Rostering of passenger rail crew in Hungary
(with a brief overview of passenger railway operation planning)

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Outline

- The structure of railway companies in Hungary
- The planning of passenger railway operations:
  - Timetabling
  - Rolling stock circulation
  - **Crew scheduling and rostering**
  - Maintenance routing, carriage cleaning, etc.
- Conclusions

The structure of railway companies in Hungary

In the past

MÁV, vertically integrated

Due to EU regulations:

Currently

- MÁV (Infrastructure, traffic control)
- **VPE Ltd. (Infrastructure capacity allocation)**
- FKG (Track maintenance)
- ...
- SZK (IT operation)
- **Trakció (traction, recently unified with MÁV-START)**
- **MÁV START (Passenger transportation)**

Planning: resources

External

- infrastructure (track) capacity
- traction capacity

Internal

- Rolling stock
  (vehicles)
- Traveling crews
  (conductors)
- Supplementary personnel
  (ticket office staff, vehicle technicians, operators)

Planning: demands

Passenger flow

Currently: **subjective estimates**
Could be:

- Ticket sales data (no exact date except for IC
- Counting of passengers (inaccurate)

Social expectations

Continuous consultation with partners.

Passenger timetabling

Precisey: timetable proposal planning.

$$\text{proposed train paths} \leftrightarrow \text{capacity distributor}$$

Passenger timetable

- Valid for one year
- When looking within a day with resp. to a single line:
  - Periodic (e.g. *Runs everyday*)
  - Aperiodic (e.g. *Does not run on 24. December*)

Trains

- Identified by numbers
- Types: suburban, long-distance, IC, EC, ...
- Run regularly in a period of time: *regularity signs*:
  - Periodic
  - Aperiodic
- Multiple versions: versioning. (Operativity included.)

Passenger timetabling

"METERV" software

- Comparison and import from the previous two timetable versions,
- Only valid train paths drawn:
  - Interlocking settings and track occupancies
  - Track infrastructure constraints (speed, stopping)
  - Rolling stock constraints (speed)
- Costs evaluated continuously
- RailML communication with the system of the track capacity distributor.

Timetabling: OR

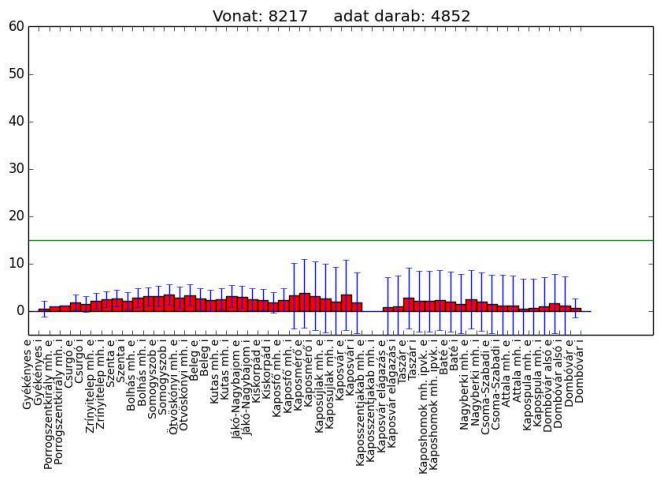
- Extensive literature
- In Hungary no experience yet
- Reasonable for subsets of trains,
  E.g. periodic within a day:
  Periodic Event Scheduling (PESP)

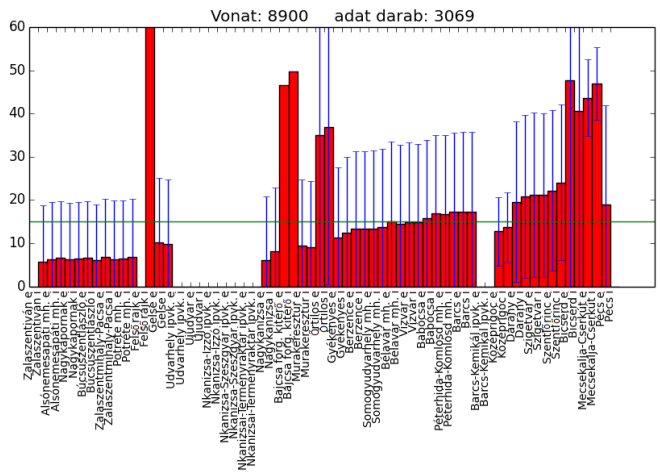
Timetable stability and expected punctuality

Stochastic point of view

- Delays at each station, delay increments, etc: random variables with a reach structure of correlations
- Delay correlations, delay propagation

A simple example





Rolling stock circulation

The task

Optimal assignment of rolling stock to the trains, s.t.

