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Quantitative analysis of an IPS² delivery planning approach

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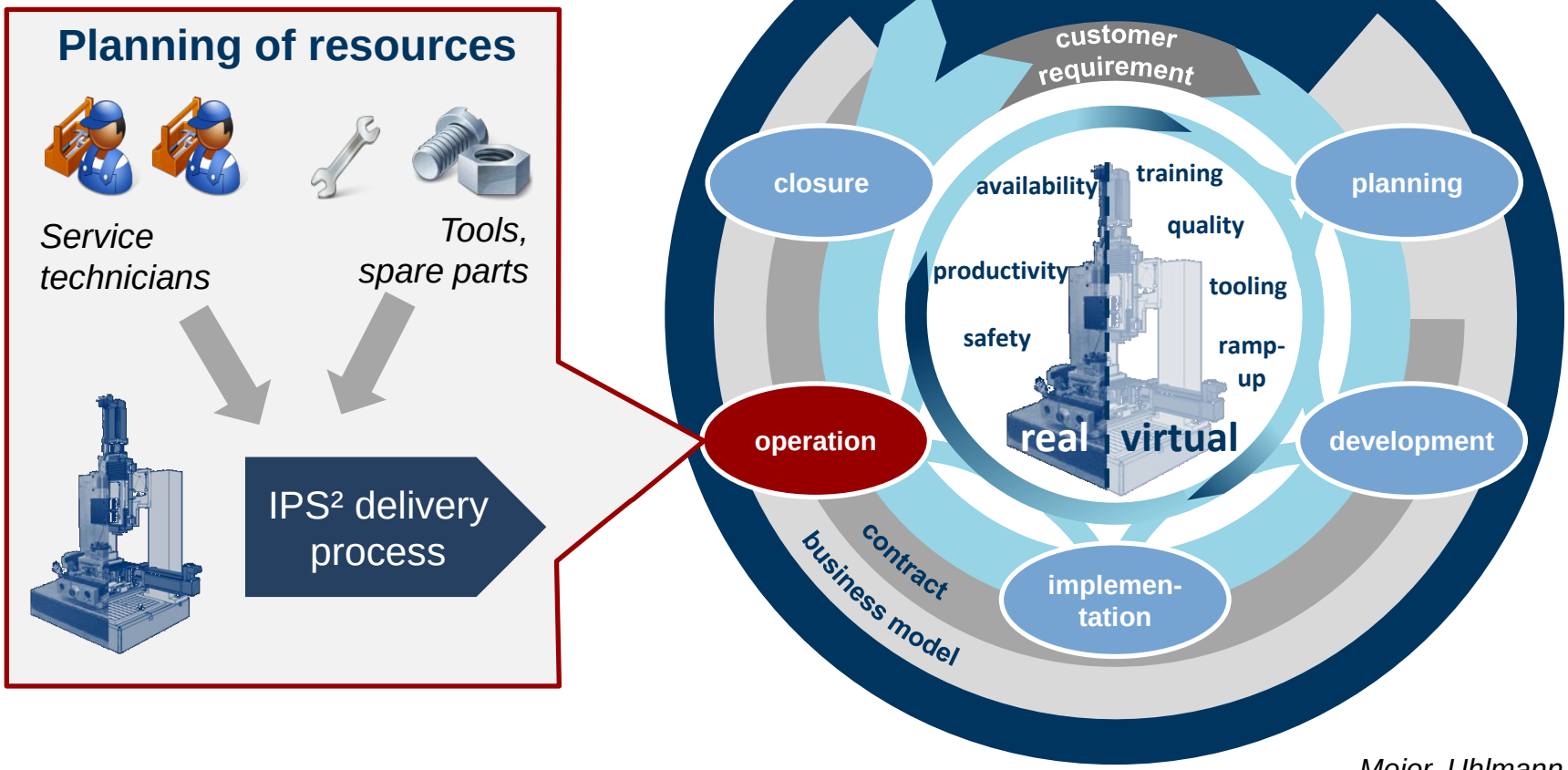
Agenda

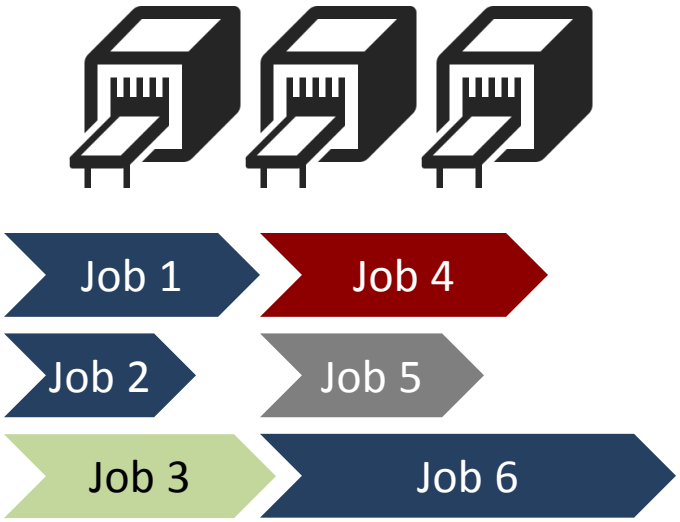
- Introduction
- Adaptive IPS² planning method (AIPM)
- Evaluation of the AIPM
- Discussion and outlook

