Operation optimization at DSB S-tog

- The Copenhagen suburban railway operator

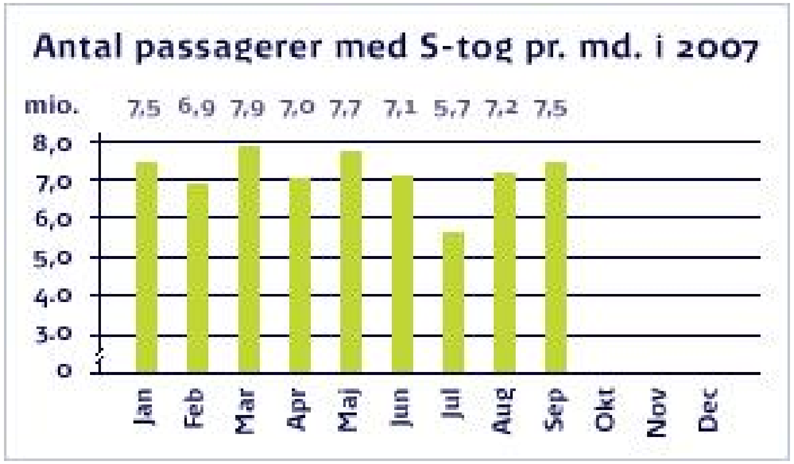
Julie J. Groth
Ph.D. Student
DSB S-tog a/s

Agenda

- Intro to S-tog
- Planning process
- Rolling stock planning
- Crew planning

Figures on S-tog

- Major supplier of rail traffic in the greater Copenhagen area
- More than 300,000 passengers daily
- Annual turnover is more than 2,600,000,000



Production planning

- Part of Production Division

- Staff a mixture of experienced planners with traffic experience, dispatchers and staff with academic background

    - 10 crew planners
    - 5 rolling stock planners
    - 9 rolling stock dispatchers
    - 7 academic analysts/developers
        - 1 partly funded ph. d. student
    - 3 IT-supporters
    - 4 managers

Resources at DSB S-tog

170 km double tracks

84 stations

104 “1/1” train units, 336 seats

31 “1/2” train units, 150 seats

Approx. 550 drivers

˜1200 departures on a daily basis

84 “1/1” train units + 2 standby

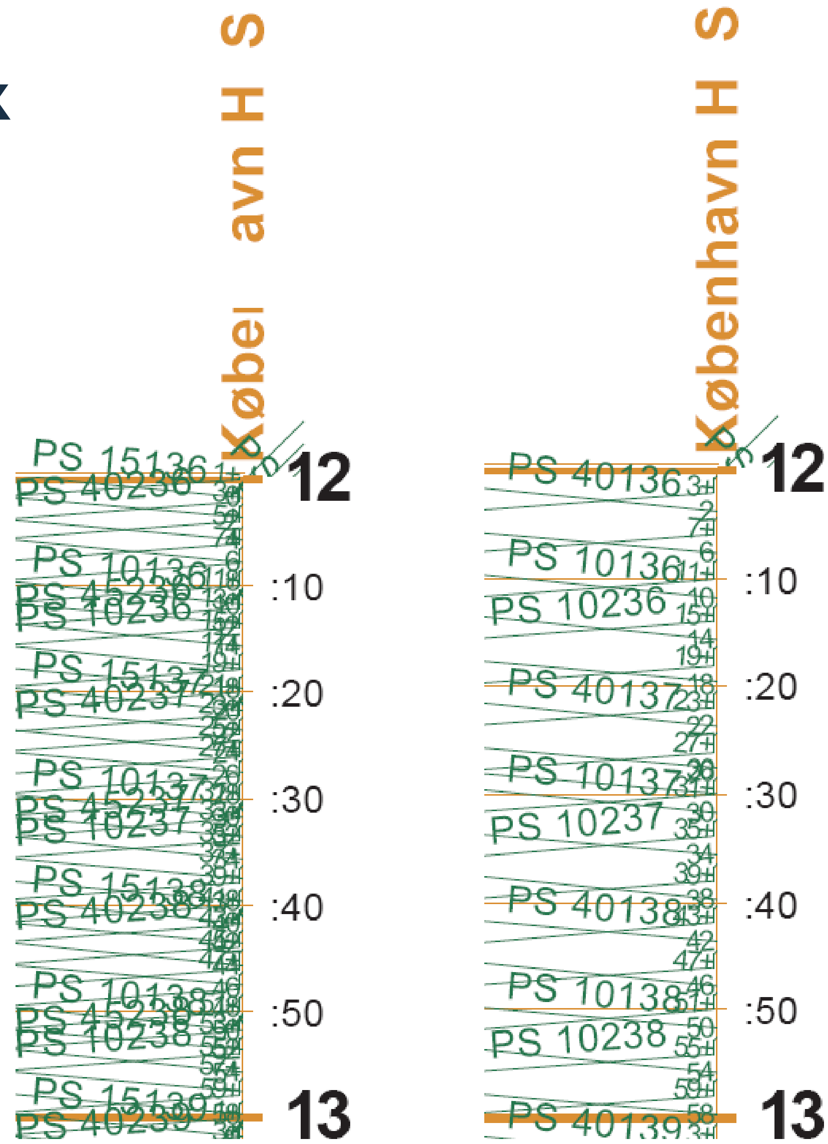
26 “1/2” train units + 1 standby

Approx. 250 drivers incl. standbys

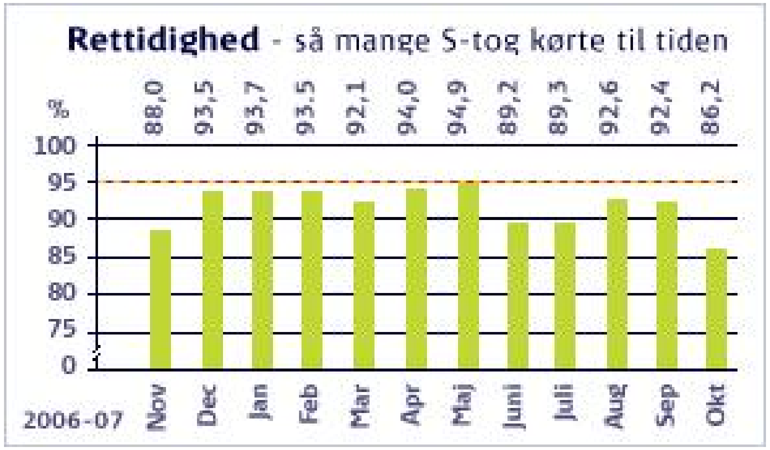
Depots and maintenance

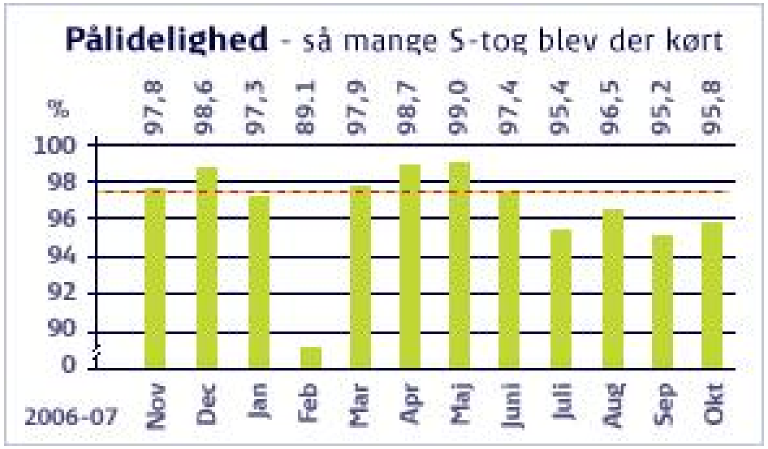
- Rolling Stock depots at line terminals and Central station
- Crew depot with break facilities at Central station
- Maintenance in Høje Tåstrup
- Expanded cleaning (train wash) in Hundige