- technical requirements,
- maintenance requirements,
- capacity requirements.

Possible objectives

- **minimize runs with larger capacity than needed (incl. logistic trips)**
- achieve optimal seat occupance

Rolling stock circulation

The "SZVÖRNET" software module

- Uses the timetable.
- Uses the database of vehicles.
- Supports manual design of *vehicle rosters*.
- Calculates the related costs.

Vehicle rosters

- Vehicles are composed to trains at the depots.
- In the roster trains are assigned to train numbers
- Periodically the trains should return to the depot (from 5-6 days to 40-50 days).
- The regularity prescriptions of the vehicles is different from those in the timetable.
- Failed vehicles are treated separately.

Rolling stock circulation

OR

- Relatively new field
  (first practical results 10 years ago)
- The problem may be split along along certain considerations:
  - depots
  - vehicle types
  - ...
- Issues may be:
  - Combining and splitting of trains
  - Order of the vehicles

No Hungarian passenger rail experience yet...

Crew scheduling and rostering

Scope

- Traveling crews (conductors)
- Supplementary staff at stations (cashier staff, technical staff)

Given

- Timetable
- Rolling stock circulation plan
- Number of employees at each depot and their skills

Crew scheduling and rostering

Aim

- cover all tasks
- handle operative situations
- meet legal requirements
- minimize overtime
- maximize productivity

Crew scheduling and rostering

Steps (traveling crews)

1. Preliminary planning

   (for the duration of the validity of the timetable or some longer period within):

   1.1 Assing tasks to trains (with regularity prescriptions)
   1.2 Assing the tasks to depots
   1.3 Arrange tasks in pairs
   1.4 Create daily duties (scheduling)
   1.5 Define rosters (rostering)

2. Monthly planning: workplans for the whole month
3. Operative planning: handle changes within the month
4. Log data and send them to payroll calculation.

Crew scheduling and rostering

Steps (station crews)

1. Preliminary planning

   (for the duration of the validity of the timetable or some longer period within): define workplans for employees
2. Monthly planning: workplans for the whole month
3. Operative planning: handle changes within the month
4. Log data and send them to payroll calculation.

Periodic rosters

Latin square

h	k	sz	cs	p	szo	v	h	k	sz	cs	...
1	2	3	4	5	6	7	8	9	10	1	...
2	3	4	5	6	7	8	9	10	1	2	...
3	4	5	6	7	8	9	10	1	2	3	...
4	5	6	7	8	9	10	1	2	3	4	...
5	6	7	8	9	10	1	2	3	4	5	
6	7	8	9	10	1	2	3	4	5	6	...
7	8	9	10	1	2	3	4	5	6	7	...
8	9	10	1	2	3	4	5	6	7	8	...
9	10	1	2	3	4	5	6	7	8	9	...
10	1	2	3	4	5	6	7	8	9	10	...

“Railm@n” system of MÁV-START

Scope

- Support for station and traveling crew planning.
- Complete handling of the planning and logging of about 3000 traveling crews serving about 3000 trains daily, and 4000 members of station staff of the company on the whole network.
- Collection of personnel data through and interface from the SAP system of MÁV-START.
- Planning of station crew requirement for all the relevant groups of employees (cashier staff, technical personnel, operators, etc.).

“Railm@n” system of MÁV-START

Main functions

- Timetable and train-composition aware advanced schedule and roster designer.
- *Monthly and operative planner with an extensive set of verification functionality an innovative user interface.*
- *Automated scheduler and roster designer.*

“Railm@n” system of MÁV-START

Supplementary functionalities:

- Logging,
- Controlling and statistical functionality,
- Generation of basis data for payroll calculation for the SAP system, and their automated transfer through an interface.
- Capability of serving mobile and station terminal applications for crew personnel. (Not used yet in the lack of appropriate hardware at MÁV-START.)

Automated rosters for traveling crews

Input

- timetable and vehicle circulation plan,
- or optionally, a predefined set of train forwarding tasks.

