Where do trains stay when they're off duty?

NGB/LNMB Seminar on Operations Research and Public Transportation

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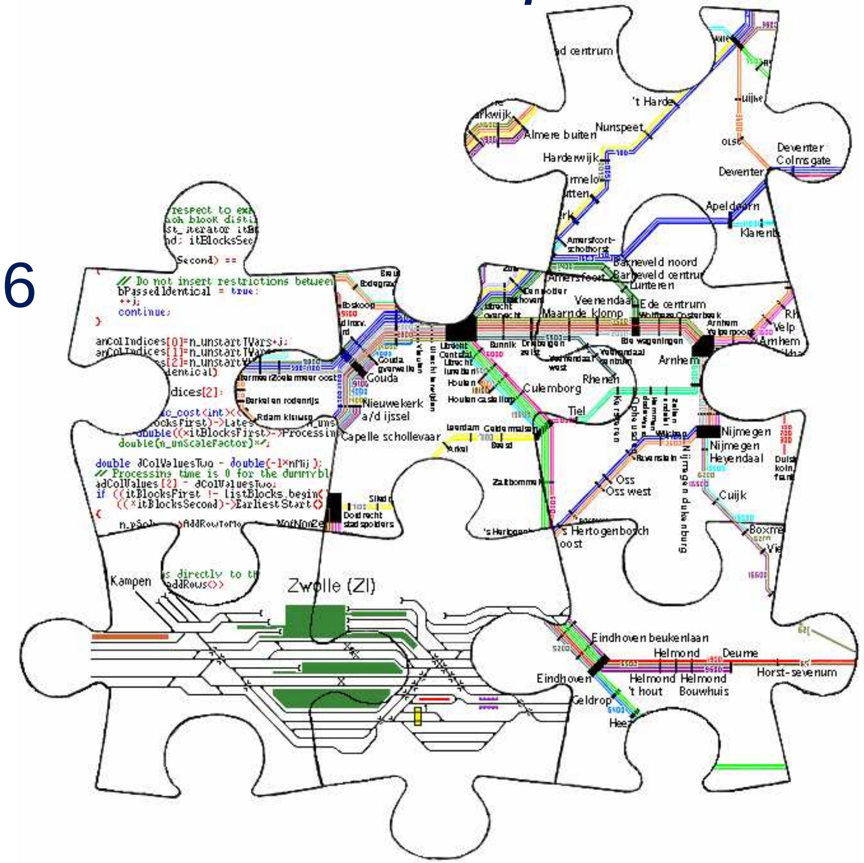
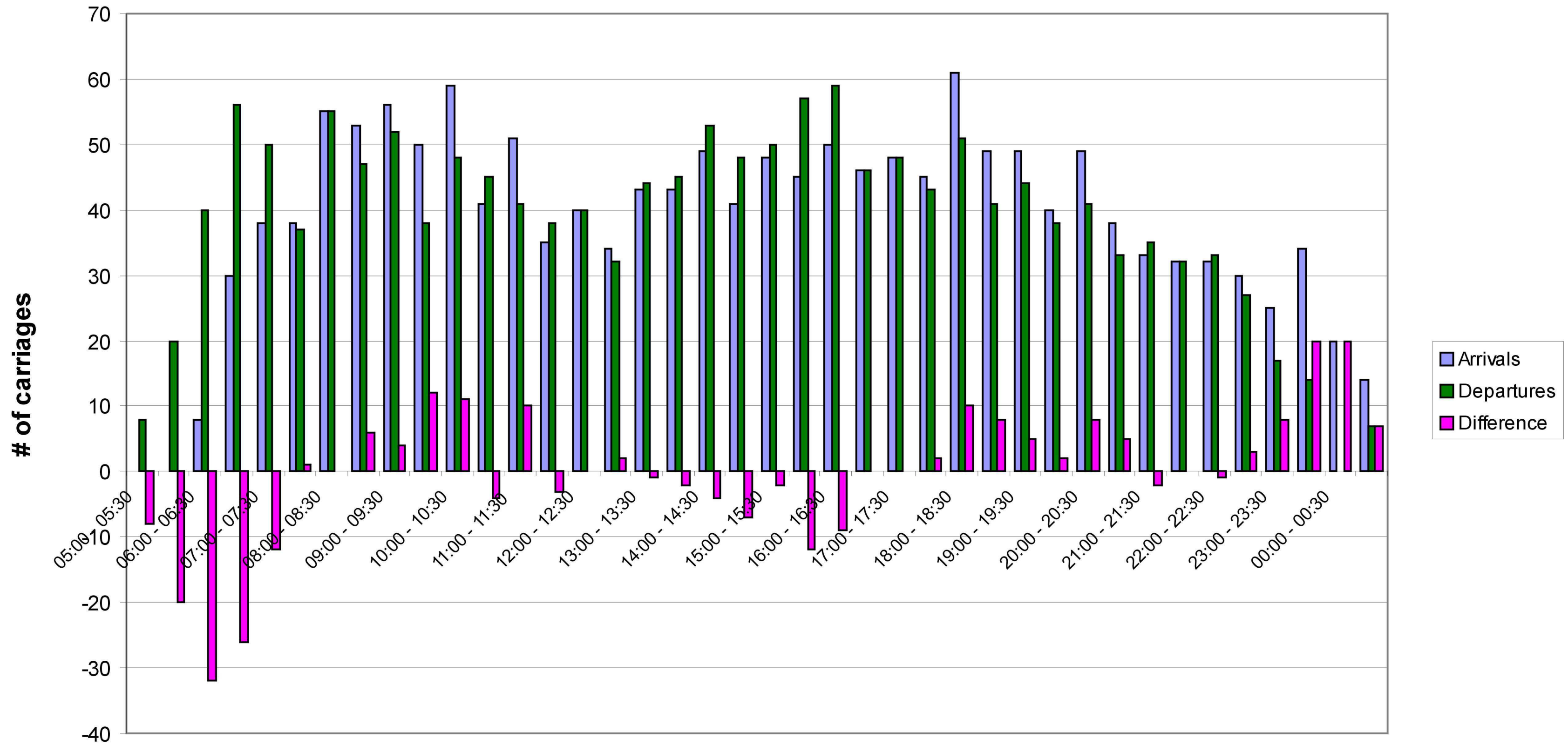


