at Tecgraf Institute (2016-).
- Intern at the Petrobras’ department of Intelligence and Strategy of Maritime Transportation (2014-2015).

# Iuri Santos – PhD Candidate at PUC-Rio

## Maritime Fleet Size and Mix

- Stochastic and deterministic optimization models for the *cabotage* tanker fleet size and mix decisions.
- 1 final project (Santos, 2015), 2 conference papers (Vieira et al., 2016; Santos et al., 2017), 1 journal article (Vieira et al., 2017) and 1 prize (Vieira et al., 2016).

## PLSVs Scheduling

- Heuristics and optimization models for ship scheduling.
- 1 conference paper (Cunha et al., 2017) and 1 journal article (Cunha et al., 2018).

## Oil Rigs Scheduling

- Simulation, heuristics and optimization model for offshore rigs scheduling.
- 1 conference paper (Santos et al., 2017) and 1 master thesis (Santos, 2018)

# Data-driven joint chance-constrained optimization for the workover rig scheduling problem

# Introduction - The Rig Scheduling Problem

Oil rigs are the most important resources in the Exploration and Production of Oil and Gas.

Use mainly in **drilling, completion, workover and abandonment.**
(complex, expensive and risky operations)

The **Rig Scheduling Problem (RSP)** emerges as the decision-making process to determinate **which rigs** will attend **which wells** and **when**.

# Systematic Literature Review
## The Rig Scheduling Problem

Article “A Systematic Literature Review for the Rig Scheduling Problem: classification and state-of-the-art” currently in revision (R1) for the *Computers and Chemical Engineering*. (Qualify paper)

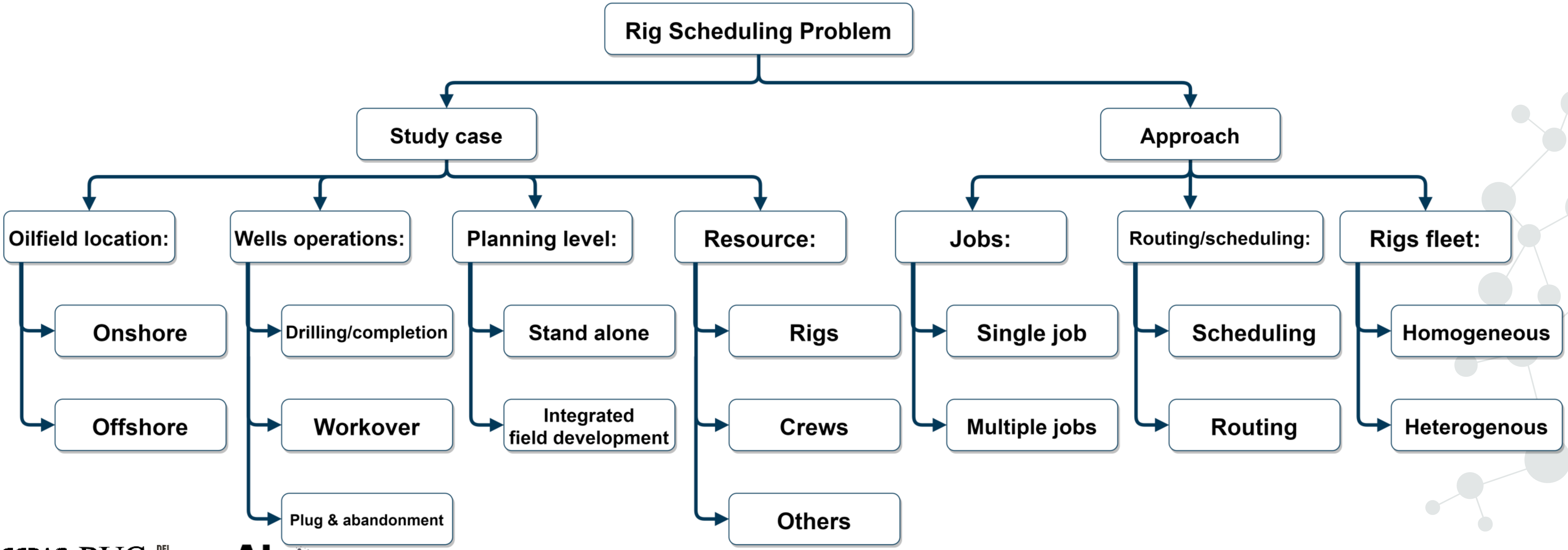
Analysis of 128 papers from Scopus (67/3248), WOS (35/551) and Google Scholar (citation links).
Proposes a classification and taxonomy.

## Main findings:

- Trend for models considering the **uncertainty** of the rig scheduling problems:
  **Stochastic/robust models**, simulation-optimization, dynamic programming and **data-driven optimization**.
- Need for models closer to the demands of the industry:
  **Realistic objective functions**, **heterogeneous fleets**, use of **real data** and **validation/implementation** of results.

# Systematic Literature Review
## The Rig Scheduling Problem – New Classification

The **Rig Scheduling Problem (RSP)** main attributes:

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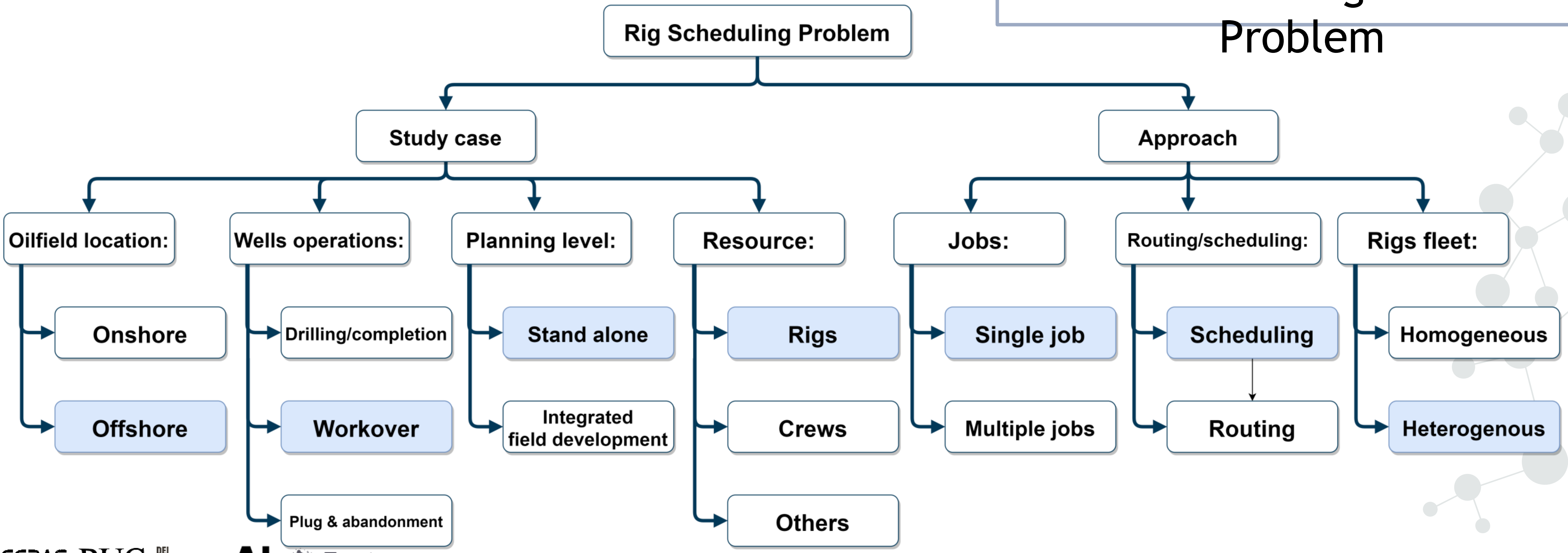
# Systematic Literature Review
## The Rig Scheduling Problem – New Classification