Density of network

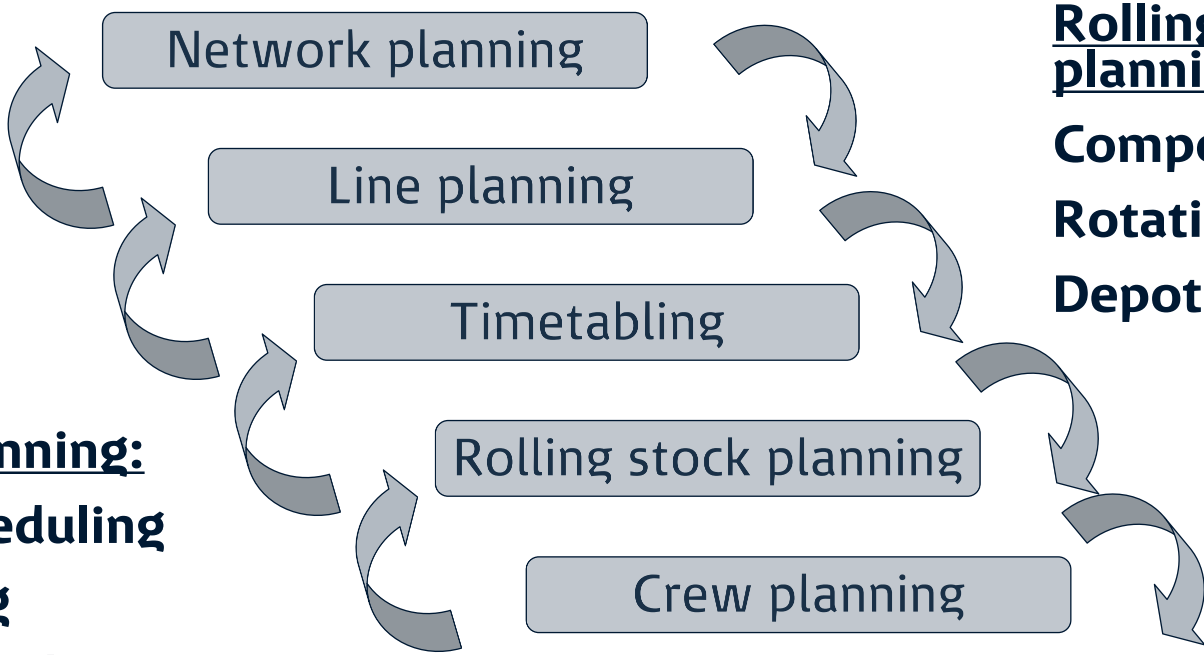


Quantifying product quality





Planning levels



<u>Rolling stock planning:</u>

Compositions

Rotations

Depot planning

<u>Crew planning:</u>

Duty scheduling

Rostering

Assigning drivers

Planning levels in time

Long term: 10-5 years

Planning levels in time

Long term: 1 year

Planning levels in time

3-2 months

Planning levels in time

14 - 1 day

Planning levels in time

Rolling stock planning

Dresden, June 2008

Strategic rolling stock planning

- Fleet management
  - Quantify future needs
  - Distribution of "1/2" and "1/1" units
  - Estimate future need for rolling stock given expected demand
  - Scenario testing with different objective functions

- Challenges
  - Passenger forecasting for future timetable
  - High degree of uncertainty
  - Defining costs

Tactic rolling stock planning

- Currently a manual process based on experienced planners
  - Compositions change 4 times during a normal day
  - Use the 104 “1/1” units and 31 “1/2” units taking into account number of passengers and operating costs

- Challenges:
  - Cost of “1/1” per km = 1.65*(cost of “1/2” per km)
  - “Up” and “down” on depots - of varying size
  - Limits on shunt personnel at the depots
  - Depot balances at the end of the day
  - Regular maintenance - 60 days or 20.000 km

Rolling stock optimization - OMPLS II

- Based on expected savings of the order 3 - 5 %
- A system development process has been initiated - vendor: Jeppesen
- Expected delivery in 6 - 12 months

Solution method:

1. Solve the composition problem based on passenger estimates – Pass solution to the circulation problem
1. Solve the circulation problem
    - If infeasible return to 1)
    - If feasible pass solution to depot planning
    - If depot planning infeasible return to 2) with new constraints
3. Until feasible

Operational rolling stock planning

- Same tools as tactic planning
- Less time for planning

- Challenges
    - Most days have planned rail works
    - Same as tactic
        - Limited depot capacity
        - Limit shunting personnel
        - Maintaining end of day balance
        - Enabling regular maintenance
    - Applying changes – data