Outline of Planning Off-duty Train Units

- Problem description.
- Decomposition into subproblems.
- Discussion of subproblems with focus on the parking subproblem.
- Conclusions.

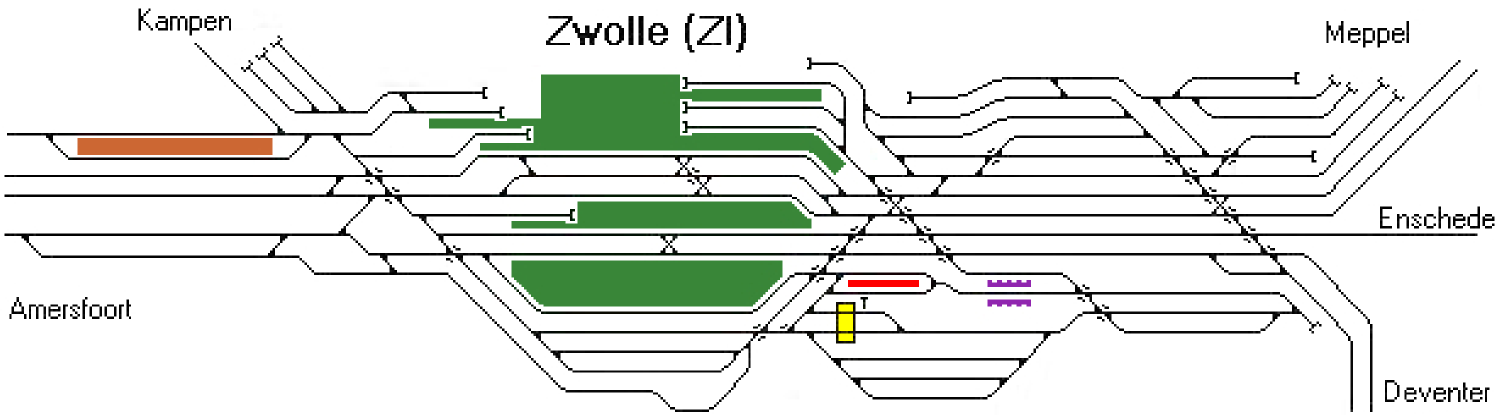
Problem Description

- Outside rush hours, demand for transportation is lower, and therefore Dutch Railways deploys less rolling stock:



Problem Description

