Data-Driven Project Management

Collecting, analysing and using project data at OR&S

Welcome to my academic family!

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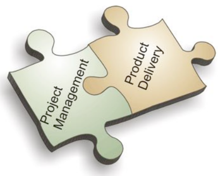
Vlerick Business School (Belgium)
UCL School of Management of University College London (UK)
Partner at OR-AS (Belgium)
University: mario.vanhoucke@ugent.be
Business school: mario.vanhoucke@vlerick.com



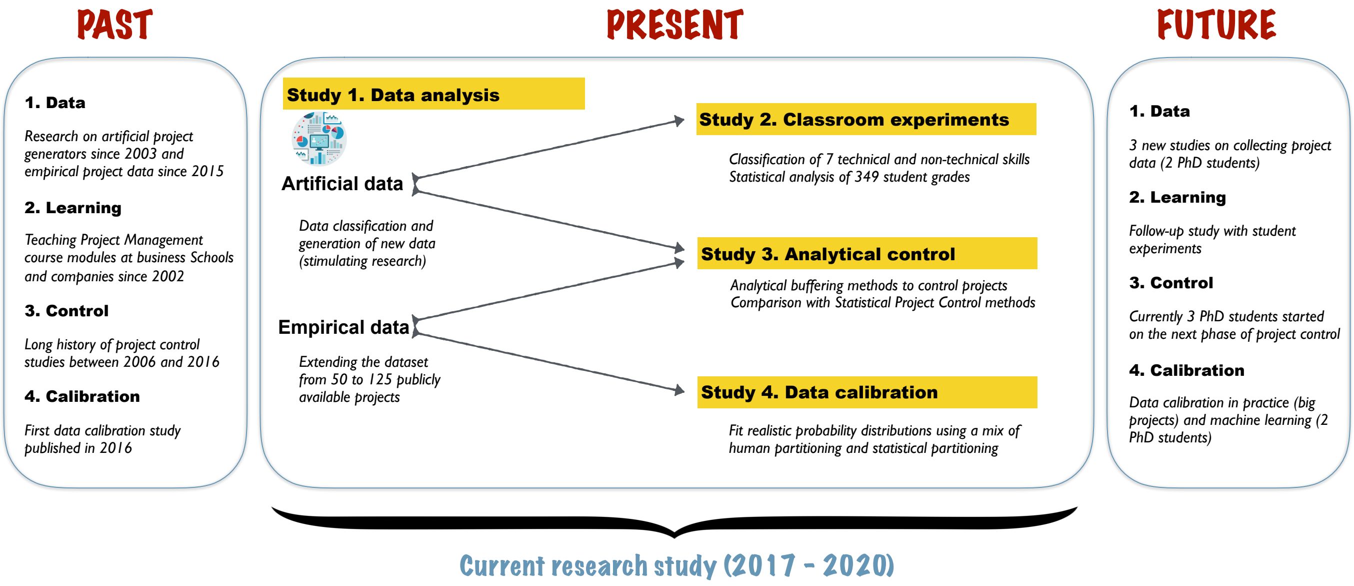
European Working Group on Project Management and Scheduling (PMS)

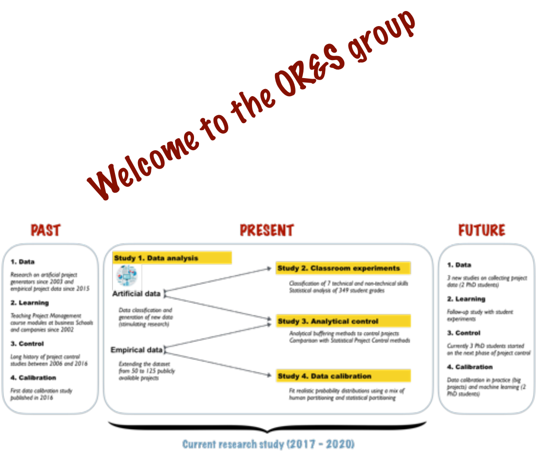
EWG PMS PROJECT MANAGEMENT AND SCHEDULING

How to explain years of research in
- **Less than an hour?**
- **An online mode?**

Tell the story of my team
(and how PMS has always been there)

Operations Research & Scheduling Research Group





Outline

- Is project data useful for
  - Academics (research)
  - Students (learning)
  - Professionals (managing)
- Which data?
  - Artificial projects, or real project?

4 themes

- Study 1. Project data analysis
- Study 2. Classroom experiments (students)
- Study 3. Analytical control (academics)
- Study 4. Data calibration (professionals)

Definitions

Project data

- \+ : Project **network** (activities and precedences and **planned estimates** (durations and costs))
- ++ : Availability and requirements for **renewable resources**
- +++ : Project progress data: **real values** (durations, costs, risk, earned value, …)

Project control

Monitoring the progress of a project using key **performance indicators** for time and cost
Generating **warning signals** when indicators exceed a threshold (project in trouble!)
Taking **corrective actions** to bring the project back on track

Data-driven project management

Integrating **project planning** with **risk analysis** and **project control** in one single decision-support system to improve the success of a project (on time, on budget, within specs)
a.k.a. ***dynamic scheduling*** or ***integrated project management and control***

Study 1.

