Optimization of Schedules of a Multi Task Production Cell

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CHALMERS

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VOLVO AERO

In cooperation with

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- Michael Patriksson, Mathematical Sciences, Chalmers and University of Gothenburg
- Torgny Almgren, Volvo Aero, Trollhättan

The Multi Task Production Cell

Background

- An investment made by Volvo in order to
  - decrease product cost
  - shorten lead times
  - increase the quality level and delivery precision
- Master thesis 2006:
  - Built-in scheduling algorithms does not suit Volvo Aero production
  - Optimization of the production schedule is hard

⇨ Industrial PhD student project financed by Vetenskapsrådet and Volvo Aero

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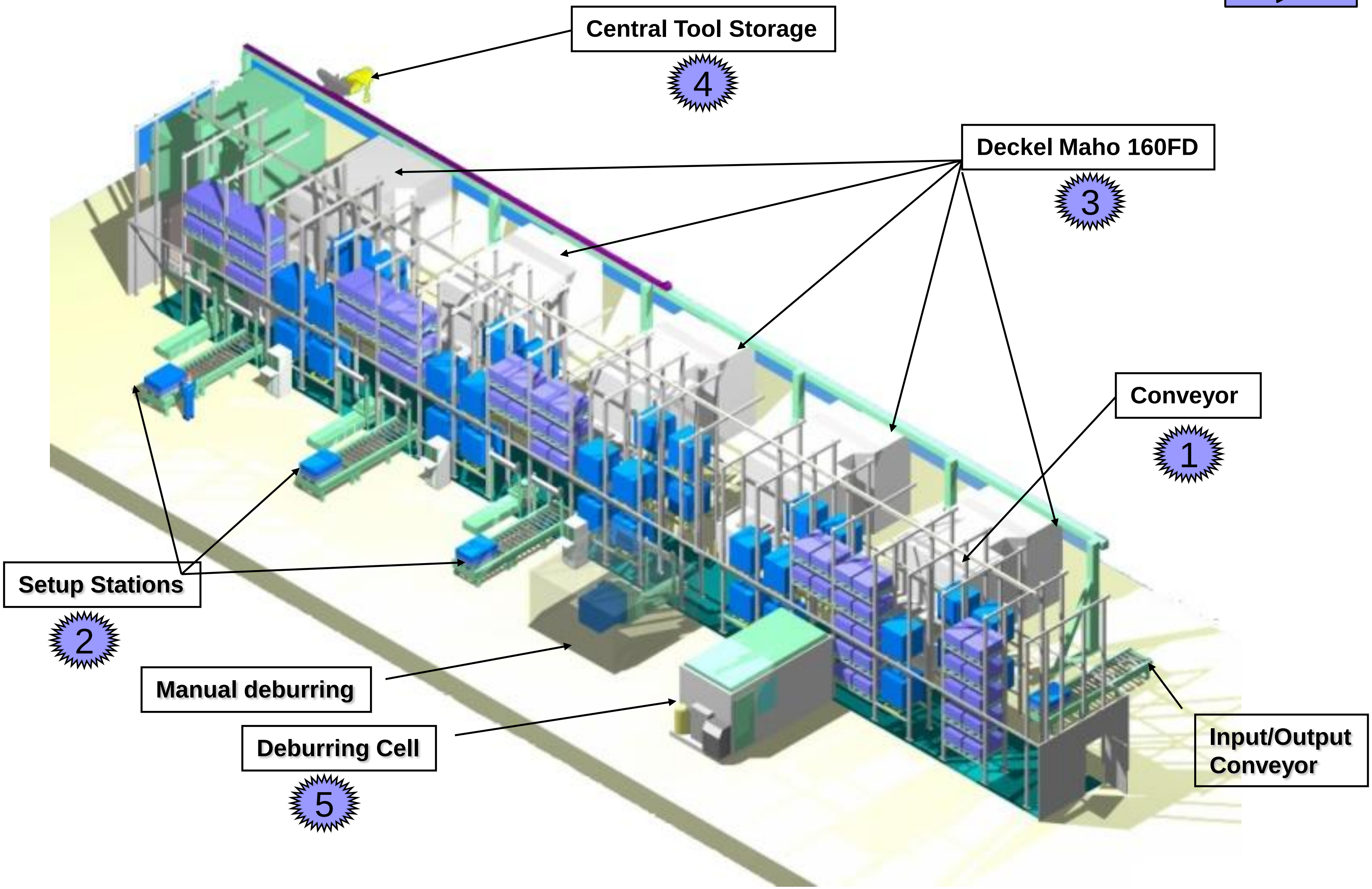
Parts processed in the Multi Task Cell

~ 7 compressor rear frames for different aero engines and gas turbines.
About 40 different jobs are processed in the Multi Task Cell.

Parts about 1 m in diameter.


Central Tool Storage
4
Deckel Maho 160FD
3
Conveyor
1
Setup Stations
2
Manual deburring
Deburring Cell
5
Input/Output Conveyor