The **Rig Scheduling Problem (RSP)** main attributes:

Focus of this study:
The Workover Rig Scheduling Problem



# Workover Rig Scheduling Problem
## Assumptions

A set of **offshore wells**, each one requiring a specific workover operation with a release date.
A set of **heterogenous rigs** is available for hiring with eligibilities and different durations.

Objectives:

- Fleet size:
  Select rigs to hire minimizing the fleet costs.
- Wells service:
  Select wells to served minimizing the oil production loss.
- Scheduling:
  Allocate a well to a rig that can serve it.
  Select when the well will be served by the rig minimizing the oil production loss.

# Workover Rig Scheduling Problem
## Deterministic Model

- Several formulations were developed and tested for the deterministic model.
- We propose a formulation based in a routing model.

### Sets:

- $i, j \in J: wells$
- $k \in K: wells$

### Parameters:

- $l_i$: oil production loss.
- $a_i$: release date.
- $d_i^k$: processing time.

### Main Variables:

- $X_{ij}^k$: If rig k goes from well i to well j.
- $S_i$: Starting time of task i.
- $Z^k$: If rig k is hired or not.

### Auxiliary Variables:

- $X1_i^k$: If rig k enters well i.
- $X2_i^k$: If rig k leaves well i.
- $W_i$: If well i is served.

Oil production loss (tardiness and well service) — Rig hiring cost

$$\text{Min} \quad \sum_{i \in J | i \neq 0} l_i \left[ S_i + \sum_{k \in K} (d_i^k - a_i) X1_i^k + H(1 - W_i) \right] + \sum_{k \in K} c^k Z^k \qquad (11)$$

Subject to:

Flow-balance:

$$X1_i^k = X2_i^k \qquad \forall i, k \qquad (12)$$

$$X1_i^k = \sum_{j \in J} X_{ji}^k \qquad \forall i, k \qquad (13)$$

$$X2_i^k = \sum_{j \in J} X_{ij}^k \qquad \forall i, k \qquad (14)$$

Well service:

$$W_i = \sum_{k \in K} X1_i^k \qquad \forall i | i \neq 0 \qquad (15)$$

$$W_i = \sum_{k \in K} X2_i^k \qquad \forall i | i \neq 0 \qquad (16)$$

Sequence timing:

$$S_i - d_j^k \geq S_j - M(1 - X_{ji}^k) \qquad \forall i, j, k | i \neq j \qquad (17)$$

Release dates:

$$S_i \geq a_i W_i \qquad \forall i | i \neq 0 \qquad (18)$$

Rigs hiring:

$$X1_i^k \leq Z^k \qquad \forall i, k \qquad (19)$$

Variable domains:

$$X_{ij}^k \in \{1, 0\} \qquad \forall i, j, k | i \neq j \qquad (20)$$

$$X1_i^k \in \{1, 0\} \qquad \forall i, k \qquad (21)$$

$$X2_i^k \in \{1, 0\} \qquad \forall i, k \qquad (22)$$

$$W_i \in \{1, 0\} \qquad \forall i | i \neq 0 \qquad (23)$$

$$S_i \in \mathbb{Z}^+ \qquad \forall i \qquad (24)$$

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Can be infeasible when simulating the deterministic model decisions for the rigs hired and wells served

# Workover Rig Scheduling Problem

## Deterministic Model

**Solution: Data-driven joint chance constrained approach**

...eloped and tested for the

...ed in a routing model.

Parameters:

- $i, j \in J$: wells
- $k \in K$: wel...
- $l_i$: oil production loss.

**Can be infeasible when simulating the deterministic model decisions for the rigs hired and wells served**

Main Variables:

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# Methodology:

## Data preparation

- Data cleaning
- Text Mining to treat qualitative data
- Task Classification using clustering methods
- Tool: R.

## Predictive Models

- Task Duration estimation (duration, log, norm)
- Regressions models (GLM and Ridge)
- Best distribution for residuals
- Tool: R.

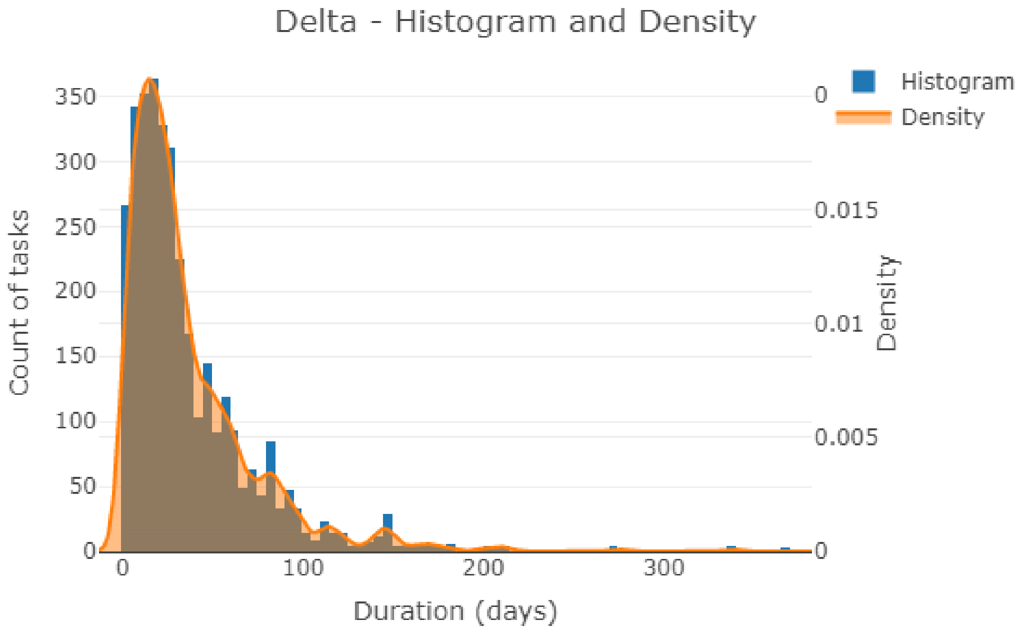
## Joint Chance-Constrained Model

- Representation of the probability
- Non-linear deterministic equivalent
- Stochastic programming with linear model.
- Scenario Generation techniques
- Tools: Julia and Gurobi.