Project data analysis

José Coelho

Study 1. Project data analysis

"The **resource-constrained project scheduling problem** (RCPSP) consists of finding a schedule of minimal duration by assigning a start time to each activity such that the **precedence relations** and the **renewable resource** availabilities are respected"

Professor-emeritus Willy Herroelen

Is the RCPSP research still relevant?

Who cares? (but I think it is)

Is the RCPSP research still innovative?

I doubt! (sometimes)

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Study 1. Project data analysis

Classification (Vanhoucke et al., 2016) → **SolutionsUpdate** (Vanhoucke and Coelho, 2018) → **Exact algorithms** (Coelho and Vanhoucke, 2018) → **Hard instances** (Coelho and Vanhoucke, 2020)

Artificial data
7 databases containing **4,860** projects
with known network & resource indicator values

Empirical data
1 database containing **52 → +150** projects
with real progress data

An overview of project data for integrated project management and control
Journal of Modern Project Management *(2016)*
www.or-as.be/journals

Construction and evaluation framework for a real-life project database
International Journal of Project Management *(2015)*
doi: 10.1016/j.ijproman.2014.09.004

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Study 1. Project data analysis

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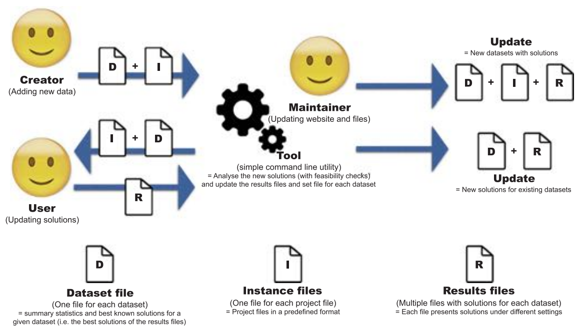
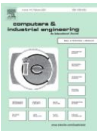
SUMMARY

- **Improve benchmarking**
  - New website to down/upload solutions
  - New software tool to work offline (SolutionsUpdate)
  - Values for LB and UB and BKS (and schedules!)
  - New database NetRes





A tool to test and validate algorithms for the resource-constrained project scheduling problem
Computers and Industrial Engineering *(2018)*
doi: 10.1016/j.cie.2018.02.001

Study 1. Project data analysis

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SUMMARY

- Dynamic lower bound selection (13)
- 3 branching schemes (SER, PAR, AST)
- 3 branching orders (BLB, MTW, RAN)
- Single-mode and multi-mode
- Datasets: PSPLIB, RG30, RG300, MT(RC), MMLIB, Boctor
- **Composite search strategy**

Algorithm 1 Dynamic lower bound selection.

```
procedure DynamicSelection()
    CLB(set) → LB_{ID|ID∈set\tabu}
    LB_best = max_{∀ID∈set\tabu} LB_ID
    for ∀ID ∈ set \ tabu do
        if ID ∉ cred then
            if LB_ID < LB_best then
                Add ID to tabu list for the next 2^{nrT_ID} iterations
                Set nrT_ID ++
            else
                Add ID to cred list for the next nrC_ID iterations
                Set nrC_ID = min(nrC_ID + 1, nrC_max)
    Remove LBs from tabu and cred lists when # iterations are exceeded
```

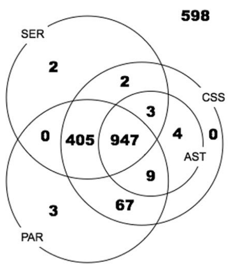

Fig. 3. Performance of branching schemes for the PSPLIB instances.

An exact composite lower bound strategy for the resource-constrained project scheduling problem
Computers and Operations Research *(2018)*
doi: 10.1016/j.cor.2018.01.017

Study 1. Project data analysis

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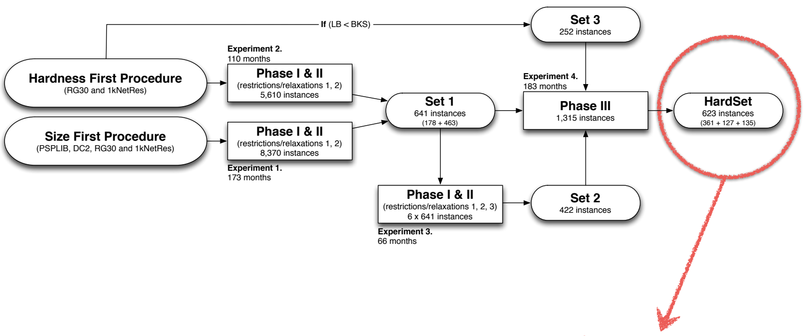
SUMMARY

- Two procedures to change instances
- Starting with 13,980 projects
- Using +40 years of computer power
- **623 new hard instances** found



Now it's up to you!

Going to the core of hard resource-constrained project scheduling instances
Computers and Operations Research *(2020)*
doi: 10.1016/j.cor.2020.104976

Study 2.