Delivery planning for IPS²



Meier, Uhlmann (2012)

Planning problems - production

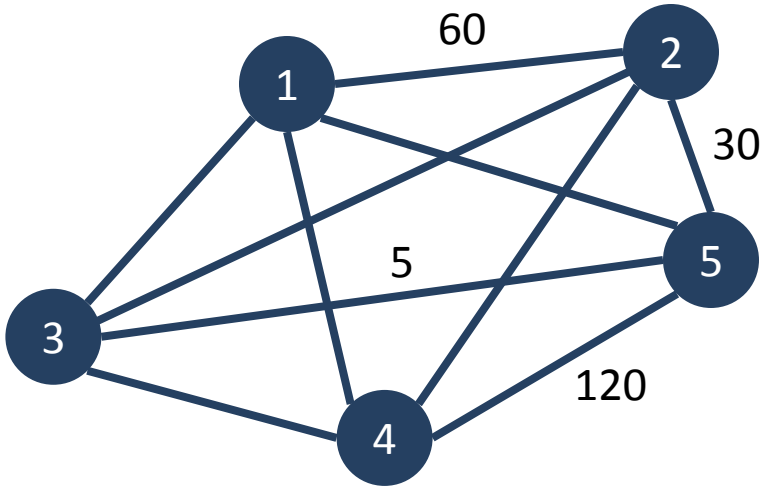


- on-time delivery
- short lead times
- low stocks
- high capacity utilization
- …

optimal job order/size?

Planning problems - service

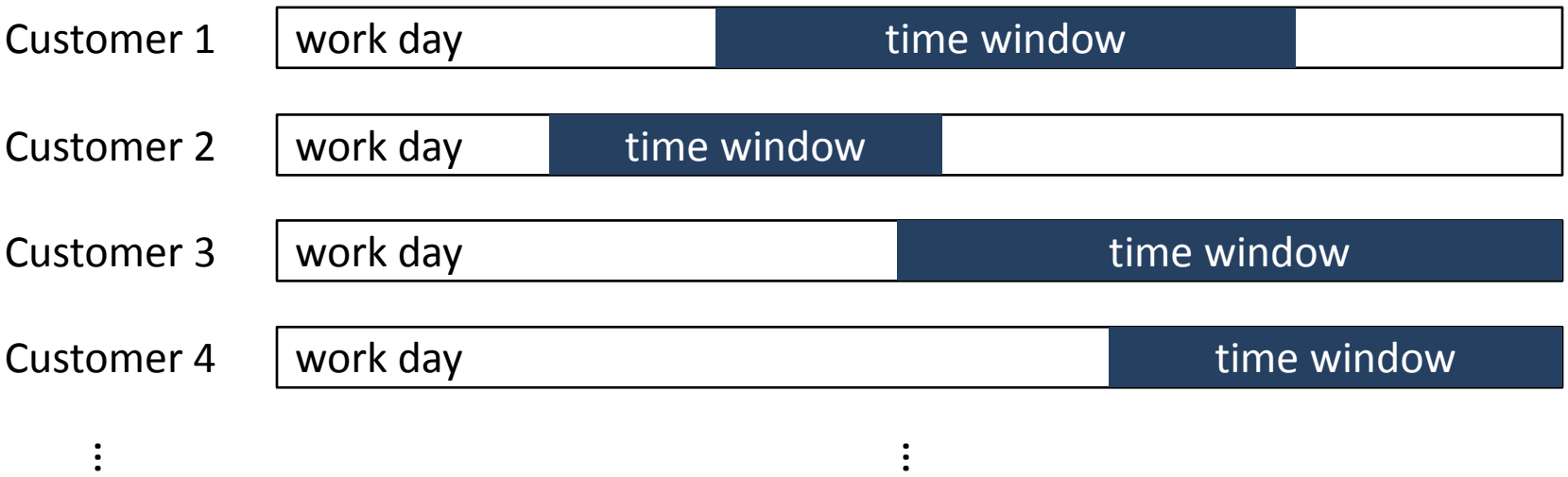
Simple example: Traveling Salesman Problem (TSP)



What is the shortest route starting and ending at 1 while visiting all other stations?