# Workover Rig Scheduling Problem
## Data preparation and prediction

The workover rig scheduling environment is full of uncertainties (durations, dates, occurrence, workover properties).

How can we predict the workover durations?

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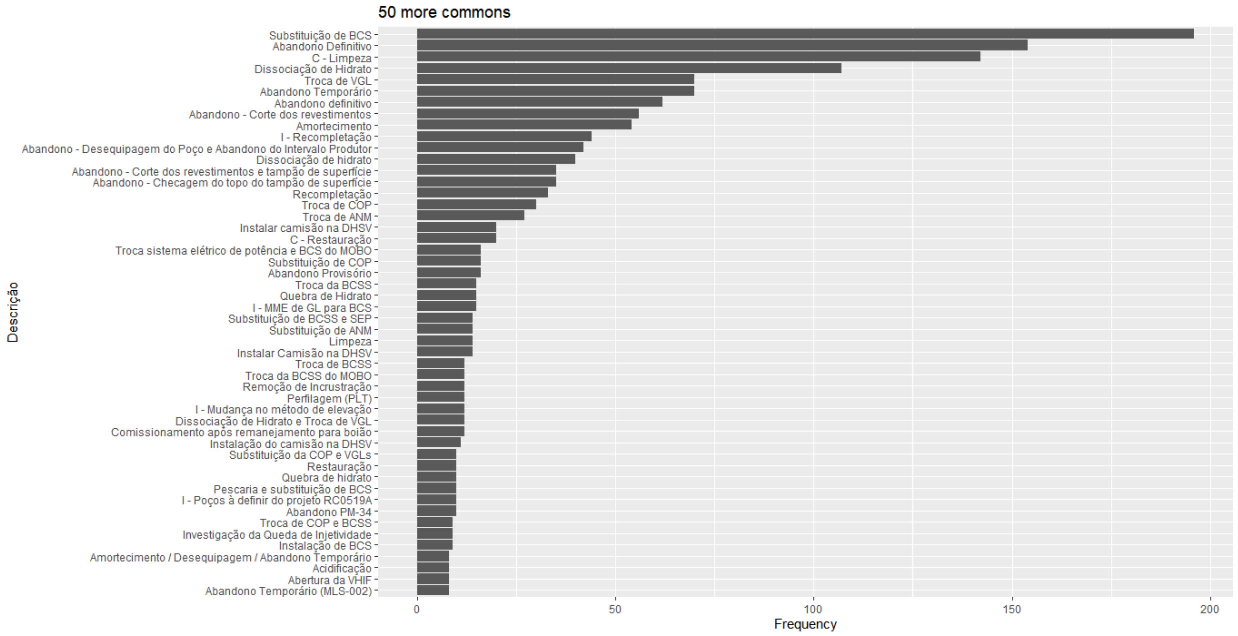
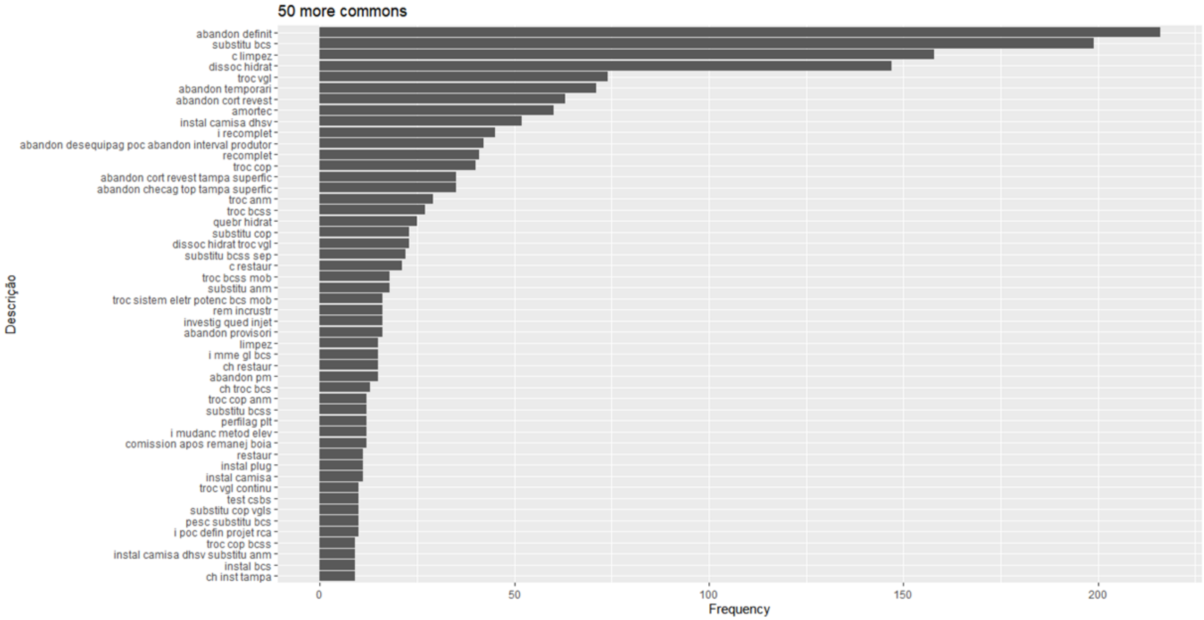
# Workover Rig Scheduling Problem
## Data preparation




**Original data** (dirty, duplicated, errors) → Data cleaning (Text Mining) → Data simplification (Text Mining: stemwords) → Words Clouds (keywords frequence) → Clustering (string similarity) → Grouped tasks

# Workover Rig Scheduling Problem
## Data preparation




Original data (dirty, duplicated, errors) → Data cleaning (Text Mining) → **Data simplification (Text Mining: stemwords)** → Words Clouds (keywords frequence) → Clustering (string similarity) → Grouped tasks