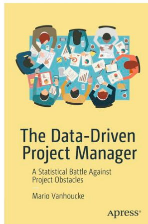
Classroom experiments

Tom Servranckx

Study 2. Classroom experiments

May 3, 2019, UCL School of Management (London, UK)

	Programme	Year	Country	#Groups	#Students
1.	MIMS	2016	Belgium	11	33
2.	MGM	2017	Belgium	9	28
3.	MSM	2017	UK	8	18
4.	MIMS	2017	Belgium	11	33
5.	MGM	2018	Belgium	6	20
6.	MSM	2018	UK	17	68
7.	MIMS	2018	Belgium	12	37
8.	DDPM	2019	Belgium	10	31
9.	MSM	2019	UK	19	81
Tot.				**103**	**349**



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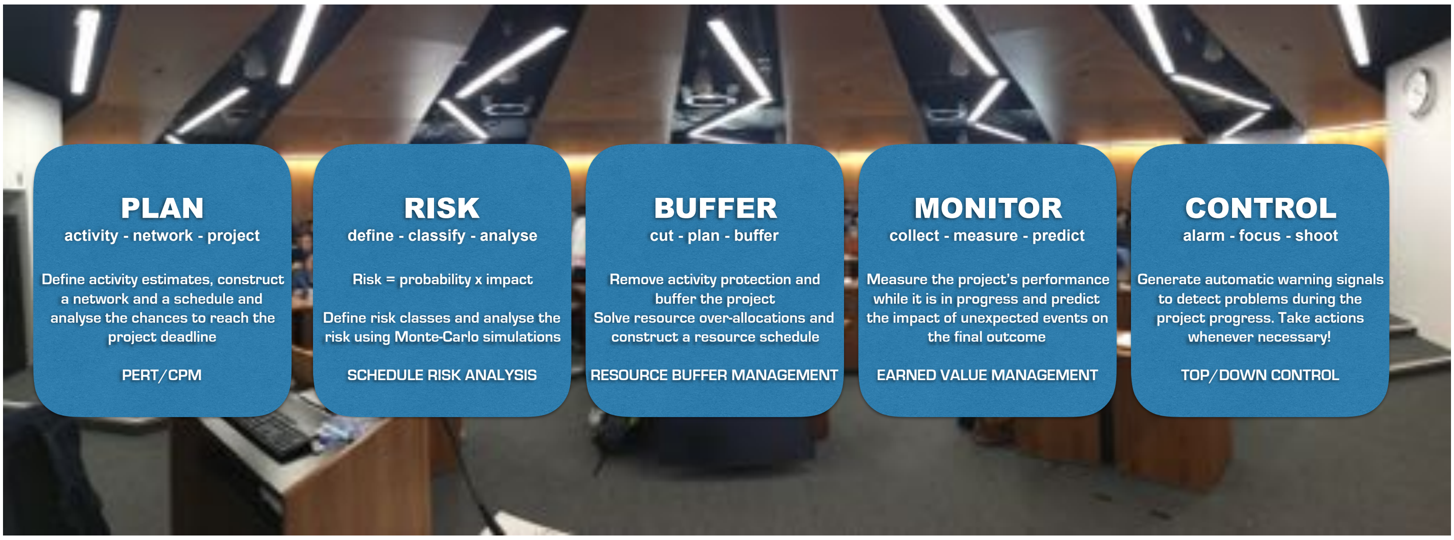
Study 2. Classroom experiments



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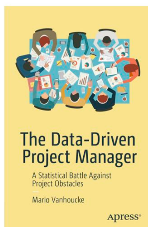

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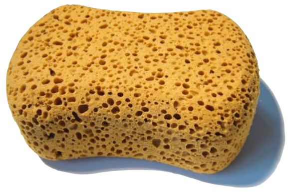
Study 2. Classroom experiments

Hard skills

(tools and techniques)

Soft skills

(it's all about people)



Understanding
(comprehension of strengths and weaknesses of methods)

Analysis
(often called "analytical thinking")

Calculus
(correctness of calculation (≈ traditional exam))

Communication
(integrating different views and opinions)

Criticality
(making sound judgements and decisions)

Holistic
(integrating exercises, often called "organisation")

Creativity
(out-of-the-box thinking and flexibility)

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Study 2. Classroom experiments

Input data

349 students

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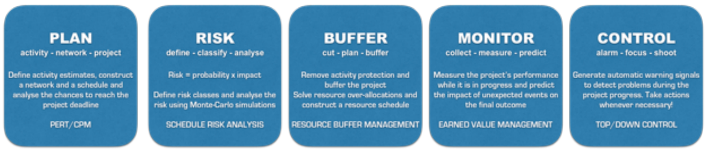
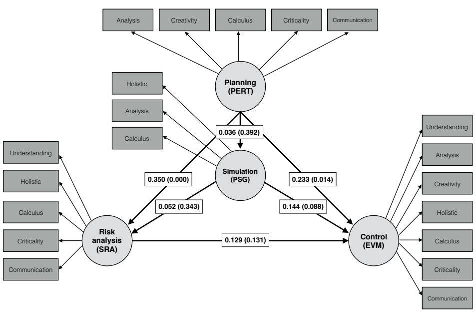
Input data