Operational rolling stock planning

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  - Applying changes – data

Januar 2005		Februar 2005		Marts 2005		April 2005		Maj 2005		Juni 2005	
1 L Nytår		1 T Val-Gl bus		1 T Val-Gl bus, Ølm-Kj		1 F Val-Gl Bus		1 S Sjæ-Åm, Dyt-Sam		1 O Ba-Her, Dyt-Sam	
2 S Val-Gl bus		2 O Val-Gl bus		2 O Val-Gl bus, Und-Klu		2 L Val-Gl Bus, Sam-Dyt		2 M Her-Ba,Val-Gl Bur,Dyt-Sam	18	2 T Ba-Her, Dyt-Sam	
3 M Val-Gl bus	1	3 T Val-Gl bus		3 T Val-Gl bus		3 S Ba-Her,Val-Gl Bur,Sam-Dyt		3 T Her-Ba,Val-Gl Bur,Dyt-Sam		3 F Valby	
4 T Val-Gl bus		4 F Val-Gl bus		4 F Val-Gl bus		4 M Ba-Her,Val-Gl Bur,Sam-Dyt	14	4 O Her-Ba,Val-Gl Bur,Dyt-Sam		4 L Valby	
5 O Val-Gl bus		5 L Val-Gl bus		5 L Val-Gl bus		5 T Ba-Her,Val-Gl Bur,Sam-Dyt		5 T Her-Ba,Val-Gl Bur,Dyt-Sam		5 S Valby, Sam-Dyt	
6 T Val-Gl bus		6 S Val-Gl bus		6 S Val-Gl bus		6 O Ba-Her,Val-Gl Bur,Sam-Dyt		6 F Val-Gl Bus		6 M Ba-Her, Sam-Dyt	23
7 F Val-Gl bus		7 M Val-Gl bus	6	7 M Val-Gl bus	10	7 T Ba-Her,Val-Gl Bur,Sam-Dyt		7 L Sjæ-Åm, Dyt-Sam		7 T Ba-Her, Sam-Dyt	
8 L Indvielse "Ny Ellebjerg", Val-Gl bus		8 T Val-Gl bus		8 T Val-Gl bus		8 F Valby		8 S Sjæ-Åm, Dyt-Sam		8 O Ba-Her, Sam-Dyt	
9 S Val-Gl bus		9 O Val-Gl bus		9 O Val-Gl bus		9 L Valby, Sam-Dyt		9 M Ba-Her,Val-Gl Bur,Dyt-Sam	19	9 T Ba-Her, Sam-Dyt	
10 M Val-Gl bus	2	10 T Val-Gl bus		10 T Val-Gl bus		10 S Valby, Sam-Dyt		10 T Ba-Her,Val-Gl Bur,Dyt-Sam		10 F Valby	
11 T Val-Gl bus		11 F Val-Gl bus		11 F Val-Gl bus		11 M Ba-Her,Val-Gl Bur,Sam-Dyt	15	11 O Ba-Her,Val-Gl Bur,Dyt-Sam		11 L Valby	
12 O Val-Gl bus		12 L Val-Gl bus, Birkerød		12 L Val-Gl bus		12 T Ba-Her,Val-Gl Bur,Sam-Dyt		12 T Ba-Her,Val-Gl Bur,Dyt-Sam		12 S Valby, Dyt-Sam	
13 T Val-Gl bus		13 S Val-Gl bus, Birkerød		13 S Val-Gl bus		13 O Ba-Her,Val-Gl Bur,Sam-Dyt		13 F Val-Van		13 M Her-Ba, Dyt-Sam	24
14 F Val-Gl bus		14 M Val-Gl bus	7	14 M Val-Gl bus	11	14 T Ba-Her,Val-Gl Bur,Sam-Dyt		14 L Sjæ-Åm, Val-Van		14 T Her-Ba, Dyt-Sam	
15 L Val-Gl bus		15 T Val-Gl bus		15 T Val-Gl bus		15 F Valby		15 S Sjæ-Åm,Val-Van		15 O Her-Ba, Dyt-Sam	
16 S Val-Gl bus		16 O Val-Gl bus		16 O Val-Gl bus		16 L Valby, Dyt-Sam		16 M Sjæ-Åm,Val-Van	20	16 T Her-Ba, Dyt-Sam	
17 M Val-Gl bus	3	17 T Val-Gl bus, Her-Ba		17 T Val-Gl bus		17 S Valby, Dyt-Sam		17 T Ba-Her, Dyt-Sam		17 F	
18 T Val-Gl bus		18 F Val-Gl bus, Ba-Her		18 F Val-Gl bus		18 M Her-Ba,Val-Gl Bur,Dyt-Sam	16	18 O Ba-Her, Dyt-Sam		18 L	
19 O Val-Gl bus		19 L Val-Gl bus, Lille Nord		19 L Val-Gl bus		19 T Her-Ba,Val-Gl Bur,Dyt-Sam		19 T Ba-Her, Dyt-Sam		19 S Her-Ba, Sam-Dyt ell. Dyt-Sam	
20 T Val-Gl bus		20 S Val-Gl bus, Lille Nord		20 S Val-Gl bus		20 O Her-Ba,Val-Gl Bur,Dyt-Sam		20 F Sjæ-Åm		20 M Her-Ba, Sam-Dyt ell. Dyt-Sam	25
21 F Val-Gl bus		21 M Val-Gl bus, Lille Nord	8	21 M Val-Gl bus	12	21 T Gj-Ly, Her-Ba, Dyt-Sam		21 L Sjæ-Åm		21 T Her-Ba, Sam-Dyt ell. Dyt-Sam	
22 L Val-Gl bus		22 T Val-Gl bus, Li-Hi		22 T Val-Gl bus		22 F Gj-Ly, Sjæ-Åm		22 S Sjæ-Åm, Sam-Dyt		22 O Her-Ba, Sam-Dyt ell. Dyt-Sam	
23 S Val-Gl bus		23 O Val-Gl bus		23 O Val-Gl bus		23 L Gj-Ly, Sjæ-Åm		23 M Ba-Her, Sam-Dyt	21	23 T Her-Ba, Sam-Dyt ell. Dyt-Sam	
24 M Val-Gl bus	4	24 T Val-Gl bus, Kl-Hl		24 T Skærtorsdag, Sjæ-Åm		24 S Gj-Ly, Sjæ-Åm		24 T Ba-Her, Sam-Dyt		24 F	
25 T Val-Gl bus		25 F Val-Gl bus, Dyt-Bud		25 F Langfredag, Sjæ-Åm		25 M Her-Ba,Val-Gl Bur,Dyt-Sam	17	25 O Ba-Her, Sam-Dyt		25 L	
26 O Val-Gl bus		26 L Val-Gl bus		26 L Sjæ-Åm		26 T Her-Ba,Val-Gl Bur,Dyt-Sam		26 T Ba-Her, Sam-Dyt		26 S Her-Ba, Sam-Dyt ell. Dyt-Sam	
27 T Val-Gl bus		27 S Val-Gl bus		27 S Påskedag, Sjæ-Åm		27 O Her-Ba,Val-Gl Bur,Dyt-Sam		27 F Sjæ-Åm		27 M Her-Ba, Sam-Dyt ell. Dyt-Sam	26
28 F Val-Gl bus		28 M Val-Gl bus	9	28 M 2. Påskedag, Sjæ-Åm	13	28 T Her-Ba,Val-Gl Bur,Dyt-Sam		28 L Sjæ-Åm		28 T Her-Ba, Sam-Dyt ell. Dyt-Sam	
29 L Val-Gl bus,Kk				29 T Ba-Her, Val-Gl Bus		29 F Val-Gl Bus		29 S Sjæ-Åm, Dyt-Sam		29 O Her-Ba, Sam-Dyt ell. Dyt-Sam	
30 S Val-Gl bus,Kk				30 O Ba-Her, Val-Gl Bus		30 L Sjæ-Åm		30 M Ba-Her, Dyt-Sam	22	30 T Her-Ba, Sam-Dyt ell. Dyt-Sam	
31 M Val-Gl bus	5			31 T Ba-Her, Val-Gl Bus				31 T Ba-Her, Dyt-Sam			