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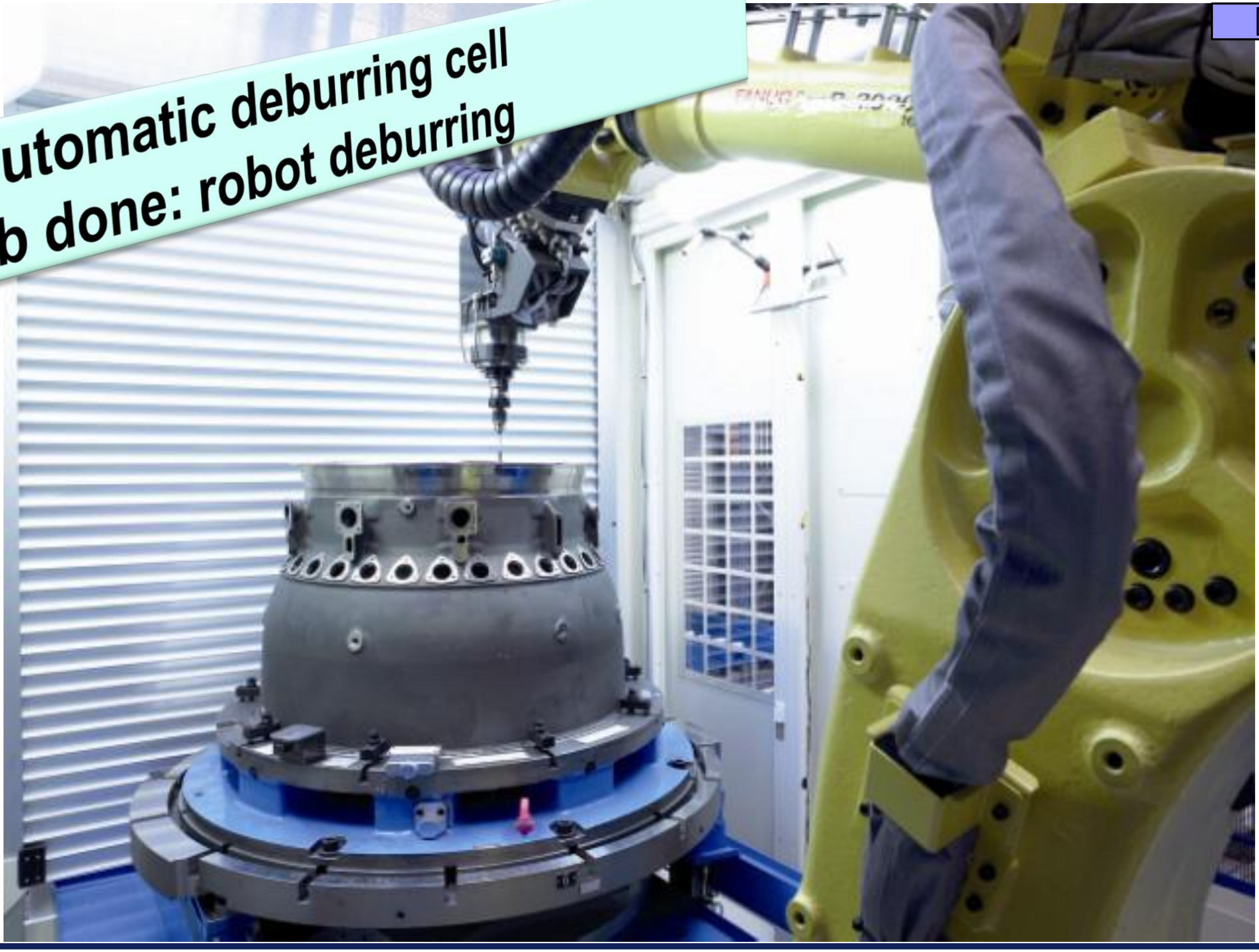
Conveyor
Job done: transports between storage and route operations

3 setup stations
Job done: mount/demount into fixtures

Central Tool Storage
Job done: collecting the right tools for coming machining operations

5 Multi Task machines
Job done: Drilling, milling and turning

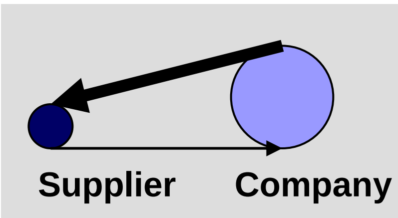
1 automatic deburring cell
Job done: robot deburring

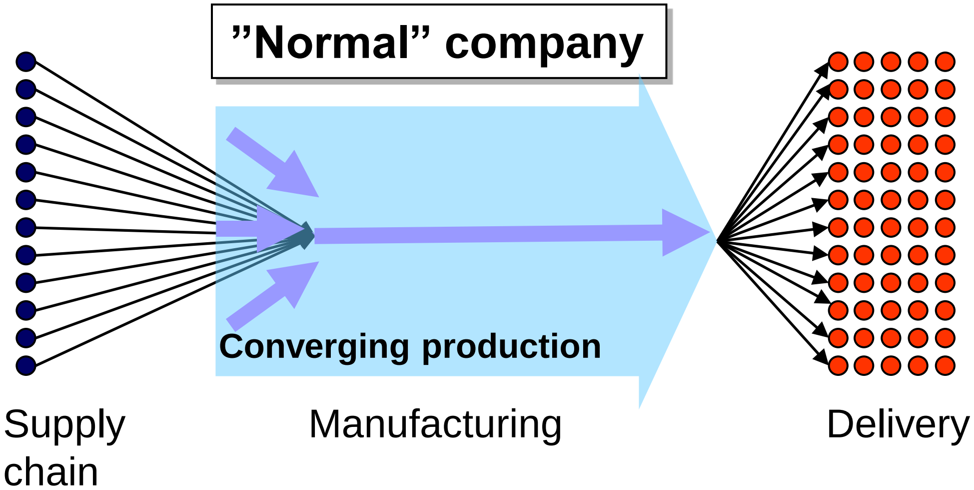


The logistic reality of Volvo Aero

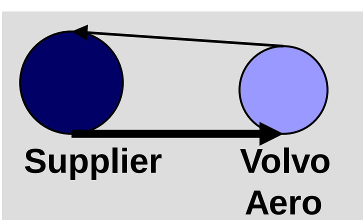
The ”normal” logistic environment

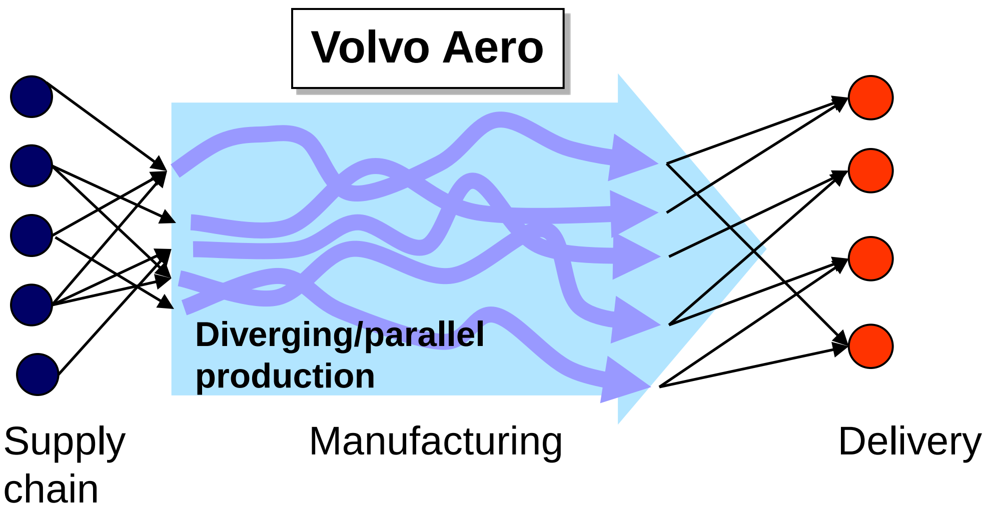
- Many suppliers
- One assembly line
- Many customers
- Possibility to sell out excess stock