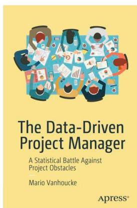
The project life cycle



Methodology

Structural equation modelling

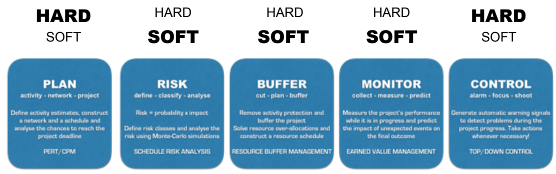




Study 2. Classroom experiments

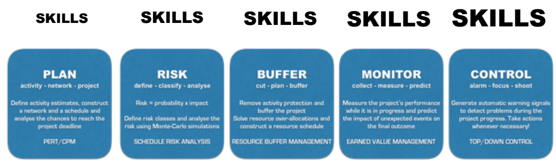
Experiment 1. Impact of skills on student performance

- Both soft and hard skills impact the student performance
  - Hard skills are mainly important at the start and end of the project
  - Soft skills are important throughout the entire project



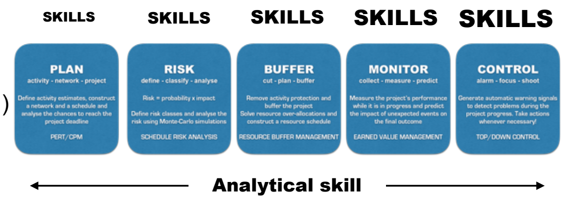
Experiment 2. Improvement of skills

- Both the hard and soft skills improve throughout the course module



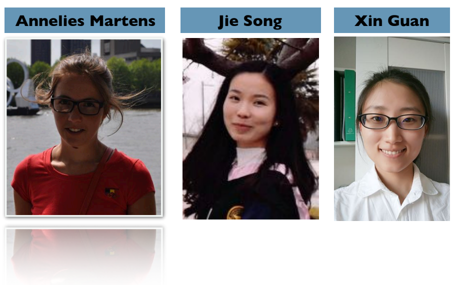
Experiment 3. Importance of skills in project phases

- Not all seven skills are equally important in each project phase
  - Always a combination of soft and hard skills in each project phase (Exp. 1)
  - Later phases require more skills *(planning is easy, control is difficult)*
  - The analytical skill the only skill that is always important



Study 3.

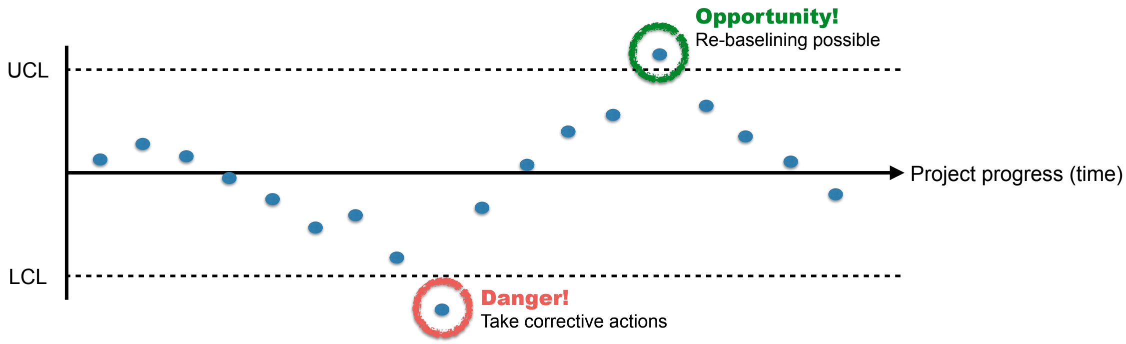
Analytical project control



Study 3. Analytical project control

Project control

Setting tolerance limits to measure time/cost performance



Study 3. Analytical project control

1995
(teacher)

1995
(student)

1995

Statistical **process** control

≠

Now
(black turns into grey)

Now
(long becomes short)

20 years later

Statistical **project** control

Study 3. Analytical project control

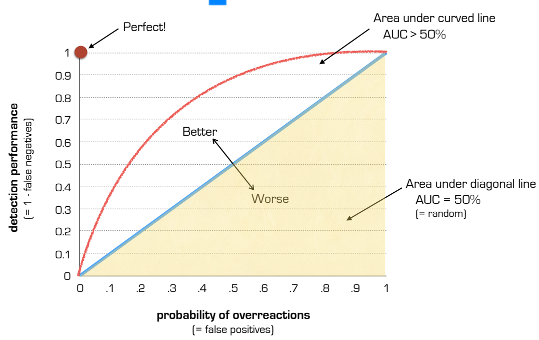
Type I error
"false positive"

Probability of overreaction

Type II error
"false negative"

Detection performance

Area under the curve
"Arbitrary choices: AUC = 0.5"