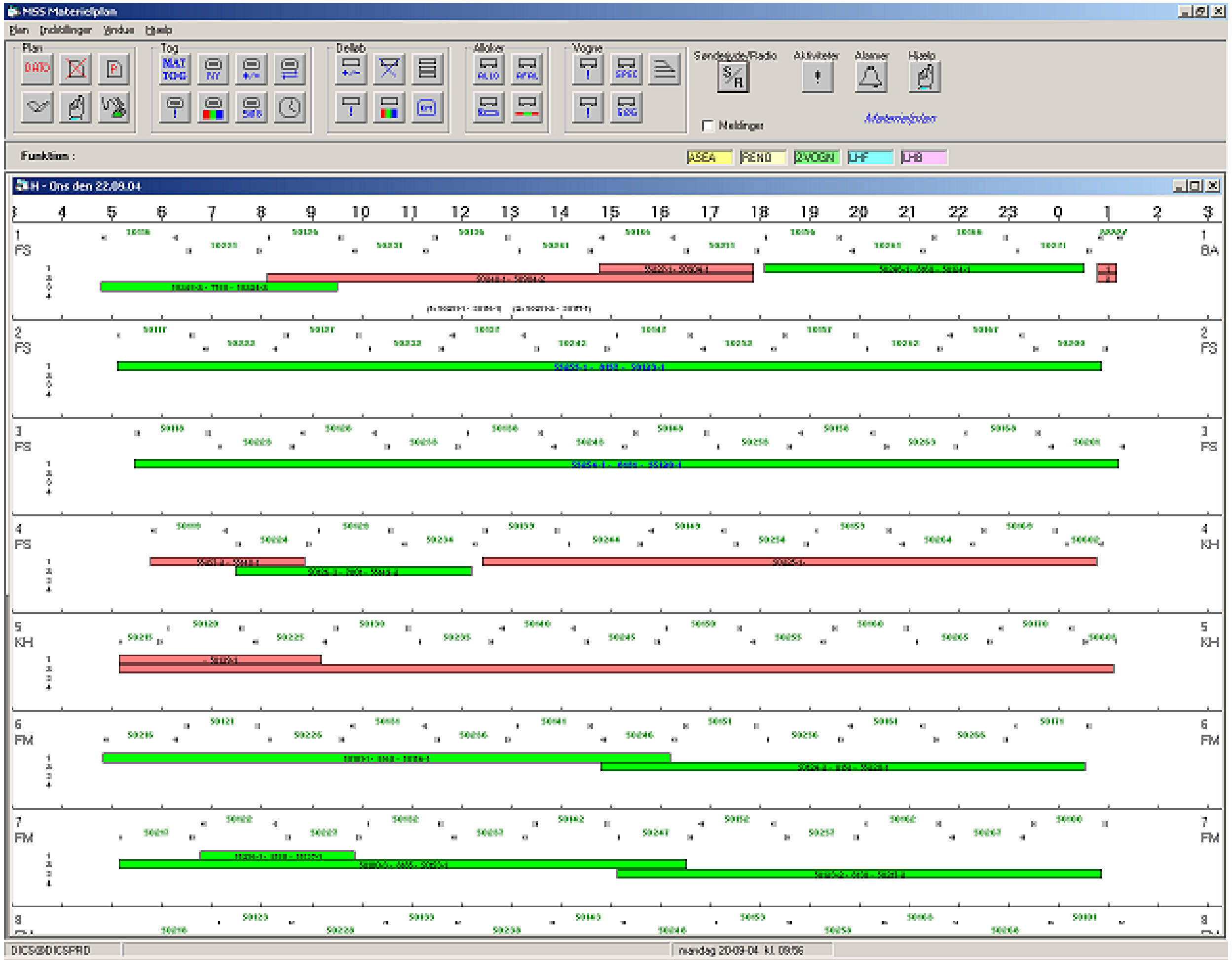
Aftentimer Hele driftsdøgnet

Rolling stock dispatching

- Allocate train units of right type and number in time to each departure
  - Restriction on driven km
  - Planned repairs at the workshop
  - Planned cleanings at prepare centre
  - Unexpected defects on train units
- Planning of central station depot
- Updating of MSS w.r.t. driven rolling stock

- Challenges
  - No decision support
  - The present rolling stock dispatching system (MSS) does not update automatically
  - Many of the planning tasks has a high “in-hand” complexity

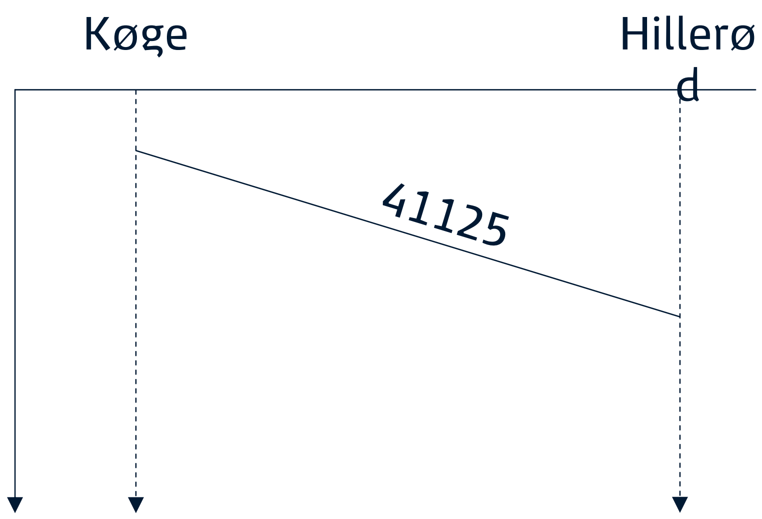
Rolling stock dispatching



Dresden, June 2008

Definition of train related terms

- **Train task**
- Train sequence
- Train unit
- Train composition
- Train
- Train Line



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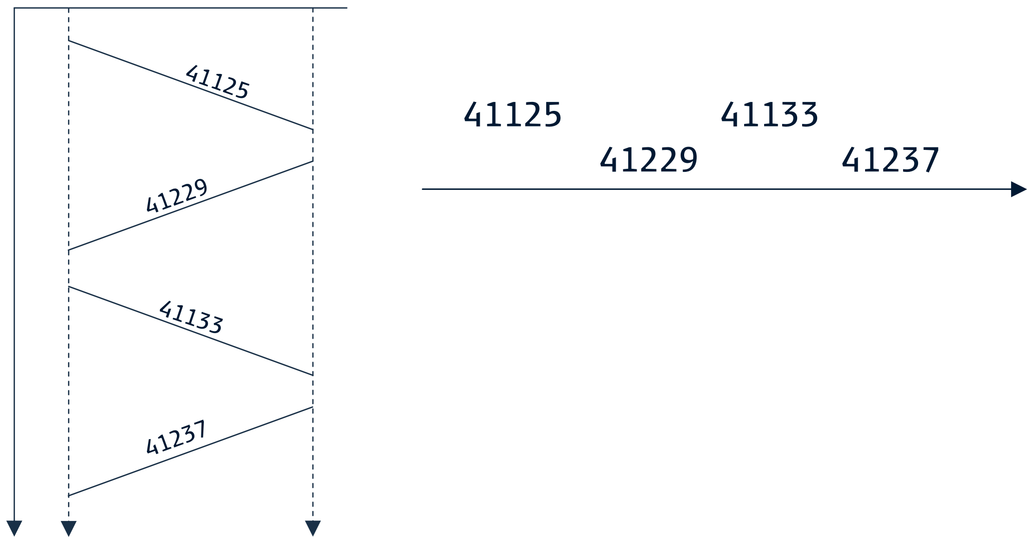

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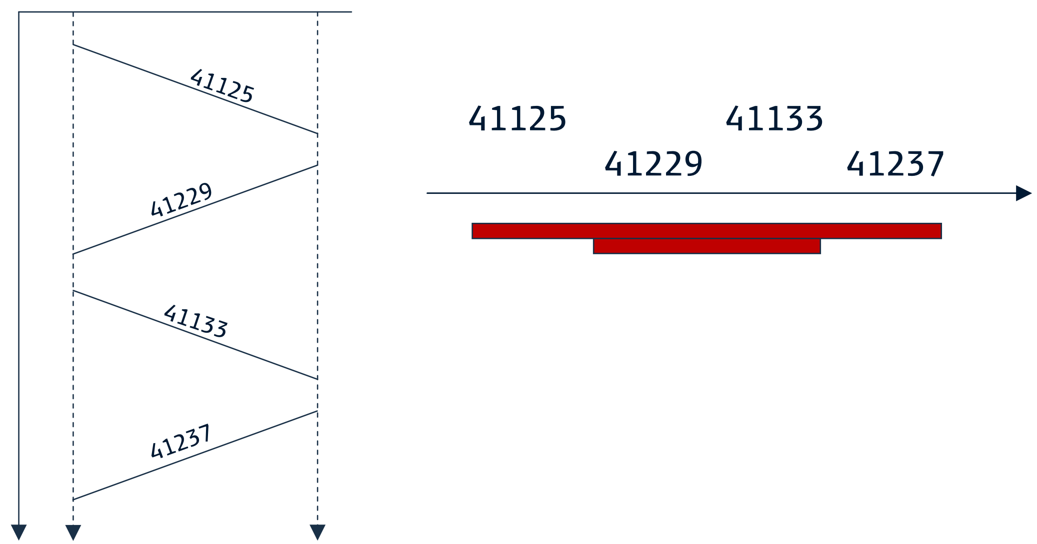