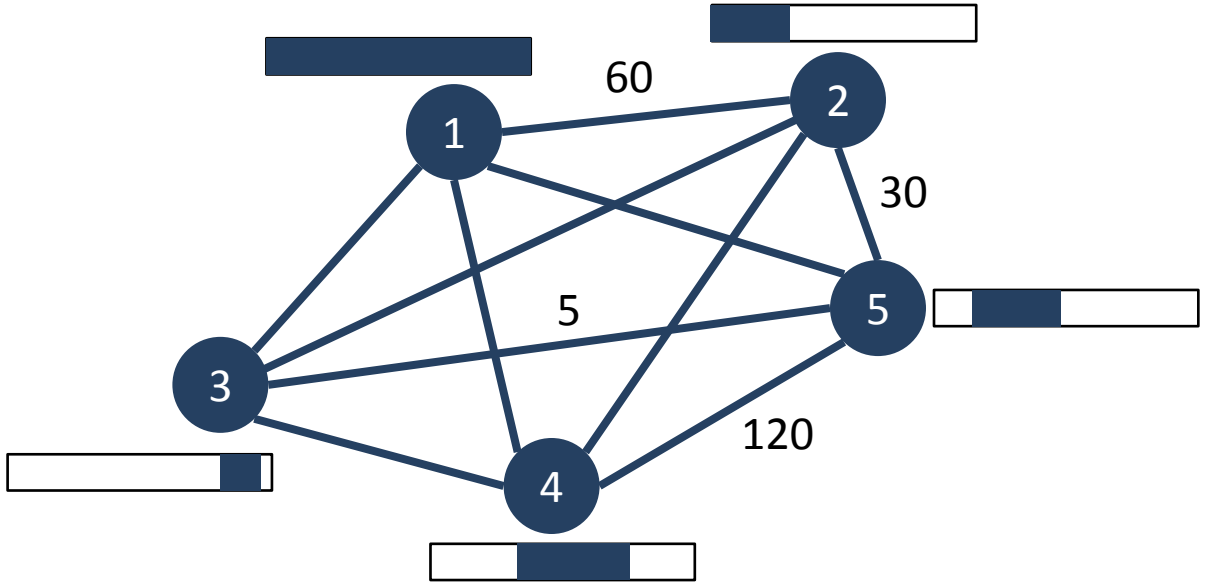
Planning problems – TSPTW

Extension of the TSP: each customer has time windows (TW) in which he can be visited



Planning problems – TSPTW

Extension of the TSP: each customer has time windows (TW) in which he can be visited



What is the shortest route starting and ending at 1 while visiting all other stations and respecting time windows?

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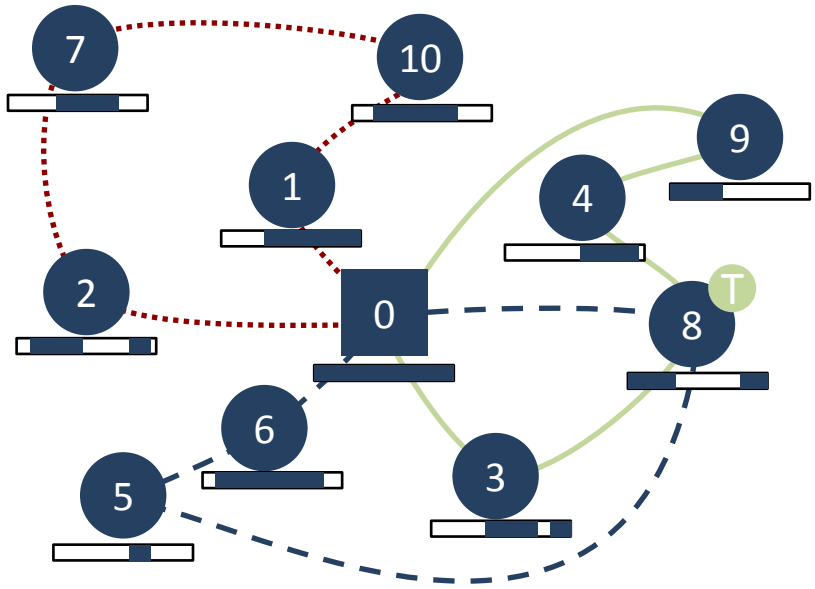
Planning problem of the IPS² delivery

- Multiple customers with multiple time windows
- Multiple service technicians with different qualifications
- Multiple delivery processes with individual delivery times and qualification/tool/spare part requirements
- Team delivery processes