# Workover Rig Scheduling Problem
## Data preparation

| CLUSTER | Original data | Number of obs. |
|---|---|---|
| A | Substituição de BCS | 100 |
| A | Substituição de ANM | 3 |
| A | Substituição de BCSS + SEP | 2 |
| A | Substituição da COP e VGLs | 2 |
| A | Substituição de BCSS e SEP | 2 |
| A | Substituição da BCSS | 2 |
| B | Abandono Definitivo | 32 |
| B | Abandono Temporário | 14 |
| B | Abandono - Corte dos revestimentos | 9 |
| B | Abandono - Checagem do topo do tampão de superfície | 5 |
| B | Abandono - Corte dos revestimentos e tampão de superfície | 5 |
| B | Abandono Permanente | 2 |
| B | Abandono Definitivo (Interrompido) | 1 |
| B | Abandono Definitivo (não finalizado) | 1 |
| B | Abandono - Concluir recuperação do revestimento de 30" | 1 |
| B | Abandono Temporário (MLS-002) | 1 |
| C | Dissociação de Hidrato | 37 |
| C | Dissociação de Hidrato e Troca de VGL | 4 |
| C | Dissociação de Hidrato + Troca de VGL | 3 |
| C | Dissociação de hidrato (Retorno) | 1 |
| C | Dissociação de Hidrato e Abandono Temporário | 1 |
| C | Dissociação de hidrato nas LGL e LPO | 1 |
| C | Dissociação de Hidrato + Desincrustração | 1 |
| D | C - Restauração | 7 |
| D | Restauração | 6 |
| D | Teste de estanqueidade | 2 |
| D | BG-16 - Restauração | 2 |
| D | CH-32 - Restauração | 2 |
| D | CH-27 - Restauração | 1 |

Original data (sujo, duplicacoes, erros) → Data cleaning (Text Mining) → Data simplification (Text Mining: stemwords) → Words Clouds (keywords frequence) → Clustering (string similarity) → Grouped tasks

# Workover Rig Scheduling Problem
## Data prediction

Objective: Predict the duration of the tasks.

Regression models:

- Generalized Linear Model Regression
- Ridge Regression

Variations of the dependent variable:

- Duration.
- log(Duration).
- Normalized Duration.

Cross-validation with several distributions (gaussian, poisson and gamma).
Samples sizes: 479 (in) and 103 (out).

# Workover Rig Scheduling Problem
## Data prediction

Final regression model:

- Ridge Regression:

$$\log(Duration) \sim WellDepth + Subpool + Basin + Clusters45 + RigType$$

- Reformulating the regression to WRSP notation:

$$\log\left(d_i^k\right) \sim \alpha \cdot Depth_i + \beta_i \cdot Pool_i + \gamma_i \cdot Basin_i + \delta_i \cdot Clusters_i + \varphi^k \cdot Type^k$$

$$d_i^k \sim \exp\left(\alpha \cdot Depth_i + \beta_i \cdot Pool_i + \gamma_i \cdot Basin_i + \delta_i \cdot Clusters_i + \varphi^k \cdot Type^k\right) + \varepsilon$$

$$d_i^k \sim \tilde{d}_i^k = \hat{d}_i^k + \varepsilon$$

Where:
$\varepsilon$ can be estimated

# Workover Rig Scheduling Problem
## Joint Chance-Constrained Model

Basic representation

$$\text{Min} \quad \mathbb{E}\left(\sum_{i\in J|i\neq 0} l_i \left[S_i + \sum_{j\in J}\sum_{k\in K}(\tilde{d}_i^k - a_i)X_{ji}^k\right]\right) + H \sum_{i\in J|i\neq 0} l_i(1-W_i) + \sum_{k\in K} c^k Z^k \quad (55)$$

Subject to

$$\sum_{j\in J} X_{ji}^k = \sum_{j\in J} X_{ij}^k \qquad \forall i,k \qquad (56)$$

$$\sum_{k\in K}\sum_{j\in J} X_{ji}^k = W_i \qquad \forall i|i\neq 0 \qquad (57)$$

$$\mathbf{Pr}(\mathbf{S_j} + \mathbf{H}(\mathbf{1} - \mathbf{X_{ij}^k}) \geq \mathbf{S_i} + \mathbf{\tilde{d}_i^k} \qquad \forall \mathbf{j},\mathbf{k}|\mathbf{i}\neq \mathbf{j}) \leq \mathbf{1} - \alpha \forall \mathbf{i}|\mathbf{i}\neq \mathbf{0} \qquad (58)$$

$$S_i \geq a_i * W_i \qquad \forall i|i\neq 0 \qquad (59)$$

$$\sum_{j\in J} X_{ij}^k \leq |J|Z^k \qquad \forall i,k \qquad (60)$$

$$X_{ij}^{k\omega} \in \{1,0\} \qquad \forall i,j,k|i\neq j \qquad (61)$$

$$S_i \geq 0 \vee S_i \in \mathbb{Z}^+ \qquad \forall i|i\neq 0 \qquad (62)$$

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Joint chance-constrained →

Probability 1-α of the well i duration respects the start of the next task start in the same rig.

# Workover Rig Scheduling Problem
## Joint Chance-Constrained Model

Basic representation

$$\text{Min} \quad \mathbb{E}\left(\sum_{i\in J|i\neq 0} l_i \left[S_i + \sum_{j\in J}\sum_{k\in K}(\tilde{d}_i^k - a_i)X_{ji}^k\right]\right) + H\sum_{i\in J|i\neq 0} l_i(1-W_i) + \sum_{k\in K} c^k Z^k \quad (55)$$

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Joint chance-constrained

Probability 1-α of the well i duration respects the start of the next task start in the same

How to represent this probability?

# Workover Rig Scheduling Problem
## Joint Chance-Constrained Model via Regression Model

Initial representation:

$$P(S_j + H(1 - X_{ij}^k) \geq S_i + \hat{d}_i^k \quad \forall j, k | i \neq j) \leq 1 - \alpha \forall i | i \neq 0 \tag{46}$$

$$P(S_j + H(1 - X_{ij}^k) \geq S_i + \tilde{d}_i^k + \varepsilon \quad \forall j, k | i \neq j) \leq 1 - \alpha \forall i | i \neq 0 \tag{47}$$

$$P(S_i - S_j - H(1 - X_{ij}^k) + \tilde{d}_i^k \leq -\varepsilon \quad \forall j, k | i \neq j) \leq 1 - \alpha \forall i | i \neq 0 \tag{48}$$