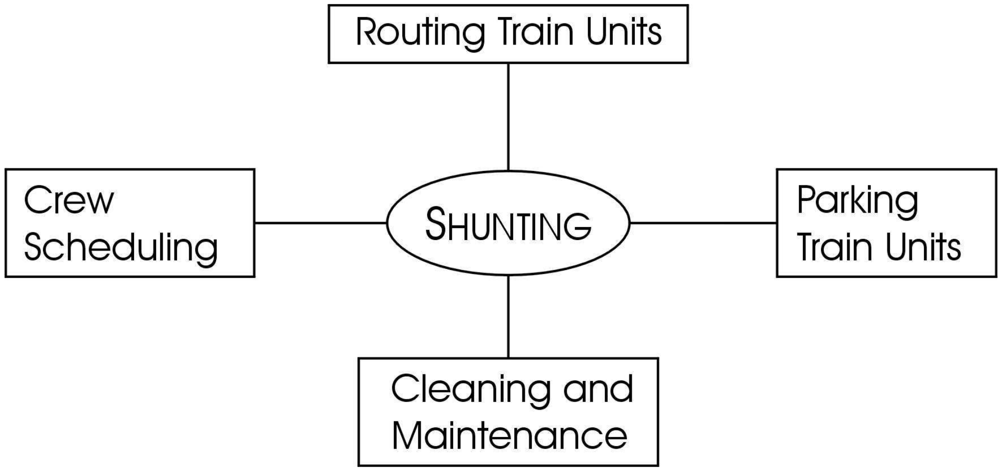
- Park off-duty rolling stock at a shunt yard:



- Shunt plans are created on a day-by-day basis and for one station at a time.
- Shunt planning is currently a bottleneck in the planning process.
- How can mathematical models and algorithms help?

Problem Description

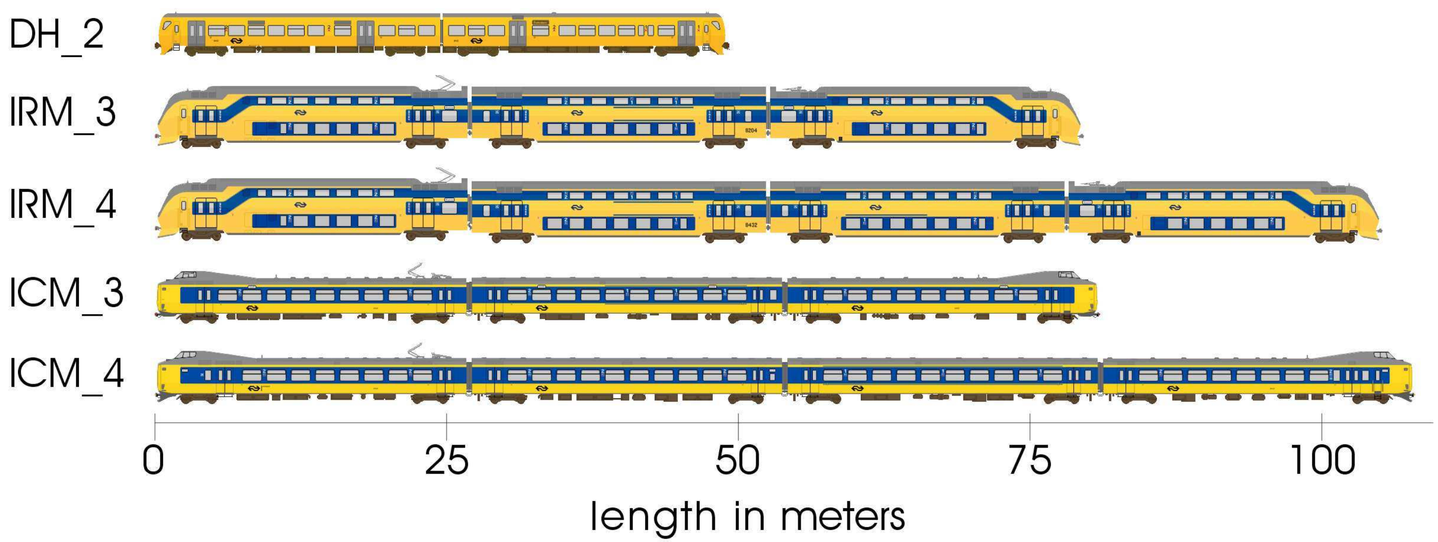
- Most important elements of shunt planning are:



- Objectives:
  - A smooth start up of the railway operations in the next morning.
  - Efficient usage of resources.
  - Robust plans.

Problem Description

- Train units have different types:



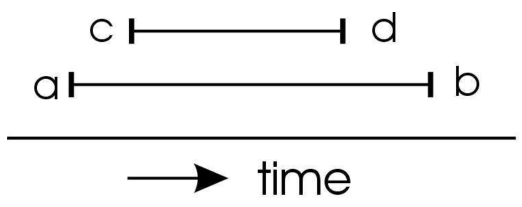
- Train units are not allowed to obstruct each other at shunt tracks.
- Capacity of shunt tracks can not be exceeded.
- Routes to and from shunt tracks have to be without conflicts.
- Shunting crews need to be available.

Problem Description

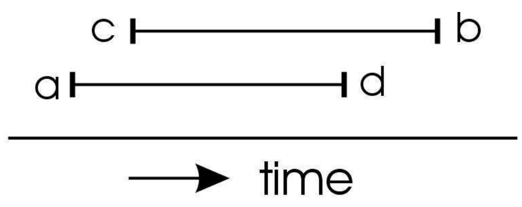
- Integrated planning provides theoretical opportunities, but is currently considered too difficult.
- Decomposition of overall problem into subproblems:
  - Matching of arriving to departing train units.
  - Parking of train units.
  - Routing of train units.
  - Cleaning of train units.
  - (Shunt crew planning.)

Matching of Train Units

- Problem: match arriving train units with departing ones.
- The problem results in *blocks*, many of these are predefined. Train unit of the same type can be interchanged.
- Objectives:
  - Keep units of the same train together.
  - Maximize the number of blocks with a minimum time difference.
  - Desirable characteristics, i.e. LIFO structure:



LIFO matching

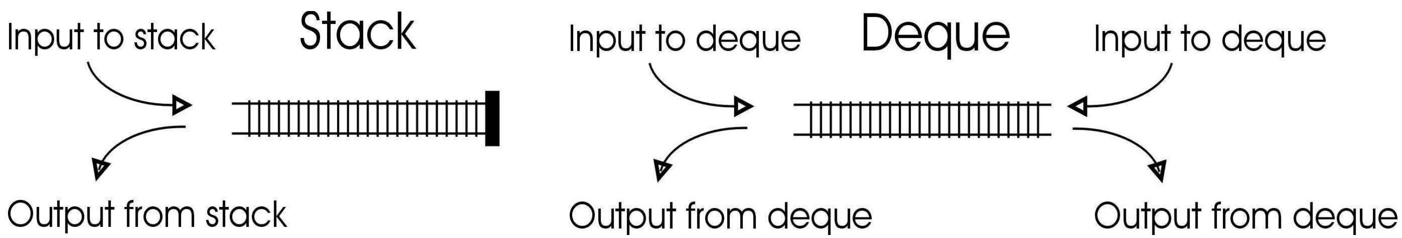


FIFO matching

- Restrictions:
  - No type-mismatches with prescribed types in timetable.
  - Adhere to the prescribed order of train units within one train.