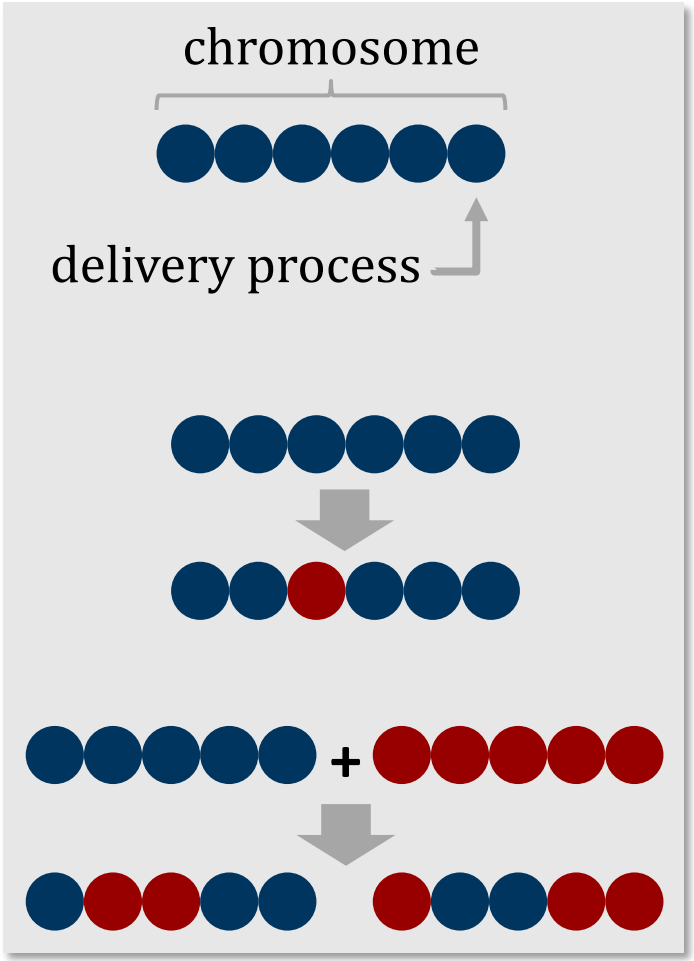


Optimal resource usage with respect to utilization, costs and process punctuality?

Adaptive IPS² planning method

Genetic Algorithm (GA)

- **population** of n individuals
- each individual chromosome represents one **delivery plan**
- each gene represents one **delivery process**
- attached to each gene is information regarding assigned resources, the place of delivery, …
- gene **mutation**: variation of delivery parameters:
  - resource replacement
  - change of transition time
  - variation of delivery process
- **crossover**: interchange of genetic information between two individuals
- **tournament selection** based on fitness value