# Workover Rig Scheduling Problem
## Joint Chance-Constrained Model via Regression Model

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MINLP deterministic equivalents:

$$\prod_{j \in J, k \in K | i \neq j} P\left(S_i - S_j - H(1 - X_{ij}^k) + \tilde{d}_i^k \leq -\varepsilon\right) \leq 1 - \alpha \qquad \forall i|i \neq 0 \qquad (49)$$

$$\prod_{j \in J, k \in K | i \neq j} P\left(-\varepsilon \geq S_i - S_j - H(1 - X_{ij}^k) + \tilde{d}_i^k\right) \leq 1 - \alpha \qquad \forall i|i \neq 0 \qquad (50)$$

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$$P(S_j + H(1 - X_{ij}^k) \geq S_i + \hat{d}_i^k \qquad \forall j,k|i \neq j) \leq 1 - \alpha \forall i|i \neq 0 \qquad (46)$$

$$P(S_j + H(1 - X_{ij}^k) \geq S_i + \tilde{d}_i^k + \varepsilon \qquad \forall j,k|i \neq j) \leq 1 - \alpha \forall i|i \neq 0 \qquad (47)$$

$$P(S_i - S_j - H(1 - X_{ij}^k) + \tilde{d}_i^k \leq -\varepsilon \qquad \forall j,k|i \neq j) \leq 1 - \alpha \forall i|i \neq 0 \qquad (48)$$

MINLP deterministic equivalents:

$$\prod_{j \in J, k \in K | i \neq j} P\left(S_i - S_j - H(1 - X_{ij}^k) + \tilde{d}_i^k \leq -\varepsilon\right) \leq 1 - \alpha \qquad \forall i|i \neq 0 \qquad (49)$$

$$\prod_{j \in J, k \in K | i \neq j} P\left(-\varepsilon \geq S_i - S_j - H(1 - X_{ij}^k) + \tilde{d}_i^k\right) \leq 1 - \alpha \qquad \forall i|i \neq 0 \qquad (50)$$

$$\prod_{j \in J, k \in K | i \neq j} P\left(\varepsilon' \geq g_{ij}^k(X)\right) \leq 1 - \alpha \qquad \forall i|i \neq 0 \qquad (51)$$

If $\varepsilon \sim N(\mu, \sigma)$, still MINLP:

$$\prod_{j \in J, k \in K | i \neq j} P\left(\frac{\varepsilon' - \mu'}{\sigma} \geq (\frac{g_{ij}^k(X) - \mu'}{\sigma}\right) \leq 1 - \alpha \qquad \forall i|i \neq 0 \qquad (52)$$

$$\prod_{j \in J, k \in K | i \neq j} \left[1 - \Phi\left(\frac{g_{ij}^k(X) - \mu'}{\sigma}\right)\right] \leq 1 - \alpha \qquad \forall i|i \neq 0 \qquad (53)$$

# Workover Rig Scheduling Problem
## Joint Chance-Constrained Model via Regression Model

Initial representation:

$$P(S_j + H(1 - X_{ij}^k) \geq S_i + \hat{d}_i^k \quad \forall j,k|i \neq j) \leq 1 - \alpha \forall i|i \neq 0 \quad (46)$$

$$P(S_j + H(1 - X_{ij}^k) \geq S_i + \tilde{d}_i^k + \varepsilon \quad \forall j,k|i \neq j) \leq 1 - \alpha \forall i|i \neq 0 \quad (47)$$

$$P(S_i - S_j - H(1 - X_{ij}^k) + \tilde{d}_i^k \leq -\varepsilon \quad \forall j,k|i \neq j) \leq 1 - \alpha \forall i|i \neq 0 \quad (48)$$

MINLP deterministic equivalents:

(49)

(50)

(51)

Solution for a MILP representation of the Joint Chance-constrained model via regression?

Stochastic programming / Scenarios

If $\varepsilon \sim N(\mu, \sigma)$, still MINLP:

(52)

$$\prod_{j \in J, k \in K | i \neq j} \left[ 1 - \Phi\left( \frac{g_{ij}^k(X) - \mu}{\sigma} \right) \right] \leq 1 - \alpha \quad \forall i | i \neq 0 \quad (53)$$

# Workover Rig Scheduling Problem
## Joint Chance-Constrained Model via Regression Model

Two-stages stochastic programming approach:

Scenario Generation (Monte Carlo Simulation) ⇨ Scenario Reduction (Wasserstein distance) ⇨ Two-stages stochastic model

# Workover Rig Scheduling Problem
## Joint Chance-Constrained Model via Regression Model

Two-stages stochastic programming approach:

New set:

- $\omega \in \Omega$ (Scenarios)

First stage variables:

- $W_i$: wells attended
- $Z^k$: rigs hired

Second stage variables:

- $X_{ij}^{k\omega}$: "travels"
- $S_i^{\omega}$: well start
- $V_{ij}^{k\omega}$: slack variable for constraint relaxation.
- $Y_i^{\omega}$: well i feasibility.

+ Auxiliary variables used for better relaxation

# Workover Rig Scheduling Problem
## Joint Chance-Constrained Model via Regression Model

Two-stages stochastic programming approach:

$$\text{Min} \underbrace{\sum_{\omega\in\Omega}\sum_{i\in J|i\neq 0} \pi^{\omega} l_i \left[S_i + \sum_{j\in J}\sum_{k\in K}(\hat{d}_i^k + \varepsilon_i^{k\omega} - a_i)X_{ji}^{k\omega}\right]}_{\text{Second stage}} + \underbrace{H\sum_{i\in J|i\neq 0} l_i(1-W_i) + \sum_{k\in K} c^k Z^k}_{\text{First stage}} \quad (66)$$

Subject to

$$\sum_{j\in J} X_{ji}^{k\omega} - \sum_{j\in J} X_{ij}^{k\omega} = 0 \qquad \forall i,k,\omega \quad (67)$$

$$\sum_{k\in K}\sum_{j\in J} X_{ji}^{k\omega} = W_i \qquad \forall i,\omega | i\neq 0 \quad (68)$$

Joint Chance-constrained (69)–(72):

Slack variable relax the uncertainty →

$$S_j^{\omega} + H(1-X_{ij}^{k\omega}) \geq S_i^{\omega} + \hat{d}_i^k + \varepsilon_i^{k\omega}(1-V_{ij}^{k\omega}) \qquad \forall i,j,k,\omega | 0\neq i\neq j \quad (69)$$

Slack variable only for when X=1 →

$$V_{ij}^{k\omega} \leq X_{ij}^{k\omega} \qquad \forall i,j,k,\omega | 0\neq i\neq j \quad (70)$$

Slack variable use counts as Infeasible →

$$V_{ij}^{k\omega} \leq Y_i^{\omega} \qquad \forall i,j,k,\omega | 0\neq i\neq j \quad (71)$$