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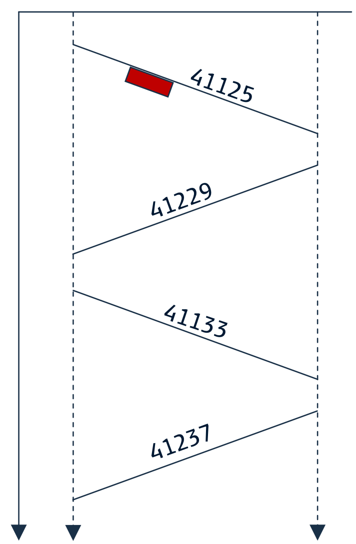

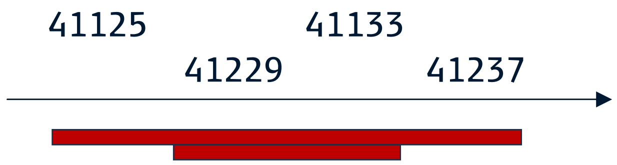

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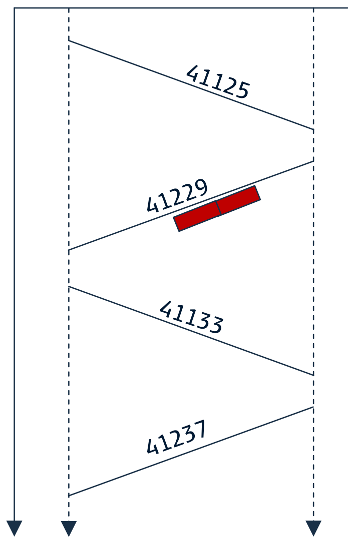

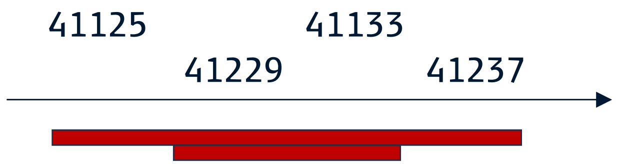

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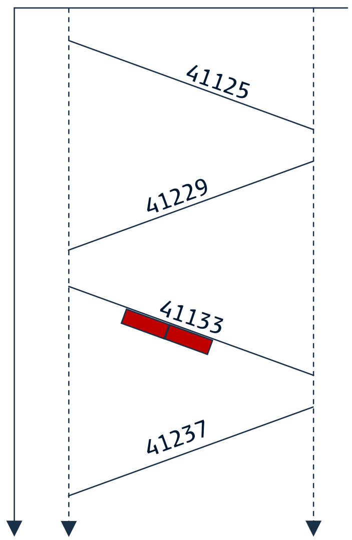

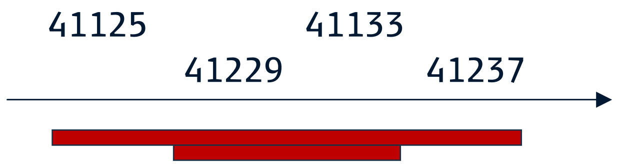

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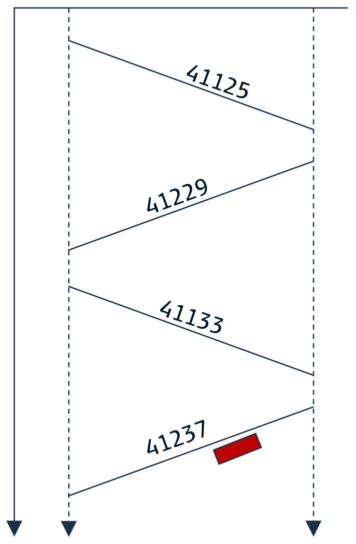

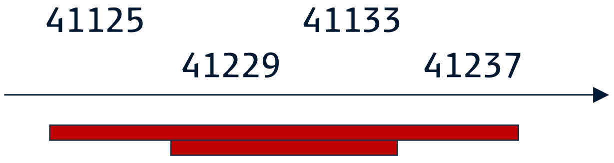

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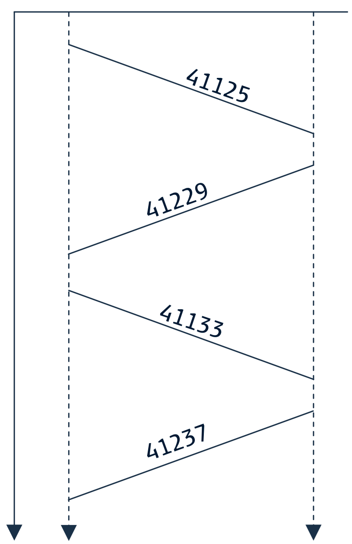

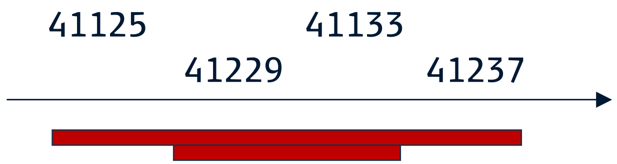

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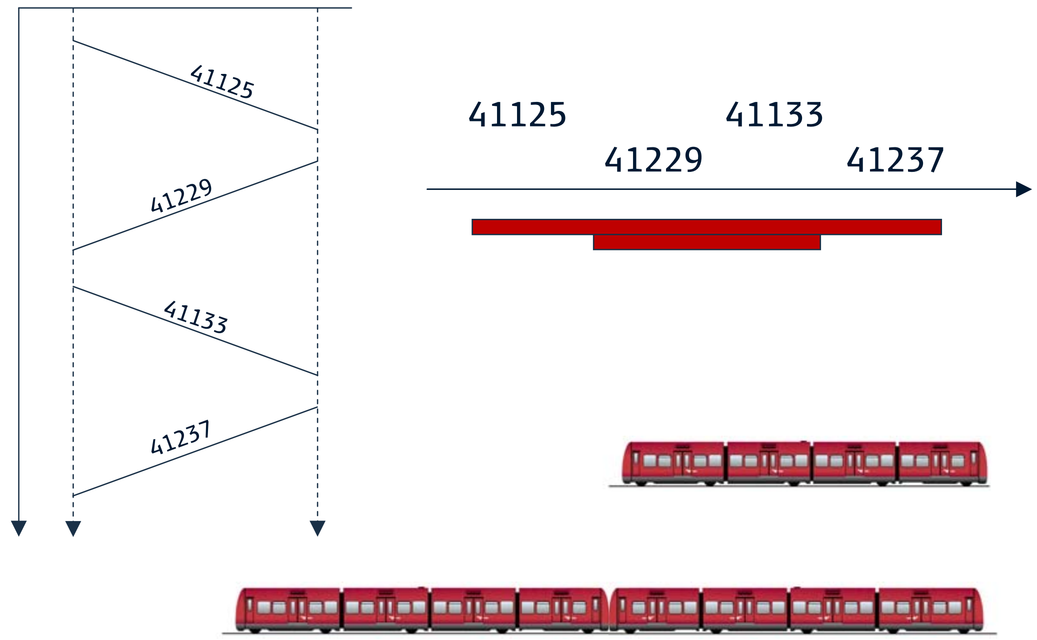