Train forwarding tasks can be defined automatically:

Possible outputs

- A large set of valid daily duties to be chosen from during the manual design
- A set of chosen daily duties the simultaneous realization of which is optimal for some reason
- Complete, optimized rosters

Currently we provide the first two, at depot level

Automated rosters for traveling crews

Duty generation

- Chose a given date, handle it periodically in time.
- train forwarding tasks: a directed, unweighted graph $G(V, E)$:
  - V: tasks
  - $e \in E$ if the target task can be performed after the source task by the same crew member
  - Ordering of the edges emerging from a vertex which is defined by the starting time of the given train task
- $4000 <\approx |V| <\approx 8000$

Automated rosters for traveling crews

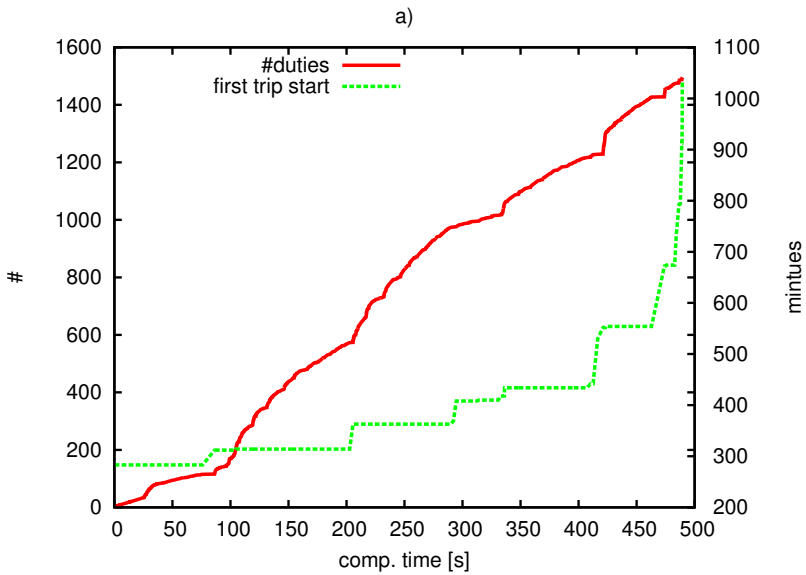
Duty generation: backtrack

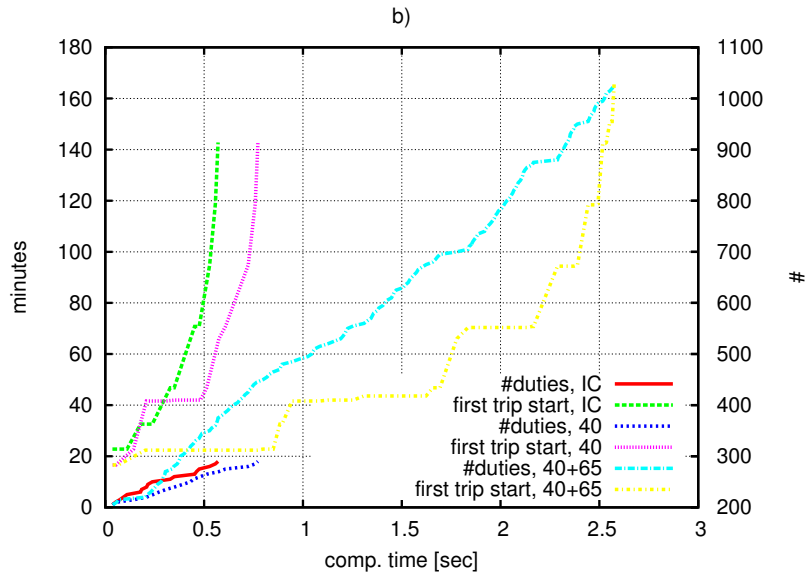
1. Pick a first vertex which is feasible at the prescribed starting time of the duty.
2. Assign the next (according to the ordering of the emerging edges) vertex which is available. If it is not possible, go to step 7 except for the case when the vertex in step 1 was chosen. In the latter case, terminate.
3. Verify if the supplementary tasks can be assigned according to technological and legal restrictions. If yes, assign them and proceed. If no, go to step 7.
4. Verify if the possible quality measures of the duty fragment meet some threshold requirement. (E.g. if most of the duty consists of large waiting times and short productive tasks, it is likely that it will not be a part of a "good" duty.) If yes, proceed. If no, go to step 7.
5. Verify if the length of the duty at the present point is above the minimum length of a duty. If yes, add the duty to the set of generated duties.
6. Go to step 2.
7. Remove the last chosen vertex from the actual duty, and go to step 2.