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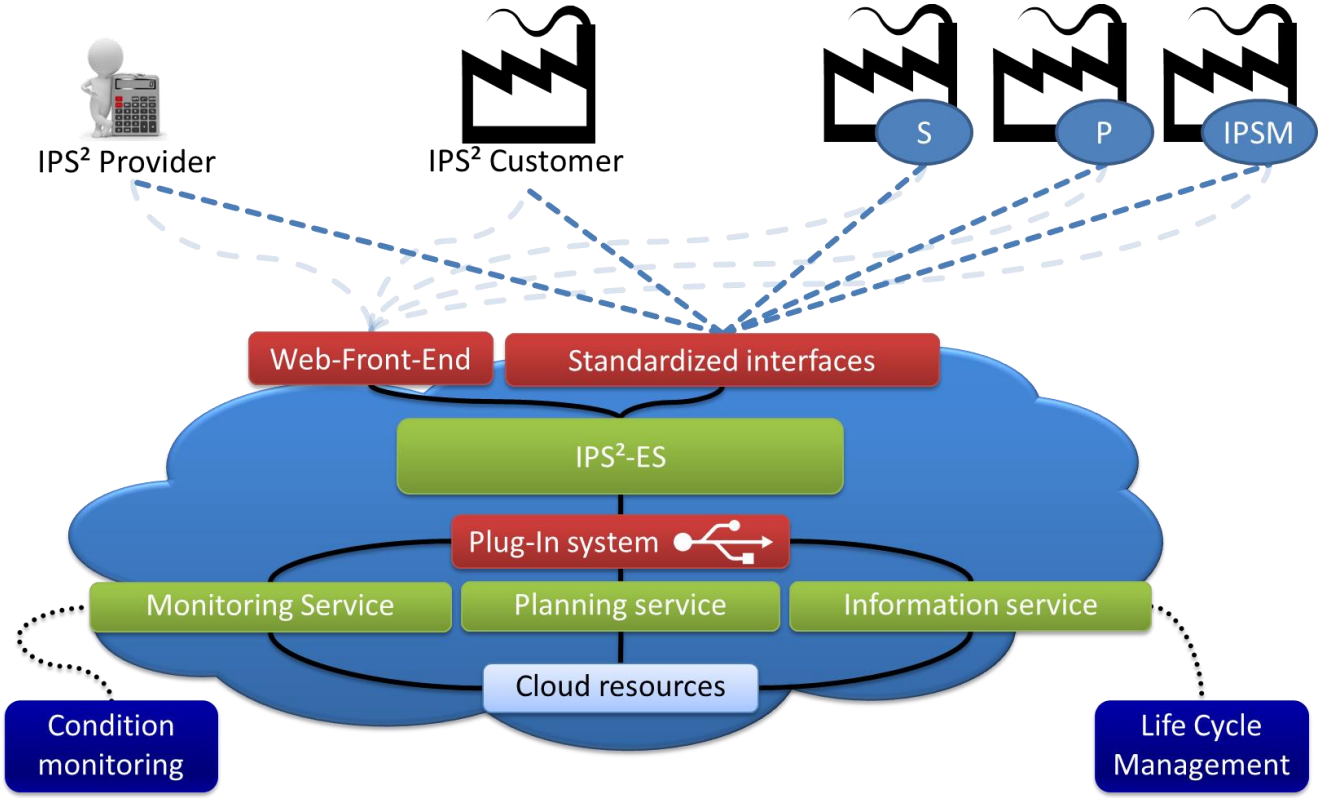
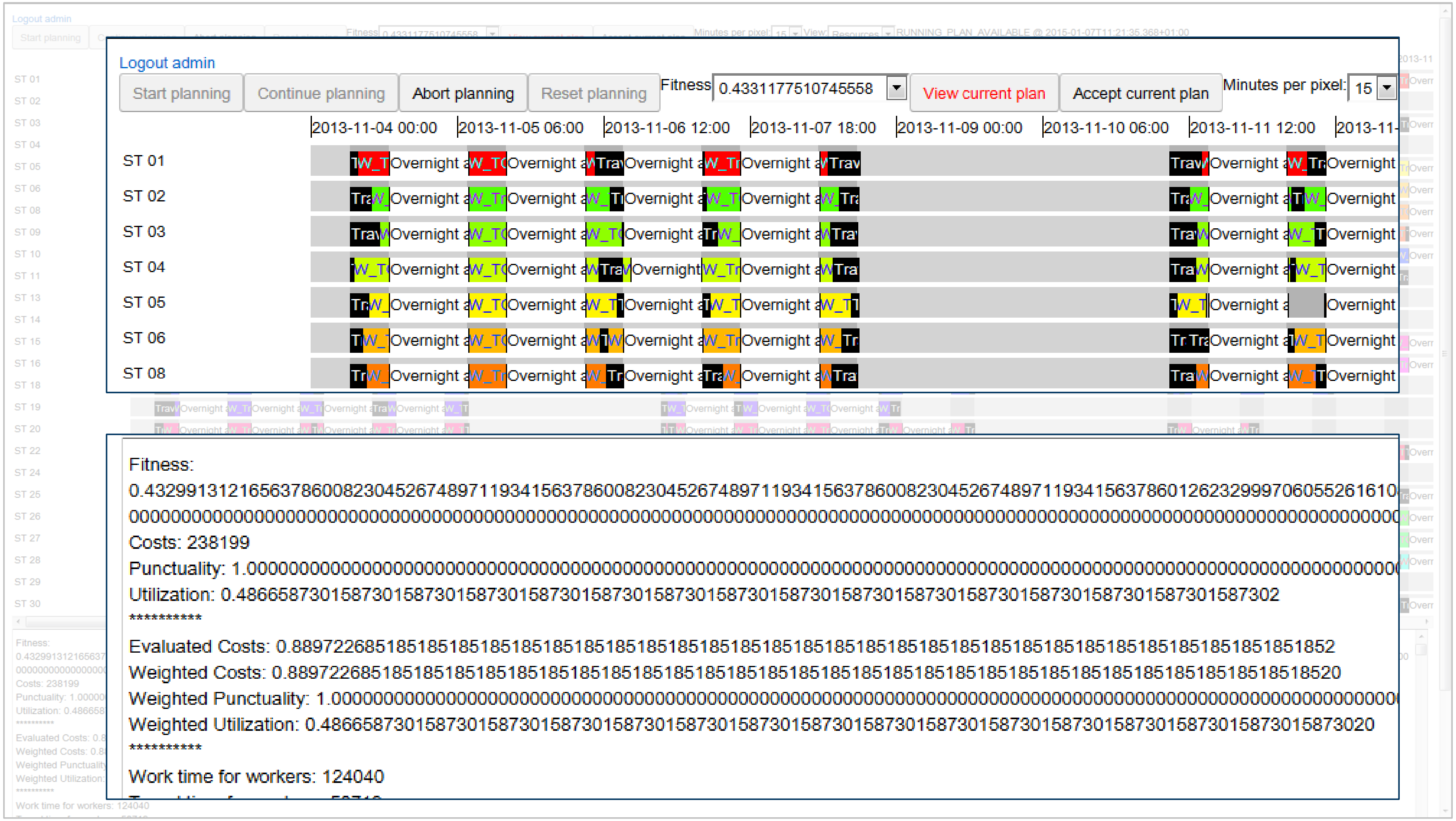
Software prototype: IPS²-Execution System

Java based web application



Meier et al. 2012

Software prototype: IPS²-Execution System



Dorka 2015

Evaluation approaches

AIPM - Algorithm

- *Speed?*
- *Quality?*
- *Applicability?*

Application to TSPTW

- *Artificial problems*
- *Machine vs. Machine*
- *„Sanity check“*

Application in industry

- *Real world cases*
- *Human vs. machine*

Evaluation results TSPTW

Problem set	Best known solution	Adaptive IPS² planning method				
		average of five			best of five	
	RL	*OTD [%]*	*Δ RL [%]*	*T_{CPU} [mm:ss]*	*OTD [%]*	*Δ RL [%]*
rc_201.1	444.54	100.00	0.90	01:19	100.00	0.90
rc_201.2	711.54	96.00	0.40	00:45	96.00	0.40
rc_201.3	790.61	98.06	1.72	03:25	100.00	1.62
rc_201.4	793.64	92.00	0.00	07:03	92.00	0.00
rc_202.1	771.78	99.38	0.86	08:55	100.00	0.46
rc_202.2	304.14	100.00	0.00	28:23	100.00	0.00
rc_202.3	837.72	89.29	0.22	23:22	89.29	0.22
rc_202.4	793.03	99.26	1.79	15:35	100.00	0.10
rc_203.1	453.48	100.00	4.01	01:48	100.00	0.00
rc_203.2	784.16	97.50	2.74	25:28	100.00	3.49
rc_203.3	817.53	95.00	4.38	24:29	97.22	1.54