- Few big suppliers
- Complex product flow
- Few big customers
- Difficult to get rid of excess stock





The routing operations of the MT-cell

Every production order follows a routing in the planning system (R/3)

One job in the MT cell ↔ 3-5 route operations controlled by ”Fastems” system

R/3

2008-11-25	*V:00450878*	*BSC Frame Compr, Assy*			
Operation	Descr.	WC-No	Work Ce	Process	Setup
100	START	8840	9472 540	[illegible]	
200	FN	9604	9423 152	[illegible]	
300	GR	8837	9471 250	[illegible]	
[illegible]	TVÄ	9067	9444 270	[illegible]	
500	PROPFL	9081	9444 531	[illegible]	
600	KON	9042	9443 53241 MÄTMASKINSKONTROLL	[illegible]	
700	M SVTIG	8845	9424 70000 SVETSAGGREGAT	5.5	
800	MTC	9767	9471 15206 MTC	4.5	
900	MTC	9767	9471 15206 MTC	4	
1060	KON	8840	9472 54040 KONTROLL	0.5	
1100	TVÄ	9132	9451 27044 MASKINTVÄTT DARACLEAN 282	0.3	
1200	SVES	8130	9424 23284 04 EB-SVETS NC SCIAKY VX-86-4	3.3	
1300	SV	8831	9424 23045 03 SVETSMASKIN	3.0	
1400	MTC	9767	9471 15206 MTC	11.0	
1450	MTC	9767	9471 15206 MTC	2.0	
1500	FNC	9604	9423 15206 11 NC-FRÄSMASKIN MOD	21.6	
1600	GR	8837	9471 25020 GRADA	2.4	
1700	TVÄ	9067	9444 27043 70 STORA TVÄTTMASKIN	1.9	
1800	PROPFL	9081	9444 53103 PENETRANT, FLOURECERANDE	5.4	
2000	PRORAD	9085	9444 53161 RADIOGRAFISK PROVNING	20.3	
2200	TVÄ	8950	9441 27043 Luttvätt/Ultraljud	2.7	

Fastems

Route for op 800:

Operation	**time**
mount	**0,5**
machining	**3,1**
manuel deburring	**0,6**
demount	**0,3**

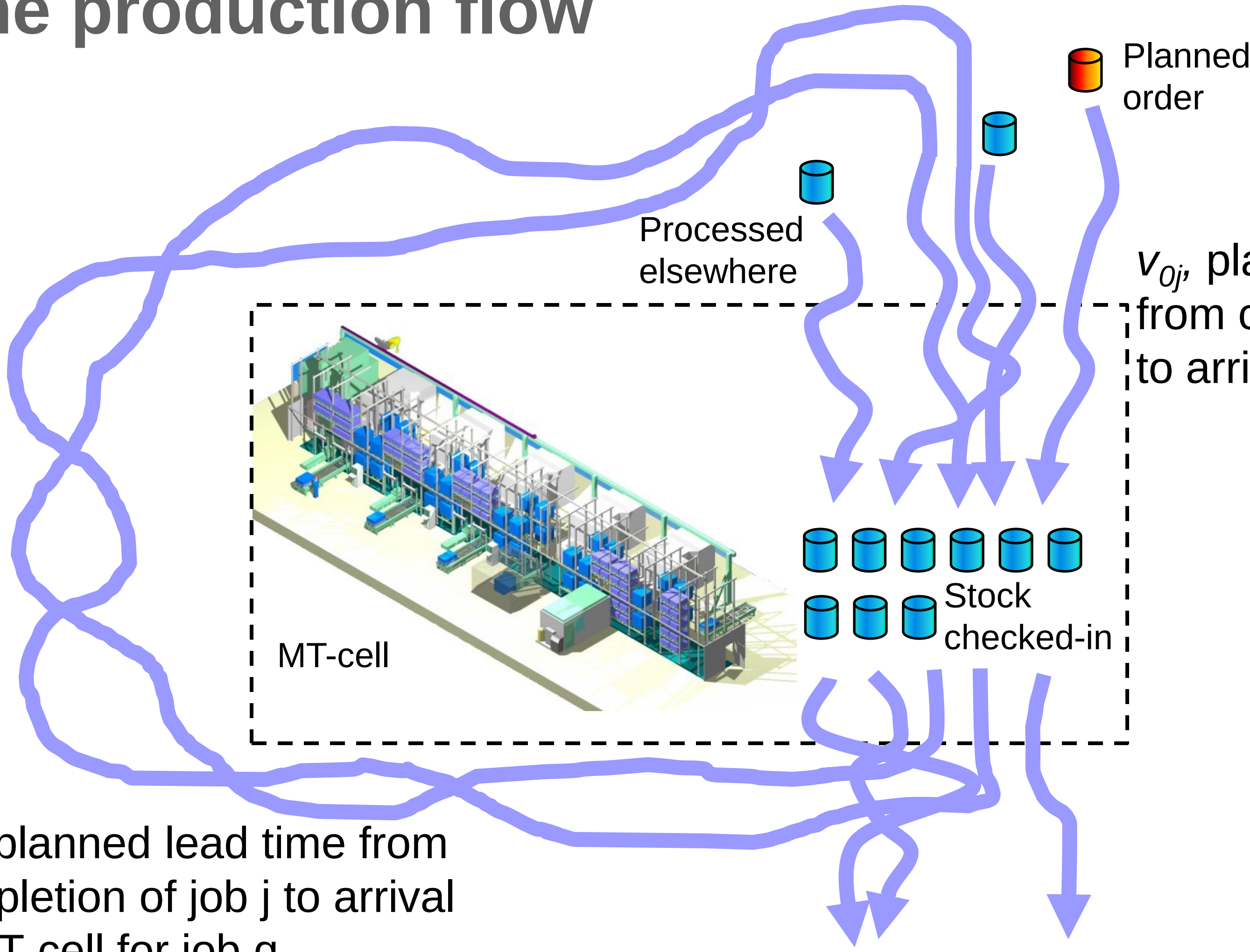
Fastems

Route for op 1400:

Operation	**time**
mount	**0,9**
machining	**9,5**
demount	**0,6**

No real data

The production flow

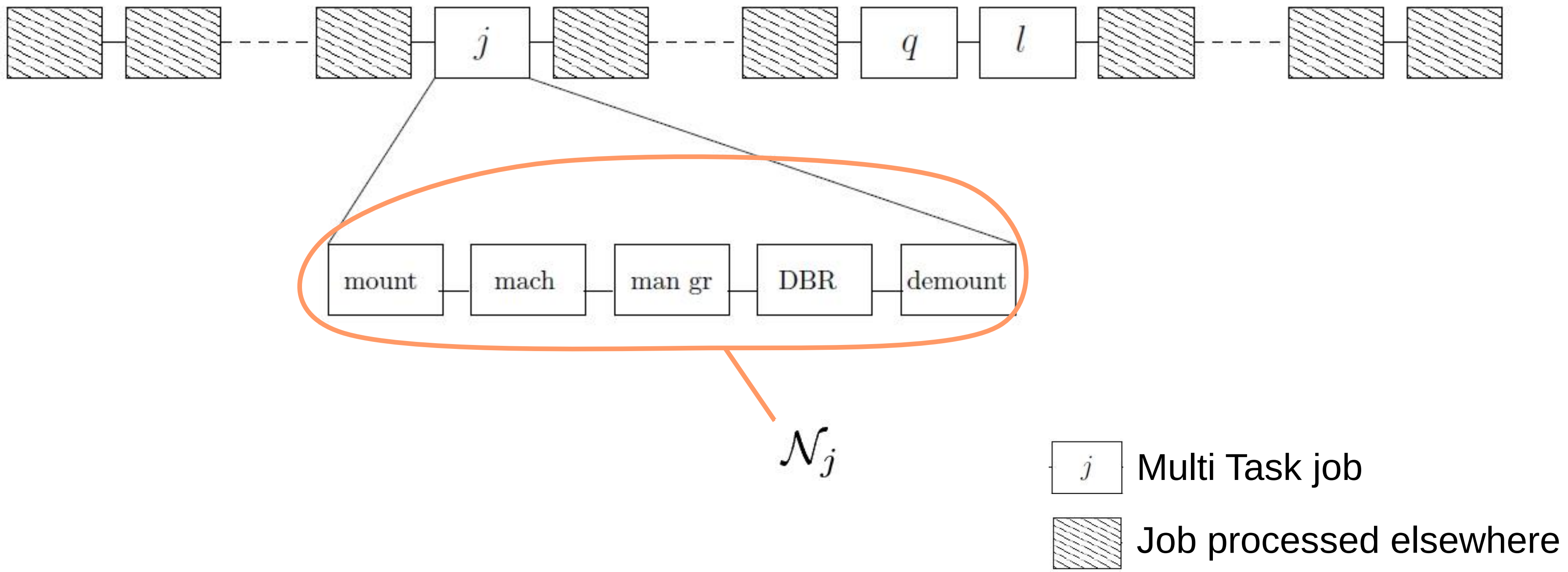


v_{0j}, planned lead time from current position to arrival at MT-cell

v_{jq} , planned lead time from completion of job j to arrival at MT-cell for job q

Sets and indices

$$i \in \mathcal{N}_j = \{1, ..., n_j\}, \text{ set of route operations}$$
$$j \in \mathcal{J}, \text{ set of jobs}$$
$$(j, q) \in \mathcal{Q}, \text{ set of pairs of subsequent jobs}$$
$$k \in \mathcal{K}, \text{ set of resources}$$



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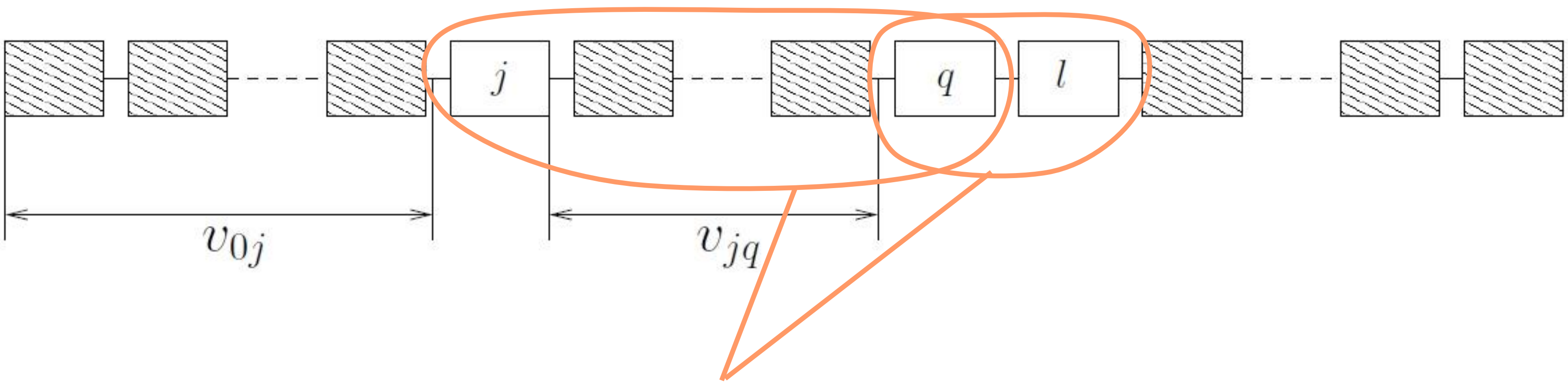
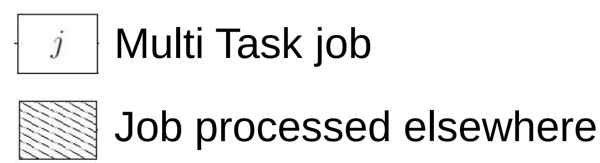