Infeasible probability less the 1-$\alpha$ →

$$\sum_{\omega\in\Omega} \pi^{\omega} Y_i^{\omega} \leq 1-\alpha \qquad \forall i | i\neq 0 \quad (72)$$

$$S_i^{\omega} \geq a_i * \sum_{j\in J}\sum_{k\in K} X_{ji}^{k\omega} \qquad \forall i,\omega | i\neq 0 \quad (73)$$

$$\sum_{j\in J} X_{ij}^{k\omega} \leq Z^k \qquad \forall i,k,\omega | i\neq 0 \quad (74)$$

$$X_{ij}^{k\omega} \in \{1,0\} \qquad \forall i,j,k,\omega | i\neq j \quad (75)$$

$$V_{ij}^{k\omega} \in [1,0] \qquad \forall i,j,k,\omega | 0\neq i\neq j \quad (76)$$

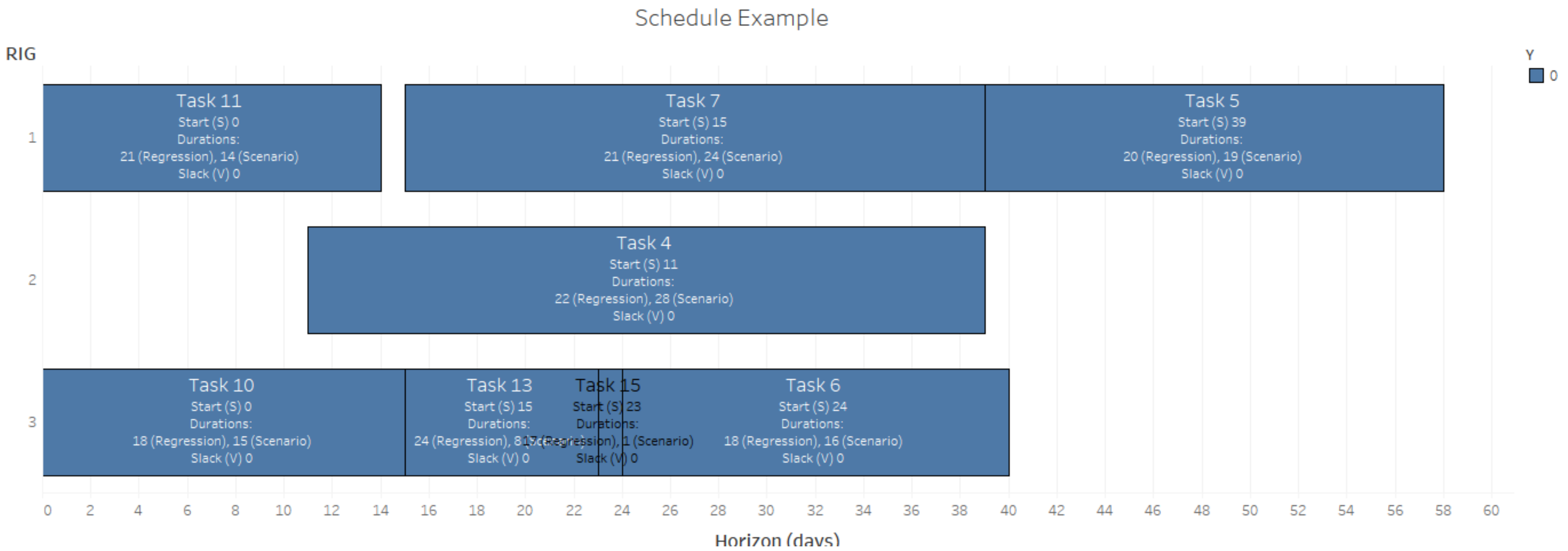
$$Y_i^{\omega} \in \{1,0\} \qquad \forall i,\omega | i\neq 0 \quad (77)$$