Parking of Train Units

- Problem: given the matching, decide where to park the *blocks* that need parking.
- Track configurations play an important role:



Parking of Train Units

- Objectives:
  - Park as many blocks as possible.
  - Account for planners preferences and routing costs.
  - Find robust plans:
    - Combine blocks destined for the same departing train.
    - Maximize tracks with only one type of train unit.
- Restrictions:
  - No *crossings:* a train unit obstructing the arrival or departure of another.
  - Respect lengths of shunt tracks.

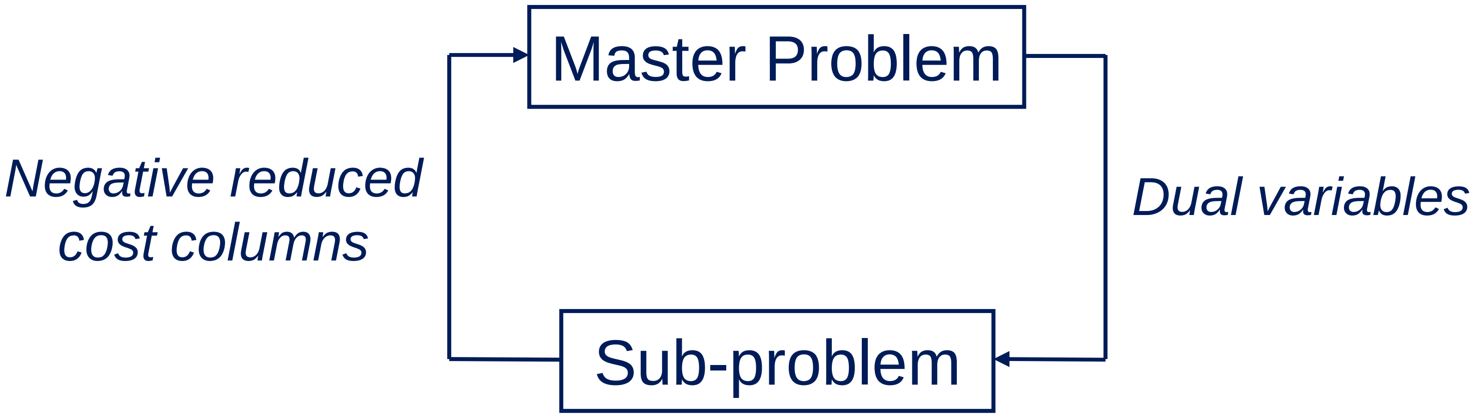
Parking of Train Units

- Set Partitioning formulation.
- Decision variables:
- X_a^s =1 iff track assignment a is used for track s.
- N_b =1 iff block b is not parked at any shunt track.

$$
\begin{array}{llll}
\text{minimize} & \displaystyle\sum_{s\in\mathcal{S}}\sum_{a\in\mathcal{V}_s} f_a^s X_a^s + d\sum_{b\in\mathcal{B}} N_b & & \\
\text{subject to} & \displaystyle\sum_{s\in S}\sum_{a\in\mathcal{V}_s^b} X_a^s + N_b = 1 & & \forall b\in\mathcal{B} \\
 & \displaystyle\sum_{a\in\mathcal{V}_s} X_a^s \leq 1 & & \forall s\in\mathcal{S} \\
 & X_a^s \in \{0,1\} & & \forall s\in\mathcal{S}, \forall a\in\mathcal{V}_s \\
 & N_b \in \{0,1\} & & \forall b\in\mathcal{B}
\end{array}
$$