(j, q) and $(q, l) \in Q$

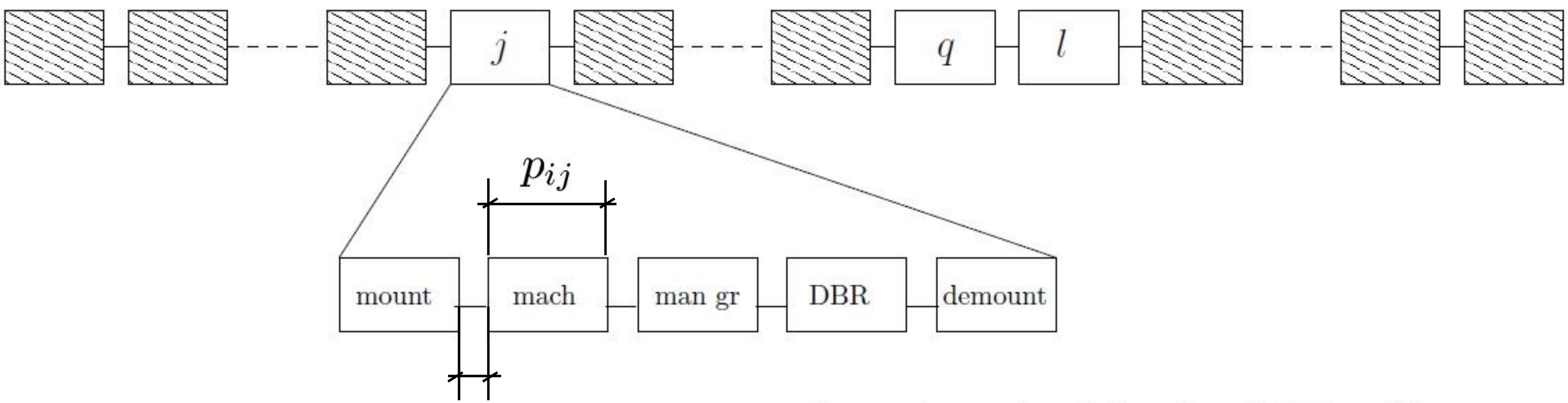


Parameters

$$\lambda_{ijk} = \begin{cases} 1, & \text{if op } (i,j) \text{ can be processed on } k \\ 0, & \text{otherwise} \end{cases}$$

a_k : k available the first time

p_{ij} : processing time for op (i,j)



w : transportation time inside the MT-cell

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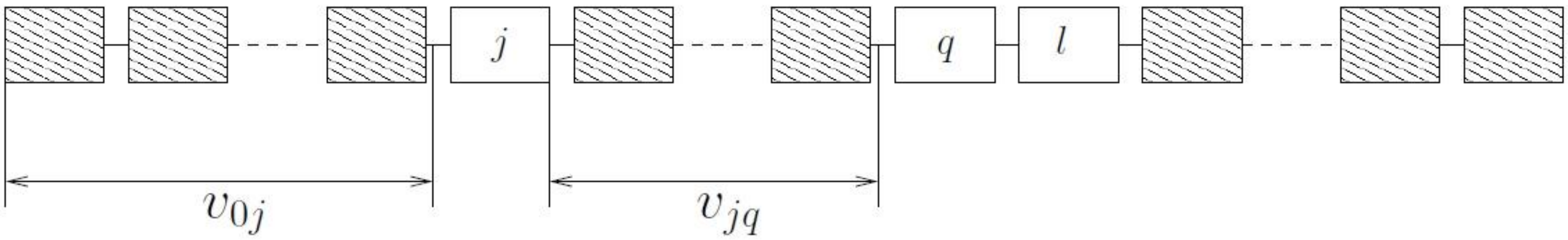
Parameters cont'd

r_j : release date for job j
d_j : due date of job j
v_{jq} : planned lead time between job j and job q, $(j,q) \in \mathcal{Q}$



If order checked-in: $r_j = r_q = r_l = 0$
Else: $r_j = r_q = r_l = max$ (date available (v_{0j}); planned release date)

Variables

- Binary variables

$$z_{ijk} = \begin{cases} 1, & \text{if op } (i,j) \text{ scheduled on } k, \\ 0, & \text{otherwise.} \end{cases}$$

$$y_{ijpqk} = \begin{cases} 1, & \text{if op } (i,j) \text{ processed before op } (p,q) \text{ on } k, \\ 0, & \text{otherwise.} \end{cases}$$

- Time variables

$$t_{ij} = \text{starting time}$$

$$s_j = t_{n_j,j} + p_{n_j,j}, \text{ completion time of job } j.$$

$$h_j = \begin{cases} s_j - d_j, \text{ if positive, i.e. the tardiness of job } j, \\ 0, \text{ otherwise.} \end{cases}$$

The optimization model of the MT-cell

weight (A=1)

$$\text{Minimize} \quad \sum_{j \in J} (s_j + A h_j)$$

The sum of completion times and tardiness, i.e. every job is done as early as possible and tardiness is punished.