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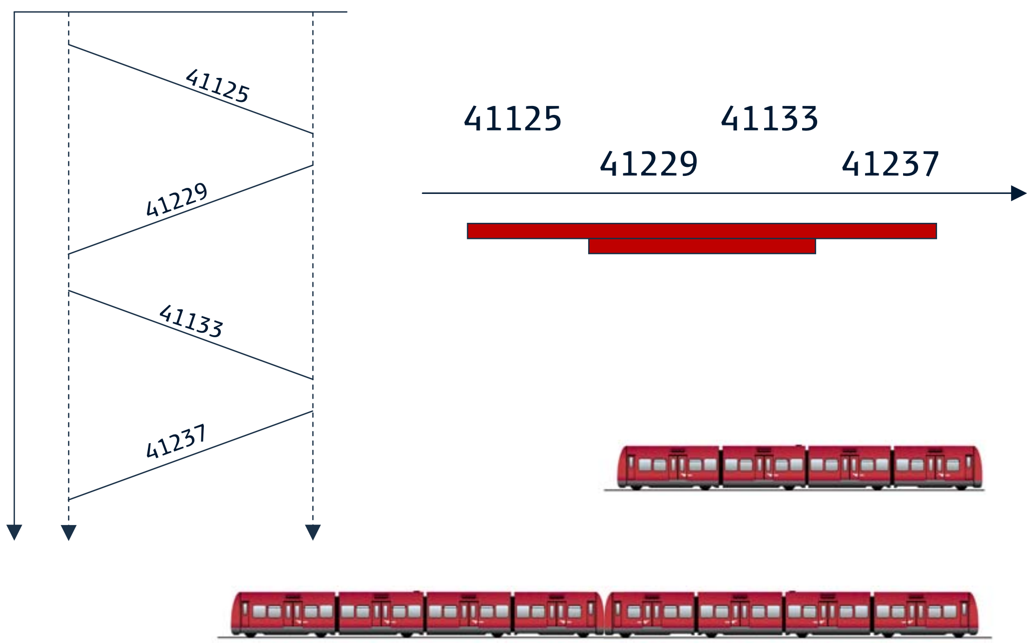
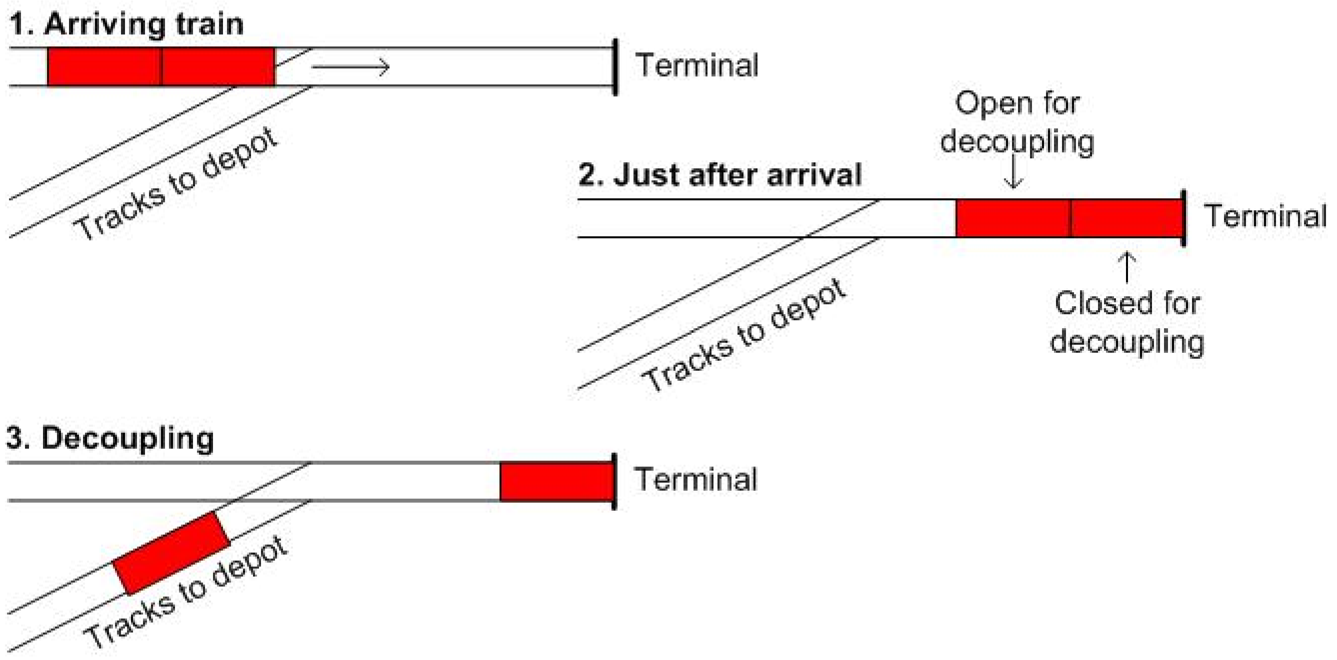


Rolling stock recovery - problem description

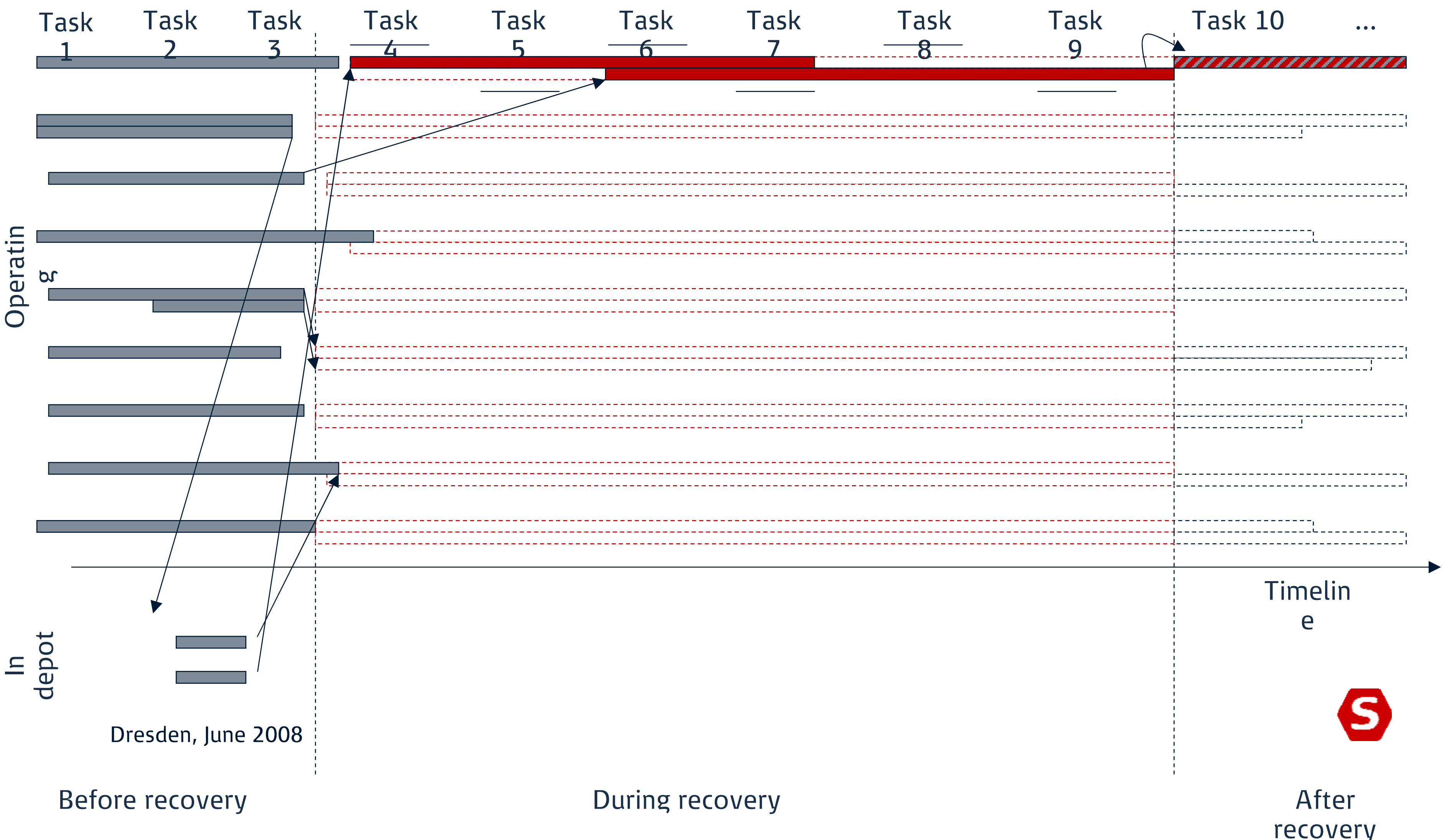
- Given a disrupted rolling stock schedule
    - Route train units to path feasible w.r.t.
        - End depot
        - Maintenance requirements
    - Cover train tasks according to demand
    - Composition changes must be legal