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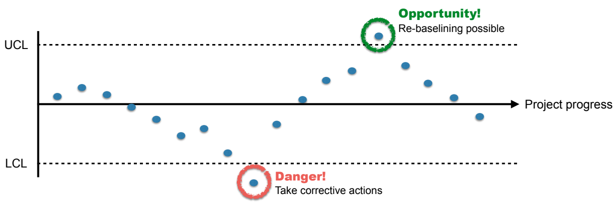
Study 3. Analytical project control

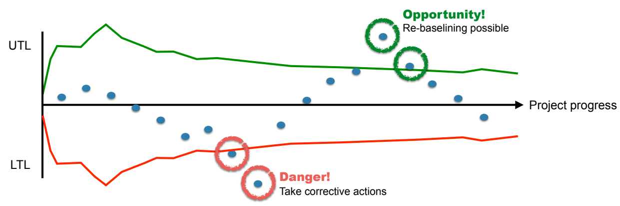
EASY

Static project control
Rules of thumb
No data analysis



ADVANCED

Statistical project control
Data generation
Statistical analysis (tolerance limits)



EASY
Time buffers
(linear action thresholds)

NOT SO GOOD
Simple rules-of-thumb
(better than gut feeling)

DIFFICULT
Statistical action thresholds
(Monte Carlo simulations)

GOOD
Data-driven decision making
(data and intuition)

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Study 3. Analytical project control

Analytical project control

No data generation or advanced statistics
Better than the (oversimplified) rules of thumb

EASY

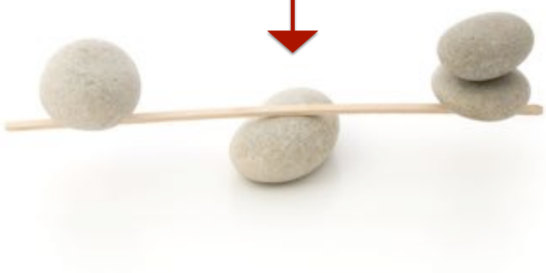
Static project control

Rules of thumb
No data analysis

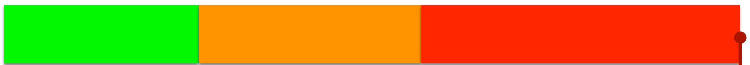
ADVANCED

Statistical project control

Data generation
Statistical analysis (tolerance limits)



Buffer control methods



Everything's under control
(project is early or on-time)

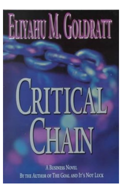
Watch out!
(project delays expected)

Action time!
(project likely to be late)

Real project problems
(project is no longer under control)

Allowable buffer consumption at each phase of the project

Time	Time	Cost	Risk	Resources
"1 day = 1 unit"	*"non-linear accrue"*	*"EVM data"*	*"activity sensitivity"*	*"work content"*



Analytical buffers (Martens and Vanhoucke, 2017a,b) → **Corrective actions** (Martens and Vanhoucke, 2019) → **Empirical validation** (Martens and Vanhoucke, 2018) → **Budget limits** (Song et al., 2020)

Analytical project control ≈ statistical project control

- Control charts (control limits): No simulations necessary!
- Project progress (warning signals): No advanced statistics necessary!
- Similar results (only slightly less reliable, not worth mentioning)

The impact of applying effort to reduce activity variability on the project time and cost performance
European Journal of Operational Research *(2019)*
doi: 10.1016/j.ejor.2019.03.020

An empirical validation of the performance of project control tolerance limits
Automation in Construction (*2018*)
doi: 10.1016/j.cie.2017.05.020

The integration of constrained resources into top-down project control
Computers and Industrial Engineering (*2017*)
doi: 10.1016/j.autcon.2018.01.002

A buffer control method for top-down project control
European Journal of Operational Research *(2017)*
doi: 10.1016/j.ejor.2017.03.034

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APC works better when **realistic data** is available (e.g. risk data)

Using schedule risk analysis with resource constraints for project control
European Journal of Operational Research (*2021*)
doi: 10.1016/j.ejor.2020.06.015

The impact of a limited budget on the corrective action taking process
European Journal of Operational Research (*2020*)
doi: 10.1016/j.ejor.2020.03.069

Tolerance limits for project control: An overview of different approaches
Computers and Industrial Engineering *(2019)*
doi: 10.1016/j.cie.2018.10.035

Study 4.

Data calibration

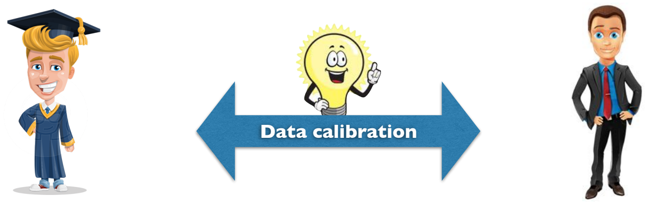
Study 4. Data calibration

"The predictive value of Monte Carlo simulations lends itself to a diverse field of business applications, ranging from risk management to financial planning to economic modelling. Monte Carlo simulations can be used in decision making to provide potential solutions to complex problems."