RL = route length
OTD = on time delivery
T_{CPU} = computing time

Best solution always found, but rather long computing time

Good solution always found after short time

Evaluation results TSPTW

Problem set	Best known solution	Adaptive IPS² planning method				
		average of five			best of five	
	RL	*OTD [%]*	*Δ RL [%]*	*T_{CPU} [mm:ss]*	*OTD [%]*	*Δ RL [%]*
average	*634.75*	*98.14*	*3.25*	***17:02***	*98.85*	*1.37*

RL = route length
OTD = on time delivery
T_{CPU} = computing time

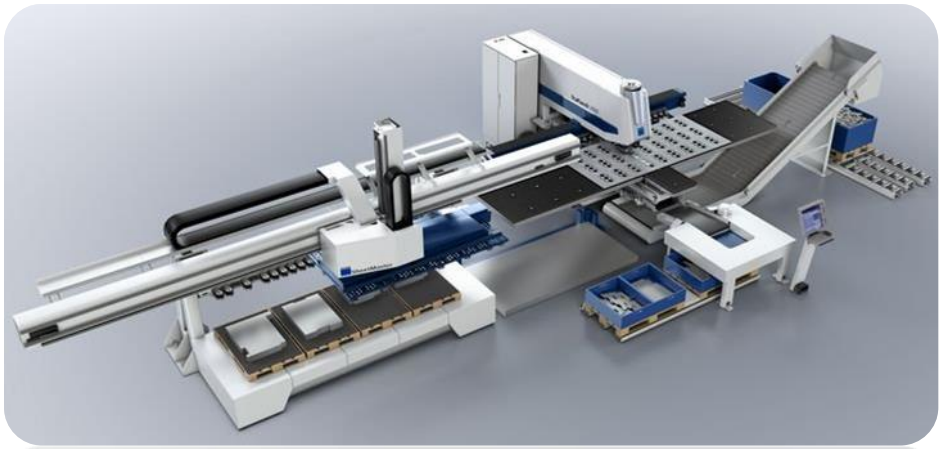
AIPM is not optimized for this class of problems, yet finds feasable solutions with respect to costs and punctuality

- Acceptable on time delivery (OTD)
- Small route length (RL) deviation
- Very long computing time (other algorithm solve the problems in seconds/milliseconds)

Evaluation in industry

TRUMPF Werkzeugmaschinen GmbH & Co. KG Germany

- production technology for sheet metal shaping
- lifecycle-spanning service activities
- more than 1000 highly skilled service technicians worldwide, cooperation with external service partners