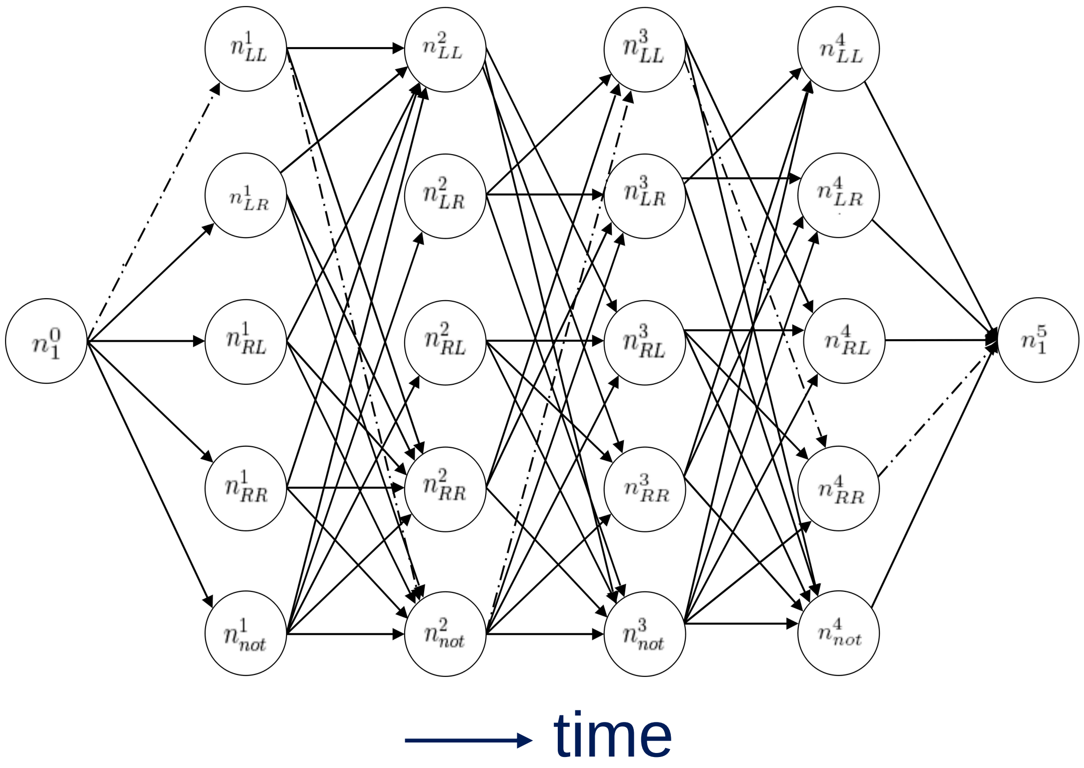
- Problem: far too many X_a^s decision variables.
- Solution: Column Generation, where columns are only generated in the root of the Branch-and-Bound tree.

- Short introduction to column generation:
- Start with a restricted set of columns in the *master problem* = LP-relaxation of original (Mixed) Integer Problem.
- Based on a solution of the *master problem*, find additional relevant columns in the *sub-problem*. Return to solving the master problem.
- Columns are relevant if they have **negative reduced cost** (equivalent to the primal simplex algorithm).
- In a figure:



Parking of Train Units

- Solve the sub-problem by a *resource constrained shortest path*.
- Resources are the earliest and latest departures at each side of a track, and the length of the units parked at the track.
- The network is structured as follows:



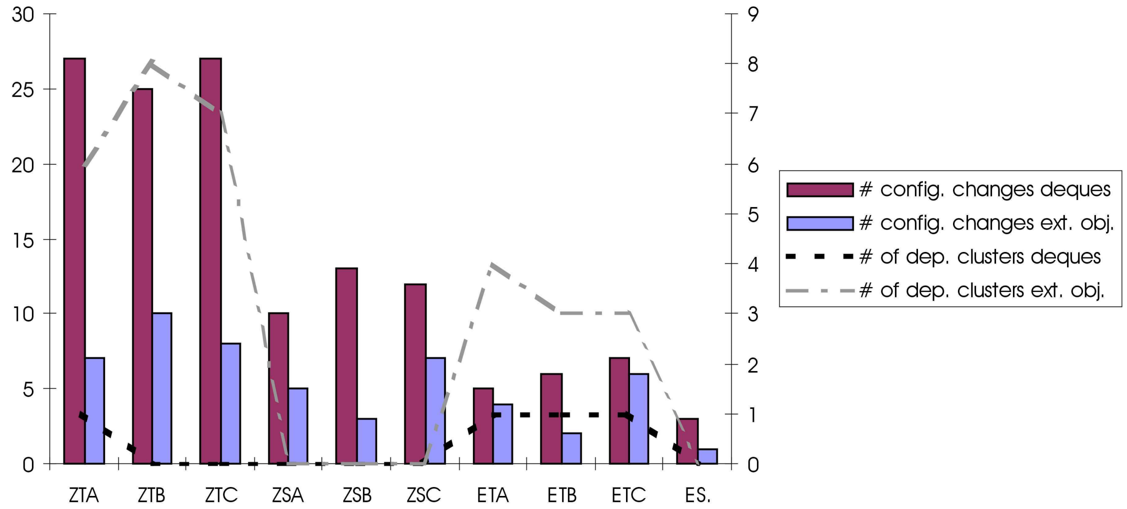
Parking of Train Units

- Some computational results for Zwolle (19 shunt tracks) and Enschede (13 shunt tracks):

Instance	ZTAD	ZTBD	ZTCD	ZSAD	ZSBD	ZSCD
Number of blocks to be parked	54	57	54	34	34	33
Comp. time for TAP (in sec.)	245.5	224.1	420.4	3.3	3.5	5.2
LP solution value	5198.40	5641.61	5053.00	5088.42	5085.67	4076.00
IP solution value	5313	5738	5155	5203	5088	4076
Gap	2.16%	1.59%	1.98%	2.15%	0.05%	0.00%
# Blocks not parked	0	0	0	0	0	0
# Columns generated	5397	5502	5157	4298	4733	4533
# Iterations column generation	38	36	35	22	30	25

Instance	ETAD	ETBD	ETCD	ES.D
Number of blocks to be parked	18	18	18	11
Comp. time for TAP (in sec.)	1.2	1.1	1.2	0.2
LP solution value	5540.00	5573.00	5538.00	1982.00
IP solution value	5541	5573	5538	1982
Gap	0.02%	0.00%	0.00%	0.00%
# Blocks not parked	0	0	0	0
# Columns generated	1147	1043	1085	158
# Iterations column generation	16	11	14	6

- The effect of robustness measures:



Routing of Train Units

- Problem: given a parking, find routes for the blocks to and from their shunt tracks.
- Account for infrastructure reservations (e.g. through trains, track maintenance, other shunt routes).
- Start- and end times of shunt routes are flexible to some extent, opposed to timetabled trains.

Routing of Train Units

- Objectives:
  - Minimum traveled distance.
  - Minimum changes in direction.
  - Minimum number of simultaneous shunt routes.
  - Minimum deviation from preferred start times.
- Restrictions:
  - No *conflicts* between any two routes at the station.
  - Respect prescribed times for activities.