(Quote from www.referenceforbusiness.com)

Full factorial design
(span the full range of complexity)

Very case specific
(realistic for **my** projects, I don't care about others)



The simple idea of data calibration

Input

Calibration

Output

Project data

PLAN: Duration estimates
REAL: Real durations

Statistical testing

H_0
durations follow predefined distribution

Probability distributions

Clusters of activities of project with known distribution
(with known average and standard deviation)

Option 1.
Curve fitting

Option 2.
Calibration

- **human errors**
- **human expertise**
- **Automatic clustering**

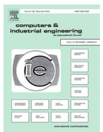
Study 4. Data calibration

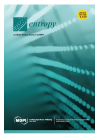
Data calibration
(Trietsch et al, 2012)

Empirical validation
(Colin and Vanhoucke, 2016)

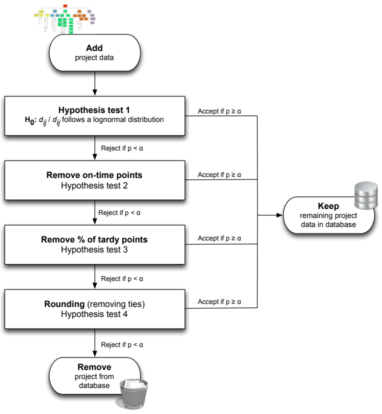
Human expertise
(Vanhoucke and Batselier, 2019a)

Statistical partitioning
(Vanhoucke and Batselier, 2019b)





1. Assume a probability distribution
2. Remove data with human errors
3. Fit remaining data



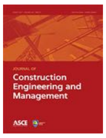
Calibrations works!
(24 projects)

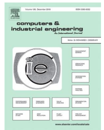
data can't replace human intuition
(97 projects)

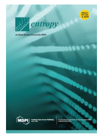
human intuition can't replace data
(125 projects)

Study 4. Data calibration

Data calibration (Trietsch et al, 2012) → **Empirical validation** (Colin and Vanhoucke, 2016) → **Human expertise** (Vanhoucke and Batselier, 2019a) → **Statistical partitioning** (Vanhoucke and Batselier, 2019b)







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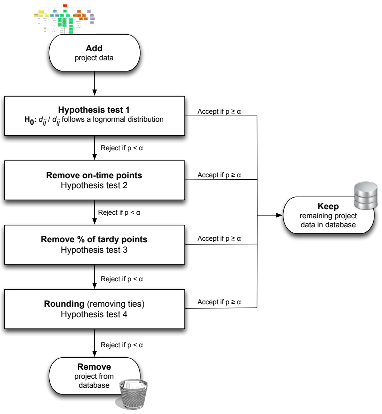

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(24 projects)

50%

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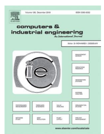

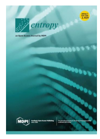

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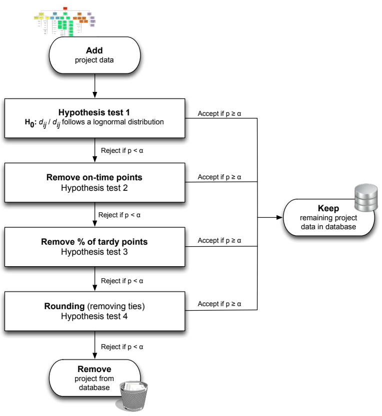

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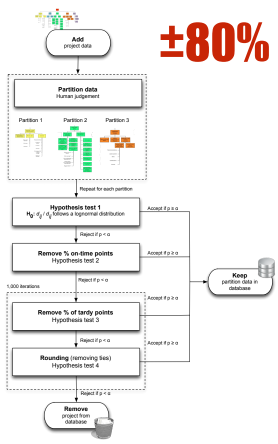

±80%

human intuition can't replace data
(125 projects)

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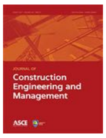
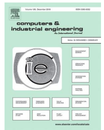
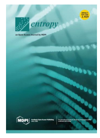
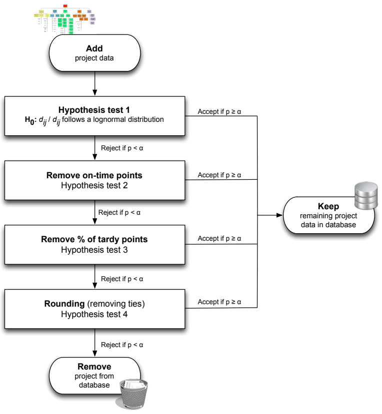
Data calibration (Trietsch et al, 2012) → **Empirical validation** (Colin and Vanhoucke, 2016) → **Human expertise** (Vanhoucke and Batselier, 2019a) → **Statistical partitioning** (Vanhoucke and Batselier, 2019b)