$$\text{subject to} \quad \sum_{k \in \mathcal{K}} z_{ijk} = 1,$$

One route operation is scheduled only once

$$z_{ijk} \leq \lambda_{ijk},$$

Operation assigned to an allowed resource k

$$y_{ijpqk} + y_{pqijk} \leq z_{ijk},$$

$$y_{ijpqk} + y_{pqijk} + 1 \geq z_{ijk} + z_{pqk},$$

These two constraints regulates the ordering of the operations for a resource k

$$t_{ij} + p_{ij} - M(1 - y_{ijpqk}) \leq t_{pq},$$

Starting time (p,q) after compl. time (i,j) if same k

Big number

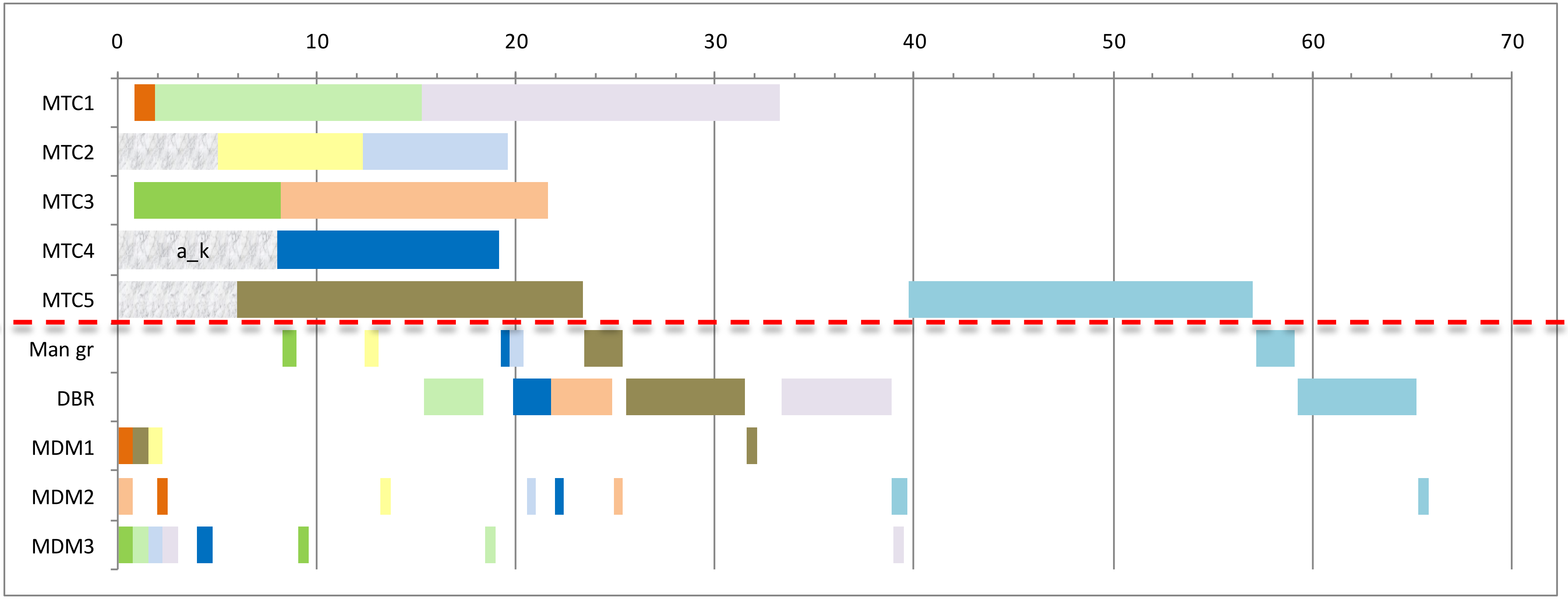
To be cont'd…

The optimization model cont'd

$t_{ij} + p_{ij} + w \leq t_{i+1,j},$	Operation processed and transported before next
$t_{1j} \geq r_j,$	Job may be started after release date
$t_{1j} \geq a_k z_{1jk},$	Resource *k* available first time
$t_{1q} \geq s_j + v_{jq},$	Job *q* may be started after completion of job *j* + planned lead time
$s_j = t_{n_j j} + p_{n_j j},$	Definition of completion time
$h_j \geq s_j - d_j,$ $h_j \geq 0,$	Definition of tardiness
$t_{ij} \geq 0,$	Positive starting times
$z_{ijk} \in \{0,1\},$ $y_{ijpqk} \in \{0,1\},$	Binary variables

Computational results

Optimal solution for 10 jobs



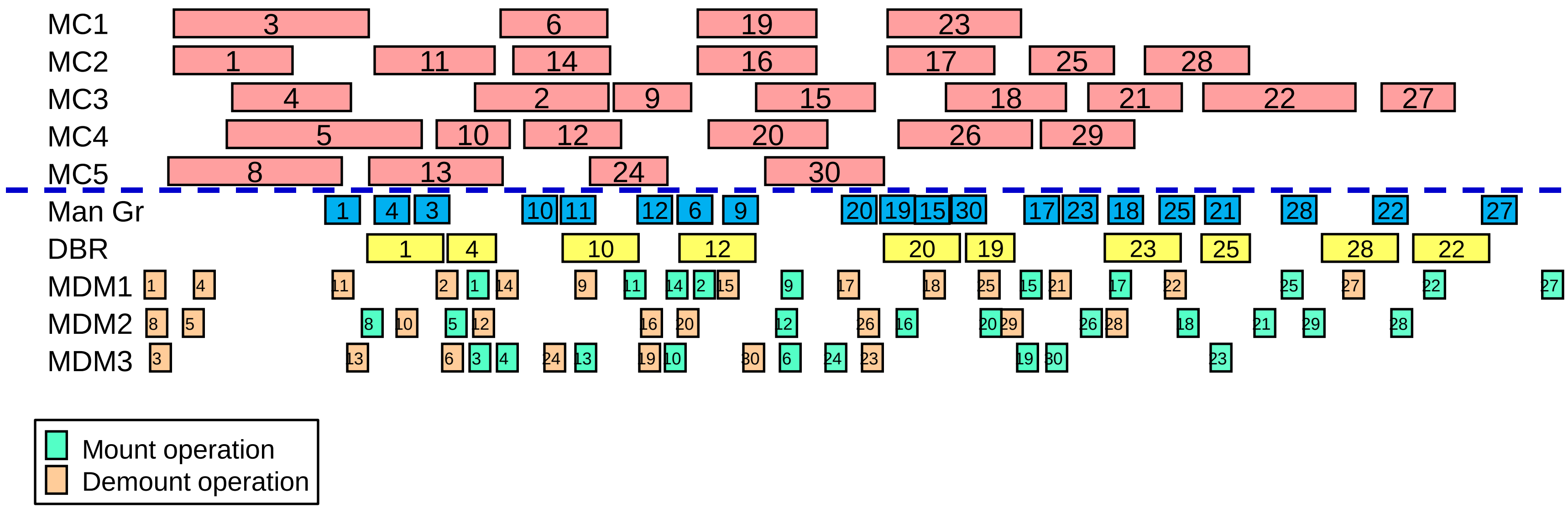
Division into two models

Too high CPU times for the whole model (AMPL-CPLEX11)

