Generating timetables with partial periodicity

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Operated timetable in Switzerland

Zürich	xx:04	xx:35	16:41	17:41	18:41	00:07
Luzern	xx:49	xx:25	17:39	18:39	19:39	01:07
Time	**0:45**	**0:50**	**0:58**	**0:58**	**0:58**	**1:00**

Wil	6:25	6:54	7:25	7:54	xx:25	xx:54	22:54
St. Gallen	6:53	7:17	7:53	8:15	xx:53	xx:15	23:17
stops	Uzwil, Flawil, Gossau	Uzwil, Gossau	Uzwil, Flawil, Gossau	Gossau	Uzwil, Flawil, Gossau	Gossau	Uzwil, Gossau
Time	**0:28**	**0:23**	**0:28**	**0:21**	**0:28**	**0:21**	**0:23**

Standard offer

Peak hour Additional offer

Off-peak hour offer

Operated timetable abroad

Standard offer

Milano	7:15	7:45	8:15	8:30	8:45	9:30	10:30	11:30
Roma	10:45	11:15	11:45	12:29	12:59	13:29	14:29	15:29
Time	**3:30**	**3:30**	**3:30**	**3:59**	**4:14**	**3:59**	**3:59**	**3:59**

Paris	10:10	12:10	14:10	14:40	15:15	15:50	16:10	17:20
Bordeaux	13:11	15:24	17:14	17:38	18:48	18:52	19:17	20:23
Time	**3:01**	**3:14**	**3:04**	**2:58**	**3:33**	**3:02**	**3:07**	**3:03**

Stuttgart	12:07	14:07	14:40	16:07	16:42	18:07	18:40	-:-
Nürnberg	14:16	16:16	17:25	18:16	19:25	20:16	21:25	-:-
Time	**2:09**	**2:09**	**2:45**	**2:09**	**2:43**	**2:09**	**2:45**	**-:-**

Arising questions

- How should we consider the presented timetables?
  Periodic or non-periodic?
- Why were these timetables so generated?
- How are they generated?

Remarks on periodicity

- Periodicity is important for the passengers
  - It should be part of the offer
- Irregularities are necessary to face changing demand over the day
  - Additional services in peak hours
  - Different demand in the evening
- Currently:
  - Manually, or
  - Manual postprocessing of automatic periodic timetabling

Why?

How?

Current approaches

- Periodic timetabling
  + Good for regularity
  – Needs postprocessing for irregularities
  – Optimises only a part of the day
- Non-periodic timetabling
  + Good for irregularities
  – Loses offer of periodicity
  – Larger size
- New approach: Partial periodic timetabling

Partial periodic timetabling

1. Consider service intention for a whole day, with periodicity and exceptions as part of the offer
2. Formalise it in the partial periodic service intention
3. Generates partial periodic timetables

- Advantages:
  - No need of postprocessing
  - Allows optimisation all over the day

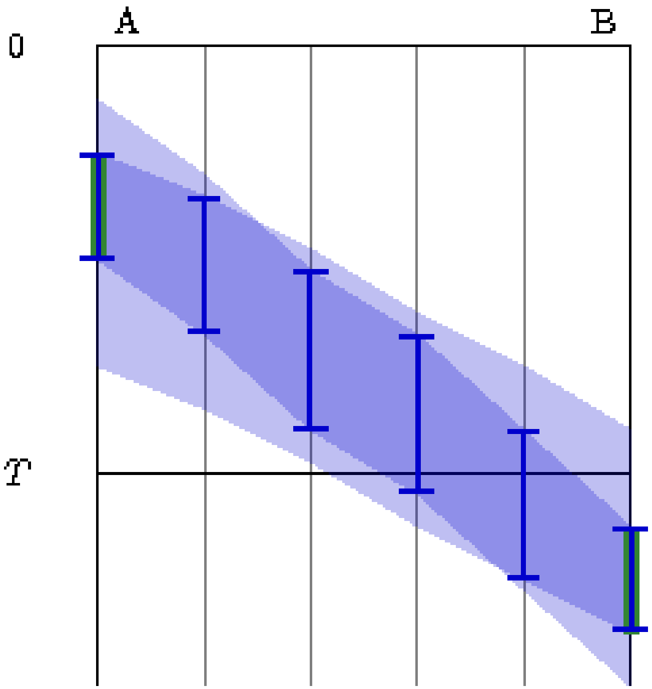
Partial periodic service intention

- Description of intended transport services for one day
- Set of services:
  - Train runs, connections, time dependencies
- Reference periodicity T
- Spatial-temporal graph