$$S_i^{\omega} \in \mathbb{Z}^{+} \qquad \forall i,\omega | i\neq 0 \quad (78)$$

$$W_i \in \{1,0\} \qquad \forall i \quad (79)$$

$$Z^k \in \{1,0\} \qquad \forall k \quad (80)$$

# Workover Rig Scheduling Problem
## Joint Chance-Constrained Model via Regression Model: stochastic approach

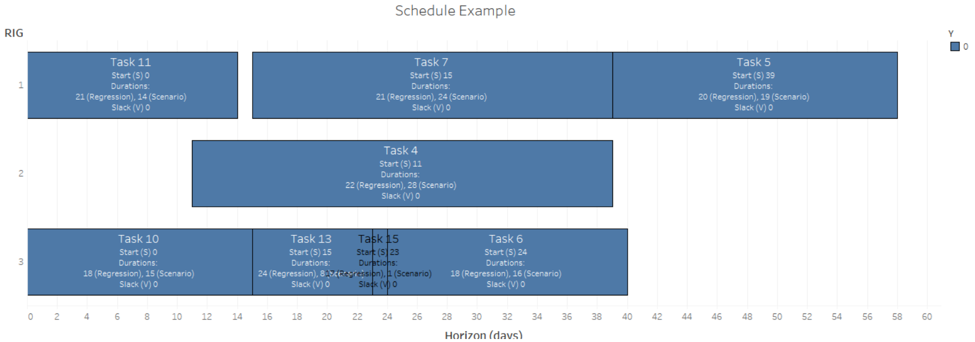



V (slack variable) = 0

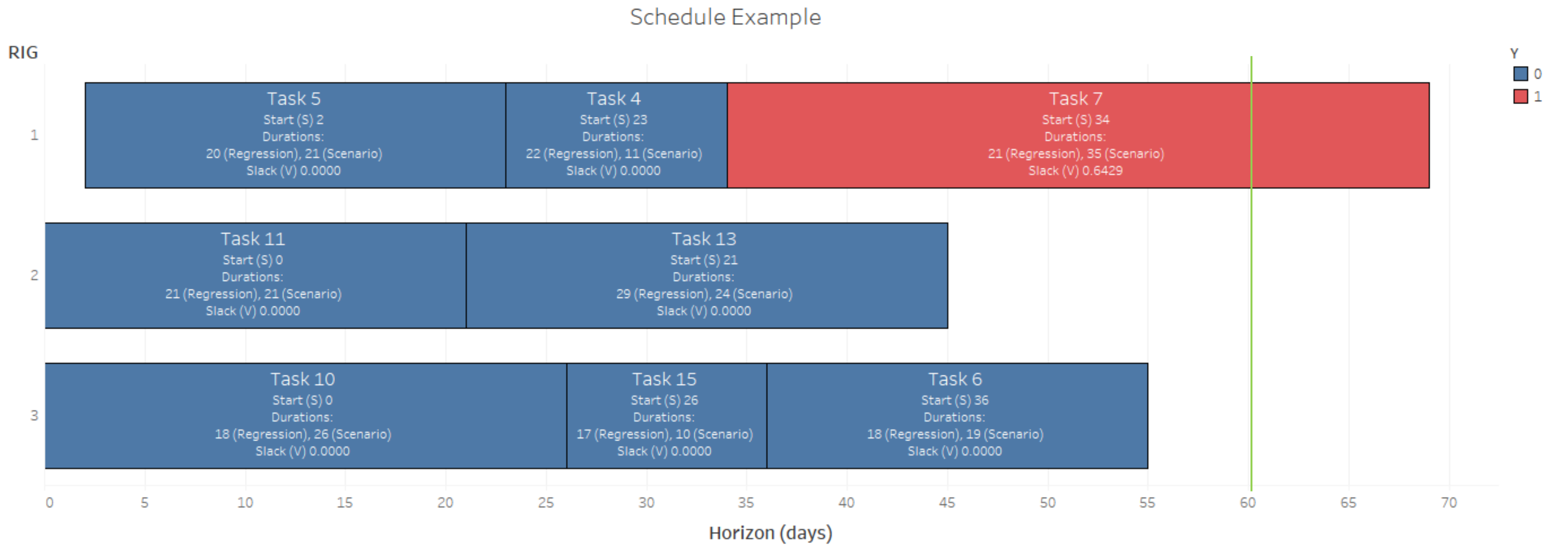
Y (infeasible) = 0

# Workover Rig Scheduling Problem

## Joint Chance-Constrained Model via Regression Model: stochastic approach




Slack variable=0




V (slack variable) = 0.6429

Y (infeasible) = 1

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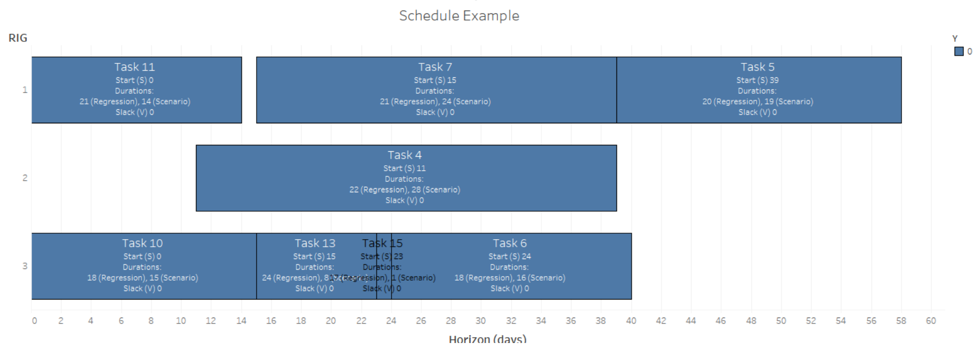
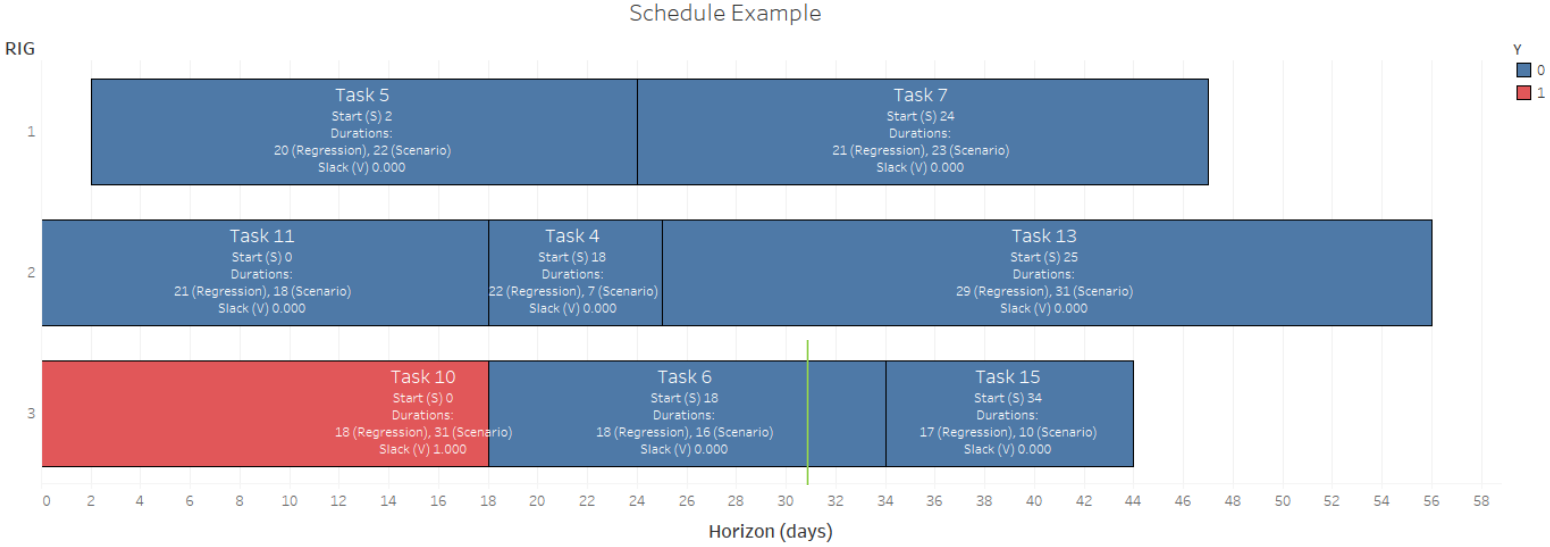
# Workover Rig Scheduling Problem

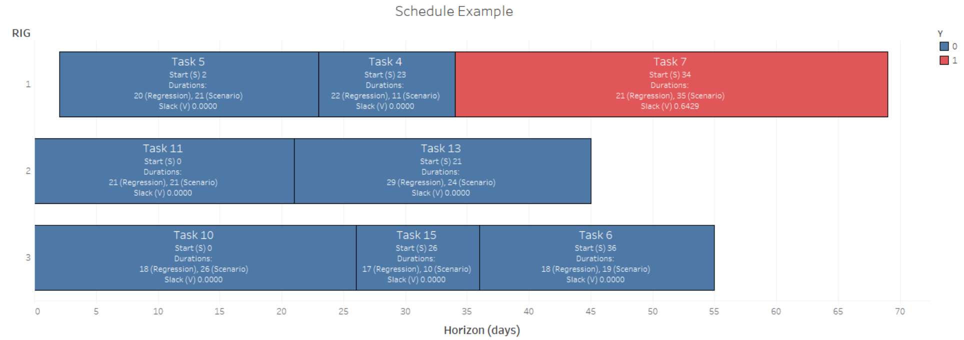
## Joint Chance-Constrained Model via Regression Model: stochastic approach