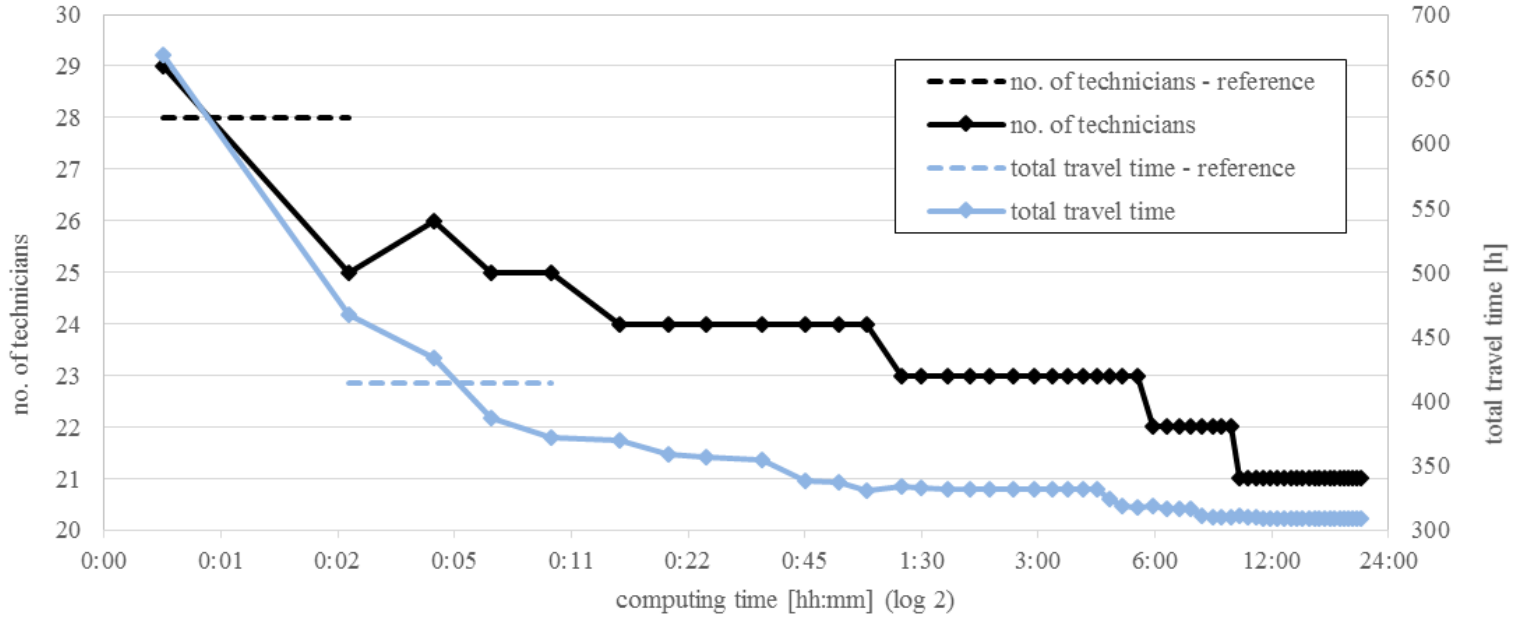
www.trumpf.com

Evaluation approach in industry

- Reference result: **manually created delivery plan**
- **118 scheduled maintenance processes** for one month with different skill requirements
  - 4 processes require two technicians
  - 1 process requires three technicians
  - 7 processes require specialized skills
- **30 technicians**, each capable of executing about 90% of the processes
- **Simplifications**:
  - Same costs for ressources
  - no vocations/sick days
  - No spare parts/tools considered
  - All IPS² available for service during the whole planning period

Evaluation results at TRUMPF

- Intel Xeon CPU (E5645, 8 cores, 2.4 GHz, 23.4 GB RAM)
- **Less technicians after 2 minutes** of planning time
- **Less travel time after 7 minutes** of planning time
- Best solution: **292h travel time, 19 technicians** (vs. 414h, 28 technicians)



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Discussion and outlook

- AIPM can be applied to industrial planning problems
- AIPM generates feasible solutions
- AIPM is slow in comparison to optimized problems solvers → optimization of algorithm towards speed is required

- Application of the AIPM to even more complex planning problems with tools and spare parts
- Improve planning algorithm

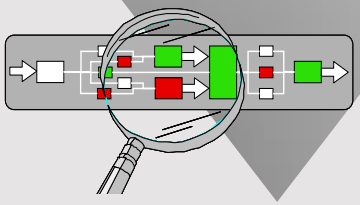
Strategic vs. operational planning

Planning of required resources

(capacity level)

Level of detail

Detailed planning, including scheduling delivery processes

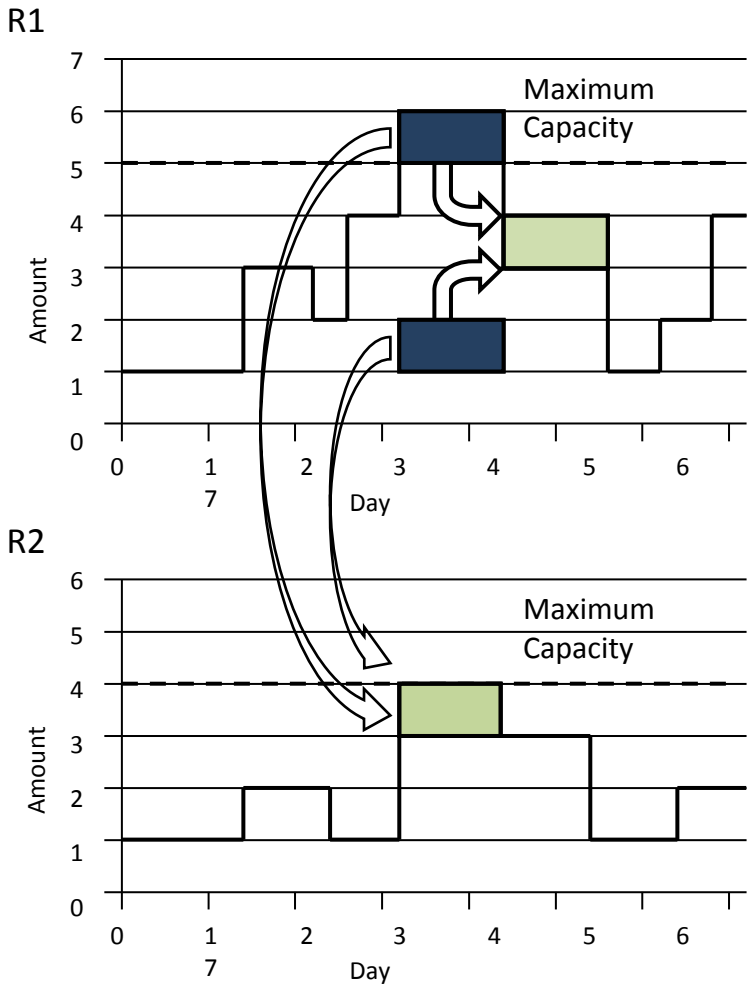


Planning problem of the IPS² delivery

IPS²-variances:

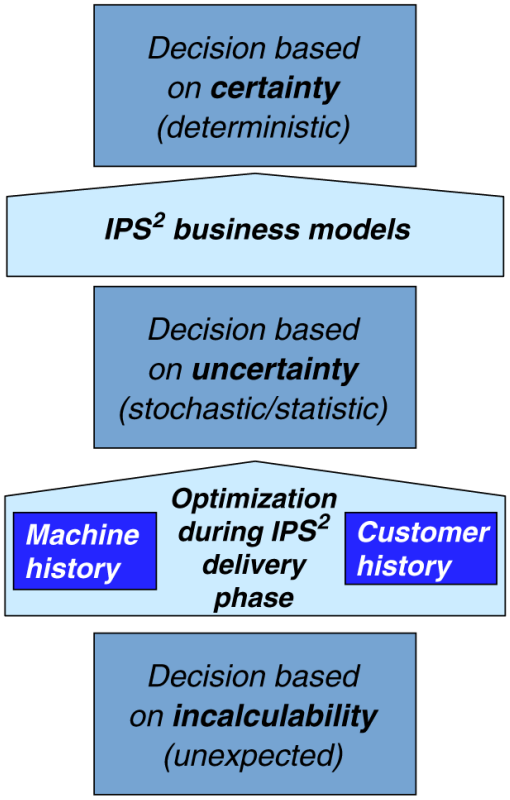
- variance in time;
- variance of resources;
- variance of processes or partial substitution of product and service shares;
- variance of transition time;
- service distribution or integration of customers' resources;

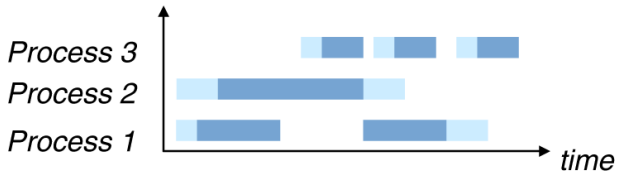
Complex opportunities for optimization

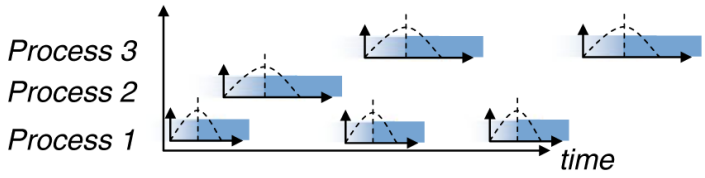


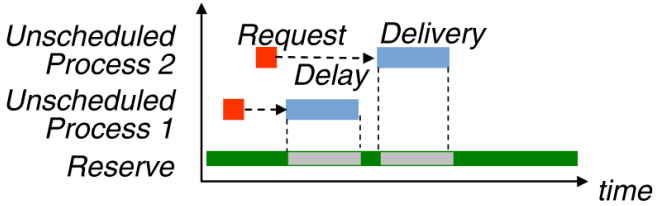
Adaptive IPS² planning method

From unexpected to deterministic:









Meier et al. 2011

Evaluation approach TSPTW

1. Find existing problem sets with best known solutions available on the internet (POTVIN and BENGIO 1996)
2. Convert problem sets into AIPM compatible format
3. Run parameter studies (GA)
4. Execute multiple planning runs
5. Analyze results
6. Compare with benchmarks

Evaluation results TSPTW

Problem set	Best known solution	Adaptive IPS² planning method				
		average of five			best of five	
	RL	*OTD [%]*	*Δ RL [%]*	*T_{CPU} [mm:ss]*	*OTD [%]*	*Δ RL [%]*
rc_203.4	314.29	100.00	3.98	14:23	100.00	0.00
rc_204.1	892.50	94.22	8.02	31:41	97.78	1.85
rc_204.2	662.16	98.75	6.43	26:01	100.00	3.70
rc_204.3	455.03	100.00	4.30	25:24	100.00	4.03
rc_205.1	343.21	100.00	2.90	05:42	100.00	2.90
rc_205.2	755.93	94.62	5.92	24:13	96.15	2.60
rc_205.3	825.06	97.06	4.04	13:49	97.06	3.38
rc_205.4	760.47	98.52	2.18	03:10	100.00	2.46
rc_206.1	117.85	100.00	0.00	00:00	100.00	0.00
rc_206.2	828.06	100.00	3.80	31:36	100.00	1.26
rc_206.3	574.42	100.00	1.86	06:59	100.00	0.00
rc_206.4	831.67	95.14	6.61	36:16	100.00	1.99
rc_207.1	732.68	100.00	1.08	21:43	100.00	0.19
rc_207.2	701.25	100.00	0.90	36:01	100.00	0.67
rc_207.3	682.40	99.38	6.43	22:02	100.00	1.08
rc_207.4	119.64	100.00	0.00	00:00	100.00	0.00

RL = route length
OTD = on time delivery
T_{CPU} = computing time

Best known solution was not found and average solutions are not very good and found slowly