Routing of Train Units

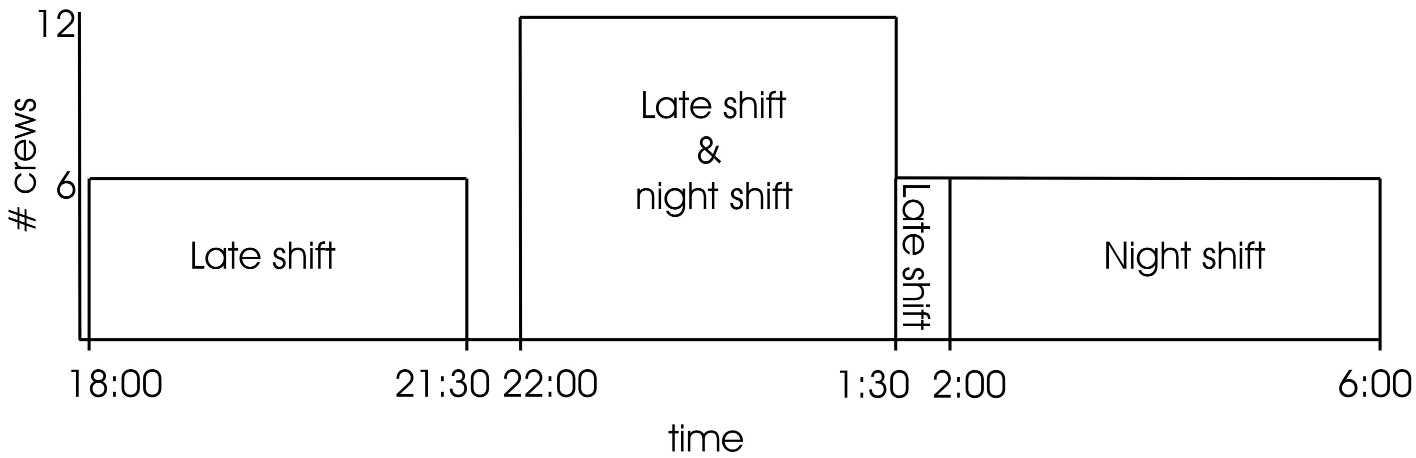
- Solution approach: apply an extension of A* Search for network occupation iteratively. (One shunt route after another)
- To reduce input data, through trains are routed before other train units.
- We have excellent estimates of the remaining length: distances from one track to another without any infrastructure reservation!
- Extensions of A* Search:
  - An upper bound on the cost of a shunt route.
  - A maximum number of changes in direction in a route.
  - Nodes can be unavailable.
- Find a route for several start times and select the best one.

Routing of Train Units

- The iterative procedure introduces a heuristic feature.
- In order to reduce the effect of the other of planning shunt routes, we apply 2-OPT:
  - Try to interchange the order of two routes, and see if it improves the overall solution (route need to overlap in time for improvement).
  - Repeat for all pairs of shunt routes.

Cleaning of Train Units

- Problem: all train units that lay over at a shunt yard need to be cleaned internally along a dedicated platform.
- This results in additional routing and possibilities to change track assignments.
- Two shifts of cleaning crews are available:



- More crews available reduces the throughput time of cleaning.
- Assumption: all crews only clean one *block* at a time.

Cleaning of Train Units

- Options for cleaning:
  1. Shortly after arrival.
  2. Just before departure.
  3. Somewhere in between.
- Option 2 is undesirable since it conflicts with the overall goal to start up as smoothly as possible.
- Option 3 is undesirable since it requires parking train units twice.

- Result: try to clean as many blocks as possible close in time after their arrival.

Cleaning of Train Units

- A cleaning schedule affects the parking problem.
- Each block that needs cleaning is split in two (before / after cleaning).
- The sizes of the instances grow (of course).
- Use a 2-OPT heuristic for generating initial columns, before the column generation heuristic

Integrated Matching and Parking

- Decomposition of matching and parking reduces solution quality, but increases computation time.
- How can we integrate these problems and solve it within reasonable computation times?
- The main problem is the huge amount of restrictions involved with prohibiting *crossings*.
- Objective:
  - Minimize shunt tracks with multiple types of train units.
  - Minimize train with units to / from different shunt track.

Conclusions

- Shunting results in complex logistic planning problems.
- Mathematical models and algorithms provide opportunities to improve automate a part of the planning process.
- Creativity of shunt planners remains required.

- Do you want more information?
  - Ask me.
  - Browse to my thesis: http://hdl.handle.net/1765/7328

Finally ...

Erasmus Universiteit Rotterdam

- THANK YOU FOR YOUR TIME AND ATTENTION!!!

- Any questions?