1. Assume a probability distribution
2. Remove data with human errors
3. Fit remaining data

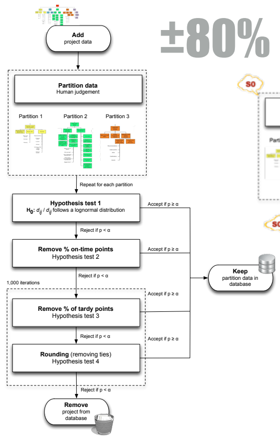


Calibrations works!
(24 projects)

50%

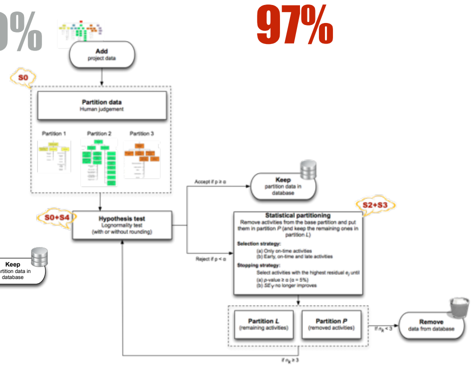
data can't replace human intuition
(97 projects)

±80%



human intuition can't replace data
(125 projects)

97%



Mario Vanhoucke

Study 4. Data calibration

Data calibration (Trietsch et al, 2012) → **Empirical validation** (Colin and Vanhoucke, 2016) → **Human expertise** (Vanhoucke and Batselier, 2019a) → **Statistical partitioning** (Vanhoucke and Batselier, 2019b)

Data calibration ≈ curve fitting + activity clusters + human errors

- Parkinson effect is considerably more substantial than the rounding effect
- Small number of clusters in project data found: Partitioning works!
- Human expertise greatly improves the calibration method
- Human and statistical calibration performs best (97% accepted partitions)

		Partitioning setting (*rounding - selection - stopping*) (1-0-1) PD (x4)	(1-0-1) PD (x5)	(1-0-1) WP	(1-0-1) RP	(1-1-1) PD (x4)	(1-1-1) PD (x5)	(1-1-1) WP	(1-1-1) RP
(*a*)	# projects	83	83	53	21	83	83	53	21
	avg. # activities	61	61	72	42	61	61	72	42
	tot. # activities	5,068	5,068	3,796	887	5,068	5,068	3,796	887
(b_1)	# partitions (human)	232	213	426	65	232	213	426	65
	# partitions (avg/p)	2.8	2.6	8.0	3.1	2.8	2.6	8.0	3.1
	# partitions (max)	4	4	26*	6	4	4	26*	6
	1 partition [%]	4	6	36	0	4	6	36	0
	2 partitions [%]	32	40	45	24	32	40	45	24
	3 partitions [%]	45	46	8	52	45	46	8	52
	4 partitions [%]	19	8	7	19	19	8	7	19
	5 partitions [%]	0	0	2	0	0	0	2	0
	6 partitions [%]	0	0	2	5	0	0	2	5
(b_2)	# subpartitions (statistical)	-	-	-	-	423	399	631	117
	# subpartitions (avg/p)	-	-	-	-	5.1	4.8	11.9	5.6
	# subpartitions (max)	-	-	-	-	4	4	5	4
	1 subpartition [%]	-	-	-	-	40	37	59	34
	2 subpartitions [%]	-	-	-	-	40	41	35	54
	3 subpartitions [%]	-	-	-	-	18	19	4	11
	4 subpartitions [%]	-	-	-	-	2	3	1	1
	5 subpartitions [%]	-	-	-	-	0	0	1	0
(*c*)	tot. # partitioning steps	2,150	2,246	835	348	689	751	555	182
	/project	26	27	16	17	8	9	10	9
(*d*)	% act. partition *L*	79	78	90	77	-	-	-	-
	% act. partition *P*	21	22	10	23	-	-	-	-
(*f*)	avg. SE_Y	0.161	0.171	0.196	0.101	0.108	0.130	0.146	0.088
	avg. *p*	0.614	0.589	0.658	0.741	0.774	0.756	0.783	0.811
	accepted (sub)partitions [%]	88	85	92	95	97	94	97	97

Mario Vanhoucke

Study 1. Project data analysis
Study 2. Classroom experiments
Study 3. Analytical project control
Study 4. Data calibration

The future of my team

PAST

1. Data

Research on artificial project generators since 2003 and empirical project data since 2015

2. Learning

Teaching Project Management course modules at business Schools and companies since 2002

3. Control

Long history of project control studies between 2006 and 2016

4. Calibration

First data calibration study published in 2016

PRESENT

Study 1. Data analysis

Artificial data

Data classification and generation of new data (stimulating research)

Empirical data

Extending the dataset from 50 to 125 publicly available projects

Study 2. Classroom experiments

Classification of 7 technical and non-technical skills
Statistical analysis of 349 student grades

Study 3. Analytical control

Analytical buffering methods to control projects
Comparison with Statistical Project Control methods

Study 4. Data calibration

Fit realistic probability distributions using a mix of human partitioning and statistical partitioning

FUTURE

1. Data

3 new studies on collecting project data (2 PhD students)