- The processing times of the machining resources >> other route operations
- Machining resources most heavy investments

The model divided into two models:

- The **machining model** optimizes the schedule of the machining resources MC1-5
- The **feasibility model** finds a feasible schedule for the rest of the route operations



The machining problem

$$
\begin{aligned}
\text{Minimize} \quad & \sum_{j \in J} (s_j^m + h_j^m) \\
\text{subject to} \quad & \sum_{k \in \mathcal{K}} z_{jk}^m = 1, \\
& z_{jk}^m \leq \lambda_{jk}^m, \\
& y_{jqk}^m + y_{qjk}^m \leq z_{jk}^m, && j \neq q,\ j,q \in \mathcal{J}, \\
& y_{jqk}^m + y_{qjk}^m + 1 \geq z_{jk} + z_{qk}, && j \neq q,\ j,q \in \mathcal{J}, \\
& t_j^m + p_j^m - M(1 - y_{jqk}^m) \leq t_q^m, && j \neq q,\ j,q \in \mathcal{J}, \\
& t_j^m \geq r_j^m, \\
& t_j^m \geq a_k z_j k^m, \\
& t_q^m \geq s_j^m + v_{jq}, && j, q \in \mathcal{Q}, \\
& s_j^m = t_j^m + p_j^m + p_j^{pm}, \\
& h_j^m \geq s_j^m - d_j^m.
\end{aligned}
$$

The feasibility model

$$\text{Minimize} \quad \sum_{j \in \mathcal{J}} (s_j + h_j) + B \left(\sum_{j \in \mathcal{J}} \sum_{i \in \mathcal{N}_j} \left(1 - \sum_{k \in \mathcal{K}} z_{ijk} \right) \right)$$

weight (B=100)

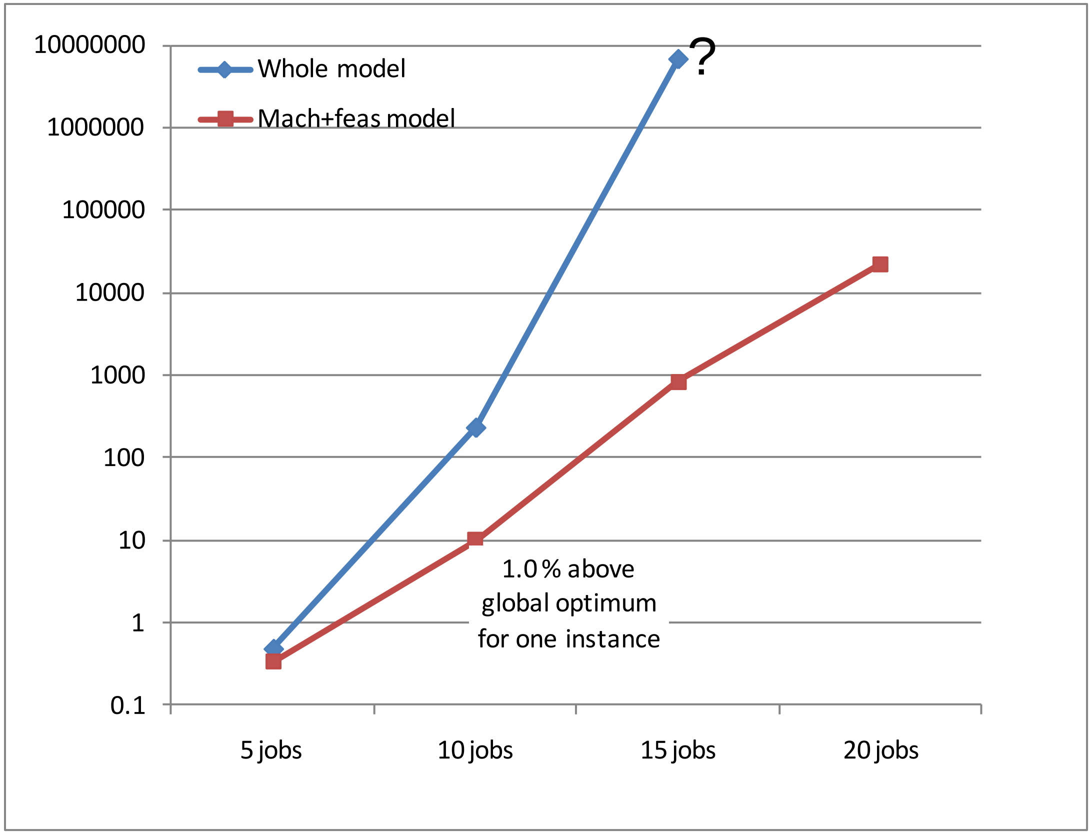
operations not scheduled

$$\begin{aligned}
\text{subject to} \quad \sum_{k \in \mathcal{K}} z_{ijk} &\leq 1, \\
z_{ijk} &\leq \lambda_{ijk}, \\
y_{ijpqk} + y_{pqijk} &\leq z_{ijk}, && (i,j) \neq (p,q), \\
y_{ijpqk} + y_{pqijk} + 1 &\geq z_{ijk} + z_{pqk}, && (i,j) \neq (p,q), \\
t_{ij} + p_{ij} - M(1 - y_{ijpqk}) &\leq t_{pq}, && (i,j) \neq (p,q), \\
t_{ij} + p_{ij} + w &\leq t_{i+1,j}, && i \in \mathcal{N}_j \setminus \{n_j\}, \\
t_{1j} &\geq r_j, \\
t_{1j} &\geq a_k z_{1jk}, \\
t_{1q} &\geq s_j + v_{jq}, && j, q \in \mathcal{Q}, \\
s_j &= t_{n_j j} + p_{n_j j}, \\
h_j &\geq s_j - d_j, \\
z_{2jk} &= z_{jk}^m, \\
t_{2j} &= t_j^m.
\end{aligned}$$