- Recovery period is predefined
- Train units directly affected by the disruption included

Open and closed end train



RSRP



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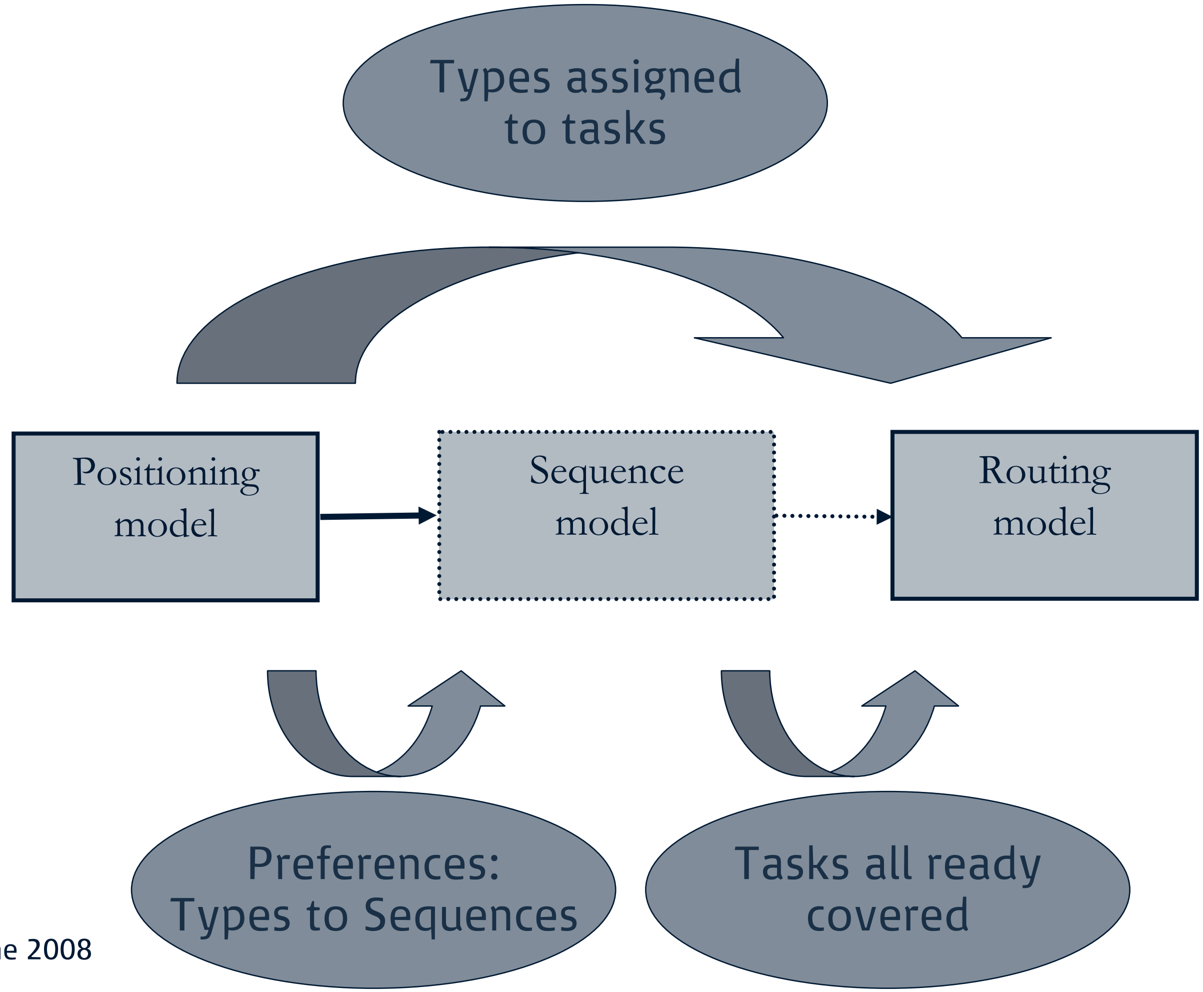
A decomposed approach



The train unit position problem

$$X_{tp}^{m} = 1, \quad \textit{if task } t \textit{ is covered in position } p \textit{ by type } m$$

- Minimizing difference to desired end capacities
- Balances of train units on depots are controlled after each arrival
- Feasible composition changes are controlled by controlling open and closed position

$$C_{tp} \cdot X_{tp}^{m} \leq X_{\nu(t)p}^{m}$$

Forcing the successor task, v(t), to be 1 if task t is one and unit is in closed position

Train unit routing problem

$$Q_t^k = 1, \quad \textit{if train unit } k \textit{ is allocated to train task } t$$

- Maximize the number of train tasks covered
- Maximize number of train units returning to original path
- Allocate train units to train tasks according to solution from *Position model*
- For each train unit a feasible path must be made
  - Start depot is given
  - Maintenance requirements must be fulfilled

$$\sum_{t' \in T \cap Pred(t)} Q_{t'}^k \geq Q_t^k, \quad \forall t \in T, k \in K$$

Train unit routing problem

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$$\sum_{t' \in T \cap TimeParallel(t)} Q_{t'}^k = 1, \quad \forall t \in T, k \in K$$

The train sequence problem

- Allocate physical train units to train sequences taking into account
  1. Each train sequence must be assigned at most one train unit
  2. The path for each train unit must be feasible

- Priorities are for the train types w.r.t. each train sequence are derived from *Position model*