Preconditioning

- We may limit the tasks to certain railway lines.
- We may limit ourselves to given types of trains, e.g. suburban or InterCity (IC) trains only.
- We may limit the maximum distance from the depot. This is considered to be 4 by default, as this results in practically accepted and stable trip patterns (pairs, etc.).
- We may limit the minimum and maximum duration of the duties to a more stringent one than the one the legislation allows for.

Preconditioning: calculation timing





Preconditioning: some cases

depot (and abbrev.)	restriction	max. dist.t	min. [hours]	max. [hours]	# tasks	calc. duration [min:sec]	# of duties generated
Pécs (PS)	none	4	6	16	3212	08:09	1492
Pécs (PS)	InterCity only	4	6	16	150	<00:01	18
Pécs (PS)	Lines 40 and 65 only	4	6	16	134	00:02	165
Pécs (PS)	Line 40 only	4	6	16	100	<00:01	18
Szolnok (SL)	none	4	6	16	3212	> 20:00	> 30 000
Szolnok (SL)	line 120a only	4	6	16	117	06:54	25 176
Szolnok (SL)	line 120 and 120a only	4	6	16	187	08:00	26 322
Szolnok (SL)	suburban trains only	1	6	16	1232	01:02	2 932
Cegléd (CV)	lines 100a and 140	4	6	16	182	08:50	28 106
Cegléd (CV)	lines 100a	4	6	16	129	08:14	27 716
Székesfehérvár (SV)	lines 30a, 42 and 44 only, suburban trains only	4	8	10	108	09:51	637
Székesfehérvár (SV)	lines 29, 30, 30a, 42, 44 and 44 only	4	8	10	288	18:20	895

Automated rosters for traveling crews

Set covering

- Basic set: tasks v_i
- Subsets: duties

$$d_k \to \delta_k = \begin{cases} 1, & \text{the duty is realized} \\ 0, & \text{it isn't realized.} \end{cases}$$

- Objective: anything proportional to the fact that a duty is done

$$\sum_k C_k \delta k$$

typically: working time

Automated rosters for traveling crews

Set covering: constraints

- Set of tasks to be covered:

$$\sum_{k,\ v_i \in d_k} \delta_k \geq 1$$

  (or equal)

- Number of days:

$$\sum_k \delta_k \leq l_{\max}$$

$$\sum_k \delta_k \geq l_{\min}$$

- Other custom (logical) constraints...

Automated rosters for traveling crews

Semi-automatic mode

- The user may chose from the generated duties.
- The model maybe run with setting some δ-s to 1.