2. Learning

Follow-up study with student experiments

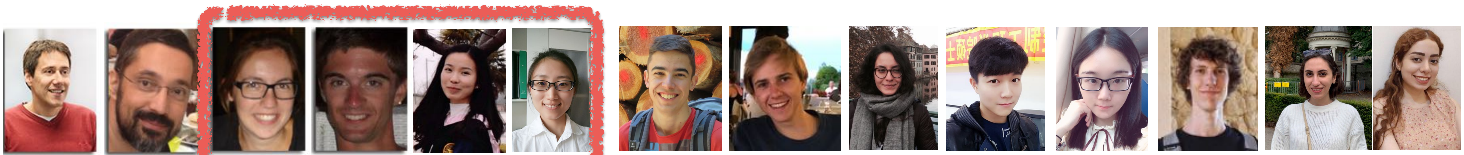
3. Control

Currently 3 PhD students started on the next phase of project control

4. Calibration

Data calibration in practice (big projects) and machine learning (2 PhD students)

Operations Research & Scheduling Research Group



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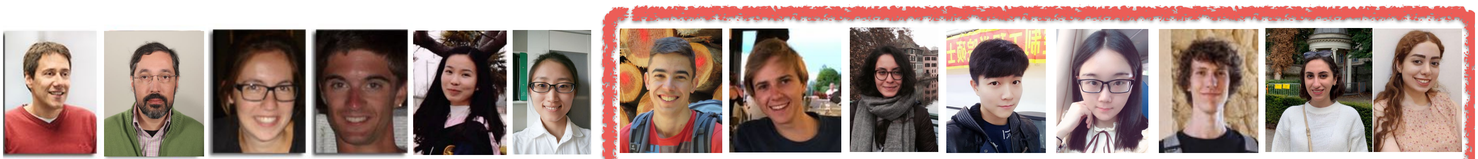

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The future

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Research on artificial p… generators since 2003 … empirical project data s…

2. Learning

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…TURE

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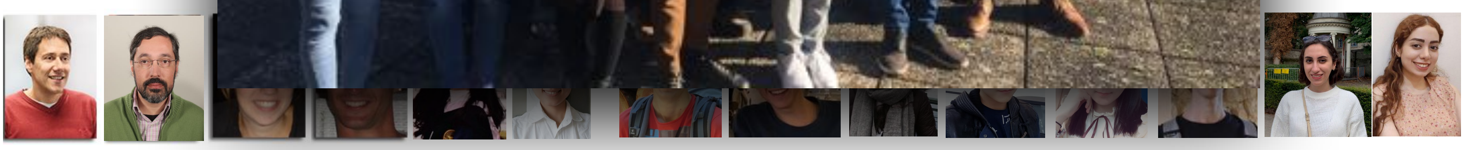

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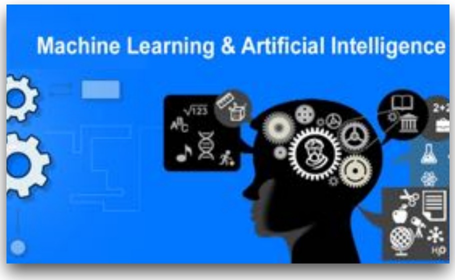
The future of project data



"Trust me"
Who needs data when you have opinions?
Solve problems when they occur!

"Automatic control"
Who needs project managers when you have algorithms?
Algorithms will replace people

Current research projects
Understanding data before going to AI
Bridging the gap between the youngsters and the elderly

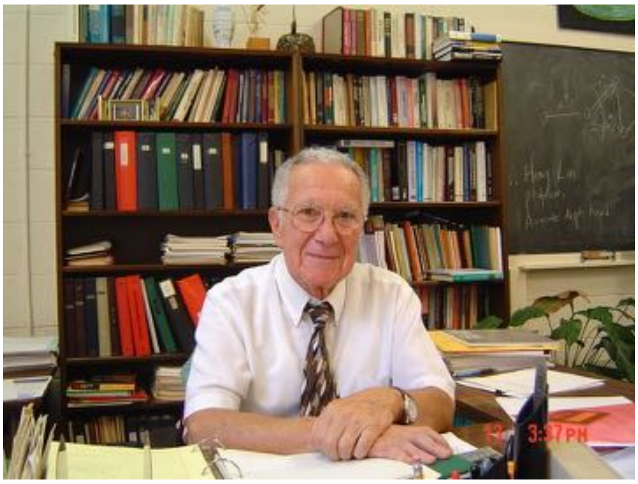
Mario Vanhoucke

The future of now (the next couple of minutes or so)

www.or-as.be/books

www.or-as.be/research/database

Download presentation slides



Gone but not forgotten

Dr. Salah Elmaghraby (1927-2016)

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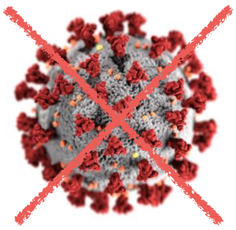

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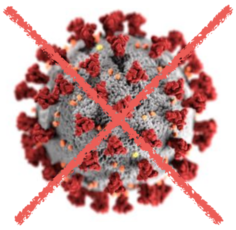

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