- Maximize the sum of priorities allocated

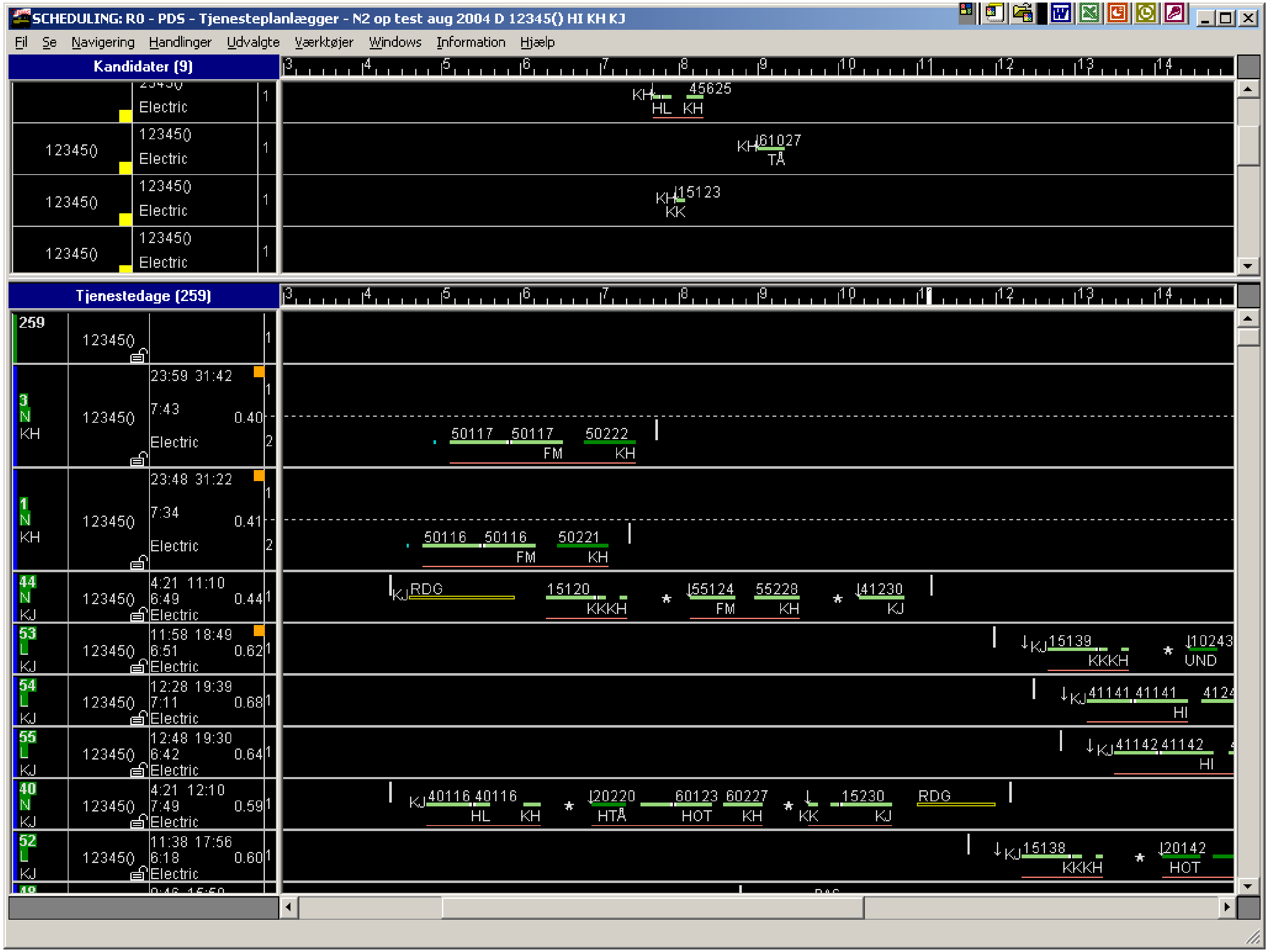
Crew planning

Dresden, June 2008

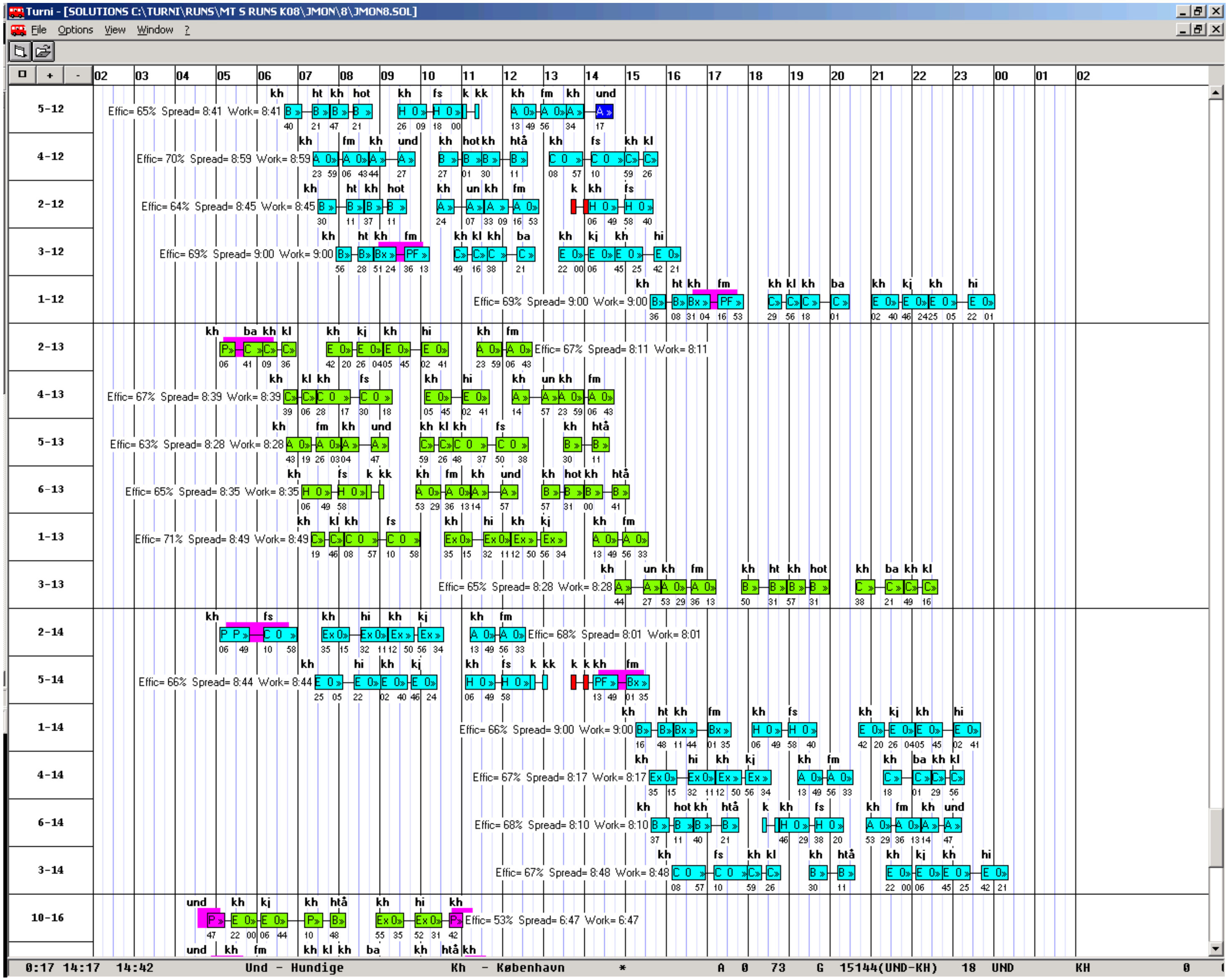
Tactic crew scheduling

- Crew scheduling has three components:
  - Building of duties from driving tasks, stand-bys, breaks, ...
    - Task: "1/2" round or full round.
    - Breaks: a) Break > 30 min; b) Break1 + Break2 > 45 min.
    - A substantial number of rules on duty time and variation.
  - Building of rosters from duties.
    - Varying, but even, number of weeks.
    - Rules for days off with respect to amount and week-ends.
    - Rules for average duty length etc.
  - Assigning persons to rosters - strict seniority.

PDS - Personnel dispatching system



TURNI - optimization tool for crew scheduling



Challenges in Crew Planning

- The general system in working quite well, but ...
  - Roster generation still manual.
  - Operational planning in relation to track-work etc.
  - Data integration (a general problem).
  - Decision support for real-time dispatch.
  - Integration with other planning tasks.

Train Driver Dispatching at S-tog

- Main responsibility is to cover uncovered task with train drivers.
  - Timetable affected by delays => train driver is late for next task
  - Train driver absent
  - Train driver is signing in late

- Combining different actions into solutions
  - Available stand-by
  - Swap of tasks to create available driver
  - Calling in stand-bys

Summing up

- Decision support systems based on mathematics and IT are valuable throughout an organization as S-tog
- Contact with system users from idea to system delivery is a must
- For moving forward the support from key persons in management is necessary