Fixed to solution from machining problem

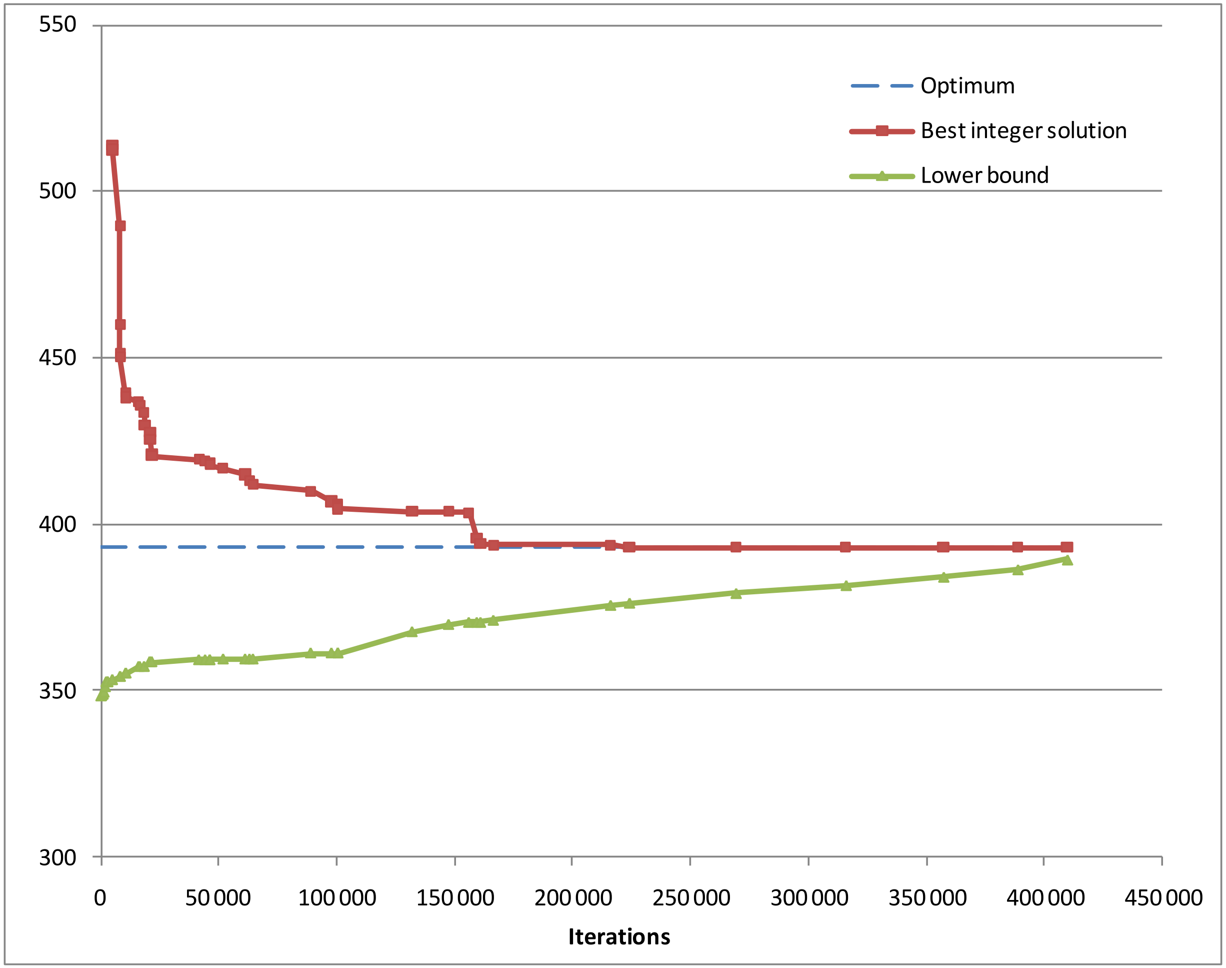
Computational results

Comparison of the CPU times of the 2 models



Computational results

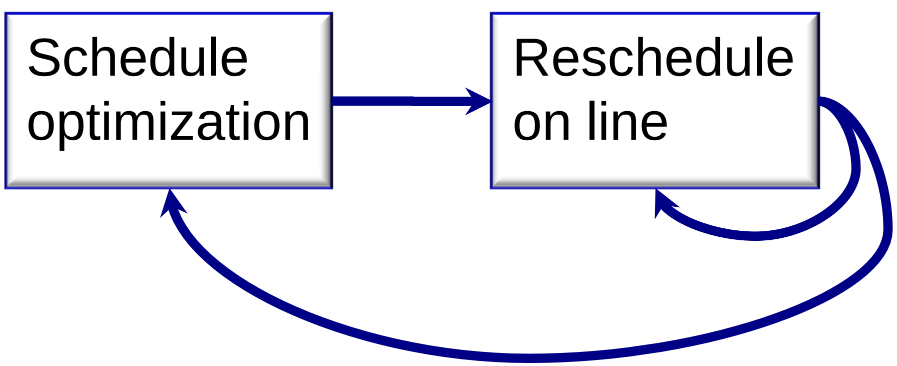
The way to optimality, 10 jobs, whole model



Coping with reality

As soon as the production schedule is optimized – something changes!

- New details in the queue with high priority
- Machine breakdown
- Operator sick
- Part with non-conformance leaves queue
- etc.



Frequency:	week	shift
CPU time:	< 2 h	< 15 min

Continued research

- Compare the computational differences between different problem formulations, i.e. discrete time steps vs continuous time variables
- Constraint programming
- Lagrange relaxation to get better lower bounds
- Other decompositions
- More realistic model: fixtures, shifts etc.
- Find best objective function
- …

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Questions and comments?

Thankyou

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