Slack variable=0




V (slack variable) = 1
Y (infeasible) = 1




V (slack variable) = 0.6429
Y (infeasible) = 1

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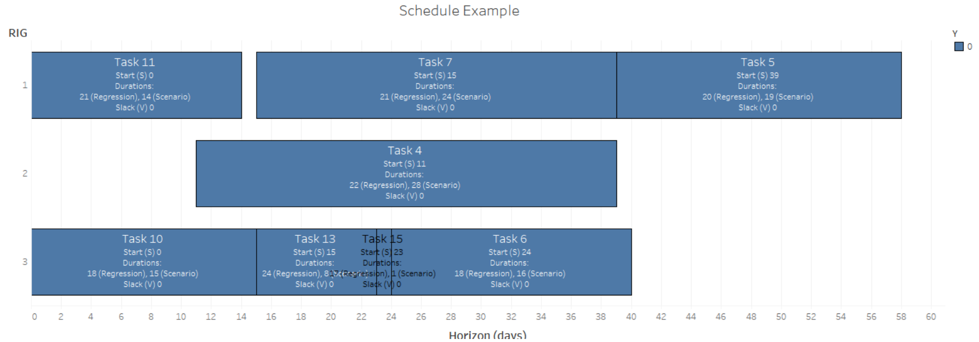
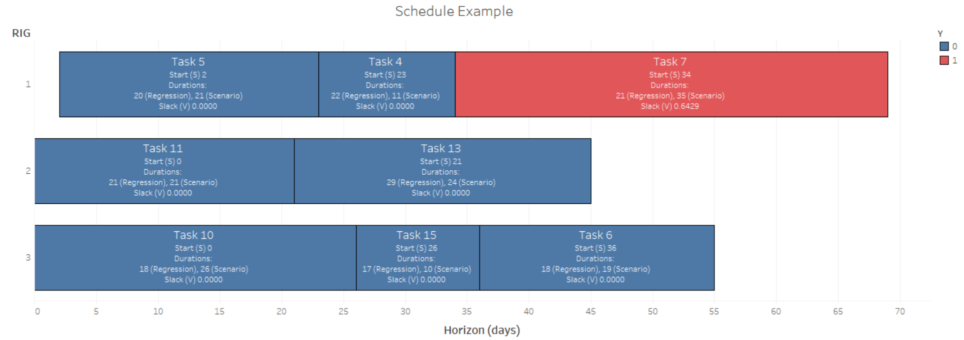
# Workover Rig Scheduling Problem

## Joint Chance-Constrained Model via Regression Model: stochastic approach

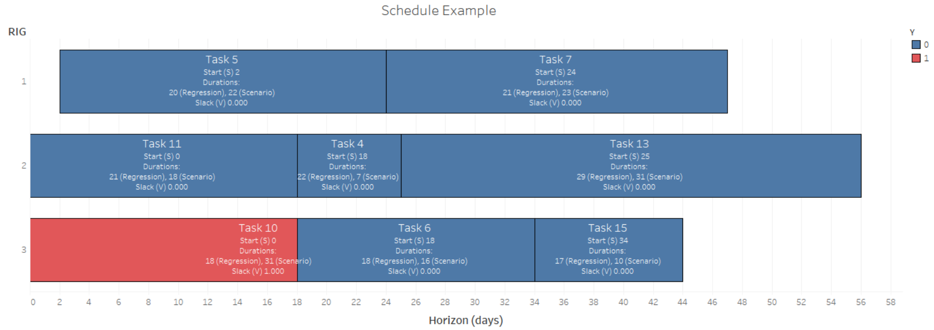



Slack variable=0




V (slack variable) = 0.6429
Y (infeasible) = 1

Penalties are used in the objective function to assure that $V_{ij}^{k\omega}$ and $Y_i^{\omega}$ are minimum.




V (slack variable) = 1
Y (infeasible) = 1

# Workover Rig Scheduling Problem

## Joint Chance-Constrained Model via Regression Model: stochastic approach

Model is able to optimize in reasonable time different sizes of instances with 30 scenarios.

| Scenarios | Jobs | Rigs | Horizon | Seed | Density | Status | Gap | Time (s) | UB (M) | LB (M) |
|---|---|---|---|---|---|---|---|---|---|---|
| 30 | 21 | 5 | 360 | 1234 | 0.3 | OPTIMAL | 0.919% | 55 | 111.81 | 110.78 |
| 30 | 21 | 5 | 360 | 1234 | 0.7 | OPTIMAL | 0.954% | 23 | 108.07 | 107.04 |
| 30 | 21 | 10 | 360 | 1234 | 0.3 | OPTIMAL | 0.000% | 49 | 93.01 | 93.01 |
| 30 | 21 | 10 | 360 | 1234 | 0.7 | OPTIMAL | 0.126% | 49 | 94.84 | 94.72 |
| 30 | 31 | 5 | 360 | 1234 | 0.3 | OPTIMAL | 0.650% | 301 | 271.58 | 269.82 |
| 30 | 31 | 5 | 360 | 1234 | 0.7 | OPTIMAL | 0.955% | 456 | 200.05 | 198.14 |
| 30 | 31 | 10 | 360 | 1234 | 0.3 | TIME_LIMIT | 4.793% | 900 | 176.80 | 168.32 |
| 30 | 31 | 10 | 360 | 1234 | 0.7 | OPTIMAL | 0.647% | 196 | 161.49 | 160.45 |

*30 scenarios seems enough for Wasserstein Distance.

Instances x Computational efforts: More tests are still needed!

# Next steps (thesis)

Instances Classification:

- Several instances were generated, yet they aren’t grouped according to its properties.

Exhaustive experiments with these instances.

Scenario generation and reduction:

- Monte Carlo Simulation
- Wasserstein distance

Simulation-optimization to check if confidence level is respected.

# Next steps (collaboration with Aalto)

Deterministic formulations for the WRSP.

- Several formulations were developed. Exhaustive tests with them is possible.

Branch-price-and-cut formulation that allows to solve the MINLP joint chance-constrained models.

# Future studies

Testing others data classification and prediction methods with the joint chance-constrained model.

- Neural networks, machine learning...

Simu-heuristics approaches for the problem.

Insertion of the regression optimization models in the joint chance-constrained model.

Closed-loop data-driven optimization under uncertainty.

# Future studies

Testing others data classification and prediction methods with the joint chance-constrained model.

- Neural networks and machine learning.

Simu-heuristics approaches for the problem.

Insertion of the regression optimization models in the joint chance-constrained model.

Closed-loop data-driven optimization under uncertainty.

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# Thank you

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