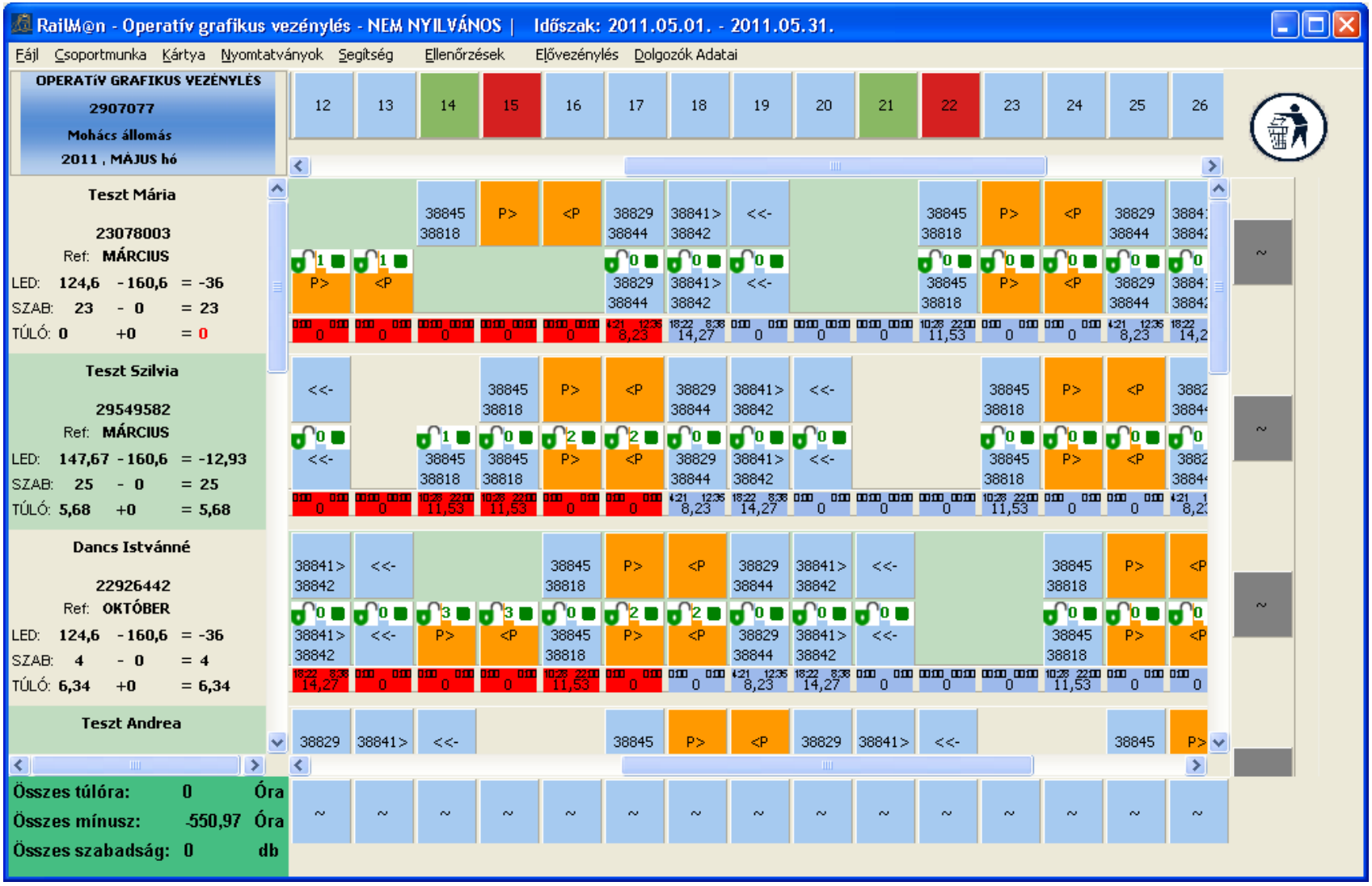
Ongoing work:

Automatic mode

- Additional constraints (order of duties, etc.)
- Network-level design

Monthly planning: the card metaphor

monthly and operative planning ≡ a card game



Concluding remarks

- From the research point of view passenger railway optimization involves modeling, as well as mathematical challenges.
- Due to the significant differences in the technology, demands and legal environment of various passenger railway companies. any case study may contain issues of academic interest.
- Meanwhile there are a lot of software solutions covering partly or fully covering the business processes of railways.
- Some of these are specialized for a given individual company's demands. while there are out-of-box solutions which can be customized to some extent.
- Since there is a significant competition amongst software companies, it is sometimes hard to compare the implemented optimization methods and their efficiency.

Some bibliography

- CAPRARA A., KROON L., MONACI M., PEETERS M., TOTH P.: Passenger railway optimization, In. : Handbook in OR & MS vol. 14., Elsevier (2007)
- ERNST A. T., JIANG H., KRISHNAMOORTHY M., OWENS B., SIER D.: *An Annotated Bibliography of Personnel Scheduling and Rostering*, Annals of Operations Research Vol. 127, 2004. pp. 21-144.
- ERNST A. T., JIANG H., KRISHNAMOORTHY M., NOTT H., SIER D.: *An Integrated Optimization Model for Train Crew Management*, Annals of Operations Research Vol. 108, 2001. pp. 211-224.
- HARTOG A., HUISMAN D., ABBINK E. J. B., KROON L. G.: *Decision support for crew rostering at NS*, Public Transport Vol. 1. 2009. pp. 121-133.
- CAPRARA, A., FISCHETTI, M., TOTH, P., VIGO, D., GUIDA, P. L.: *Algorithms for Railway Crew Management*, Mathematical Programming Vol. 79. 1997. pp. 125-141.
- GOUMOPOULOS, C., HOUSOS, E.: *Efficient Trip Generation With a Rule Modeling System for Crew Scheduling Problems*, Journal of Systems and Software, Vol. 69. 2004. pp. 43-56.
- KONIORCZYK M., TÁLAS B., GEDEON F.: Preconditioning in the backtracking duty generation of passenger rail crew scheduling: a case study, Communications: Sci. Lett. Univ. Žilina, submitted.