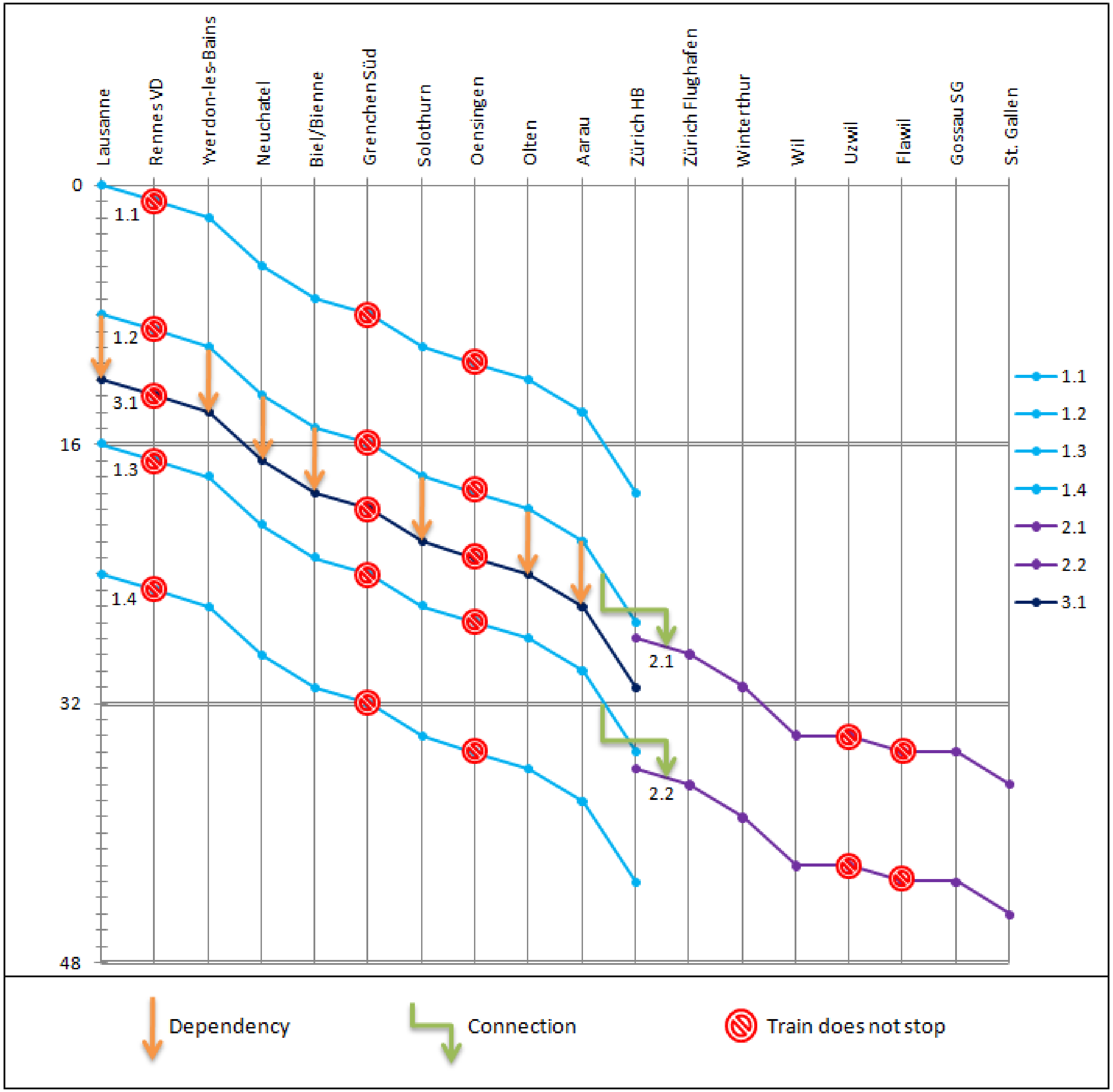
Train run

Service Intention
- Train run
- Connection
- Time dependency

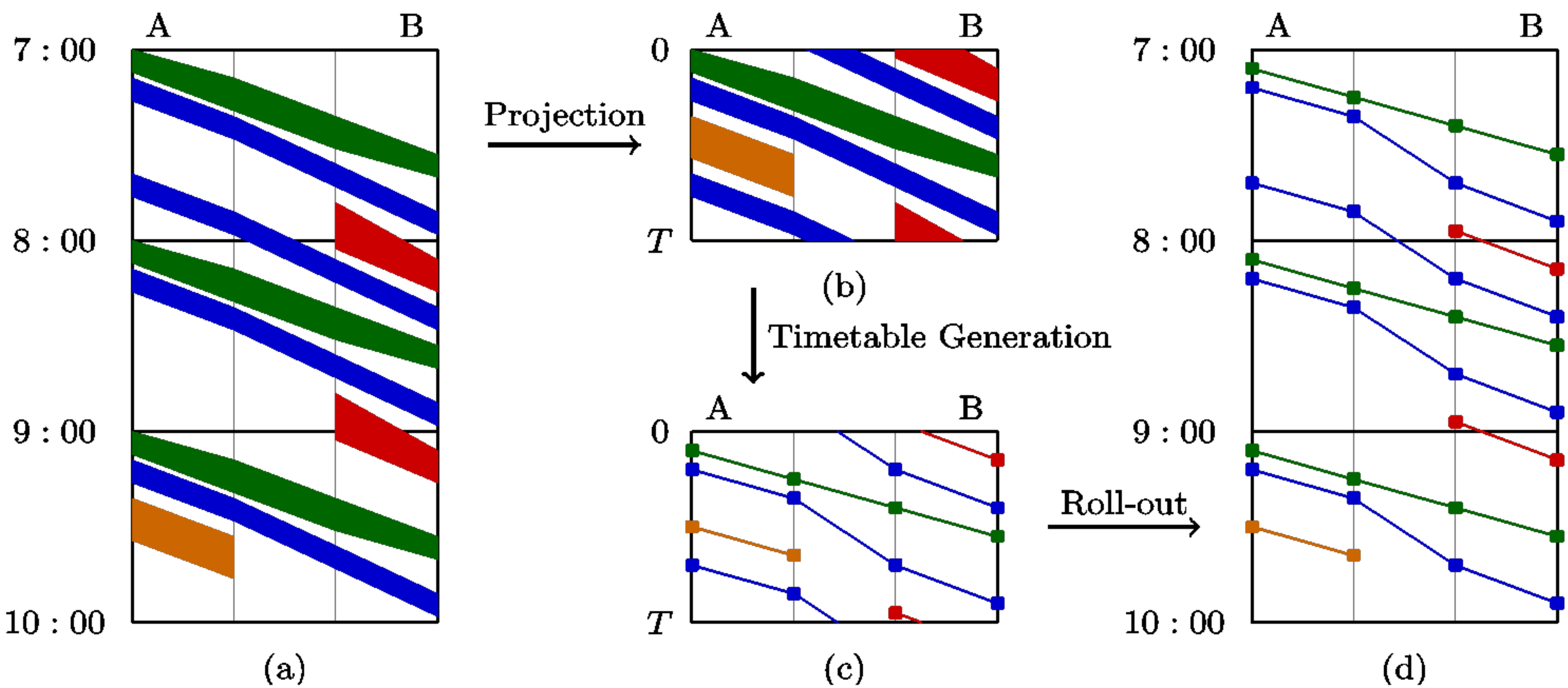
- Sequence of stations with:
  - Time slot for arrival / departure (at least one)
  - Lower/upper bounds for:
    - Trip time
    - Dwell time (= 0 if train does not stop)
  - Periodicity
  - First recurrence
  - Number of recurrences
- Similar for connections and time dependencies



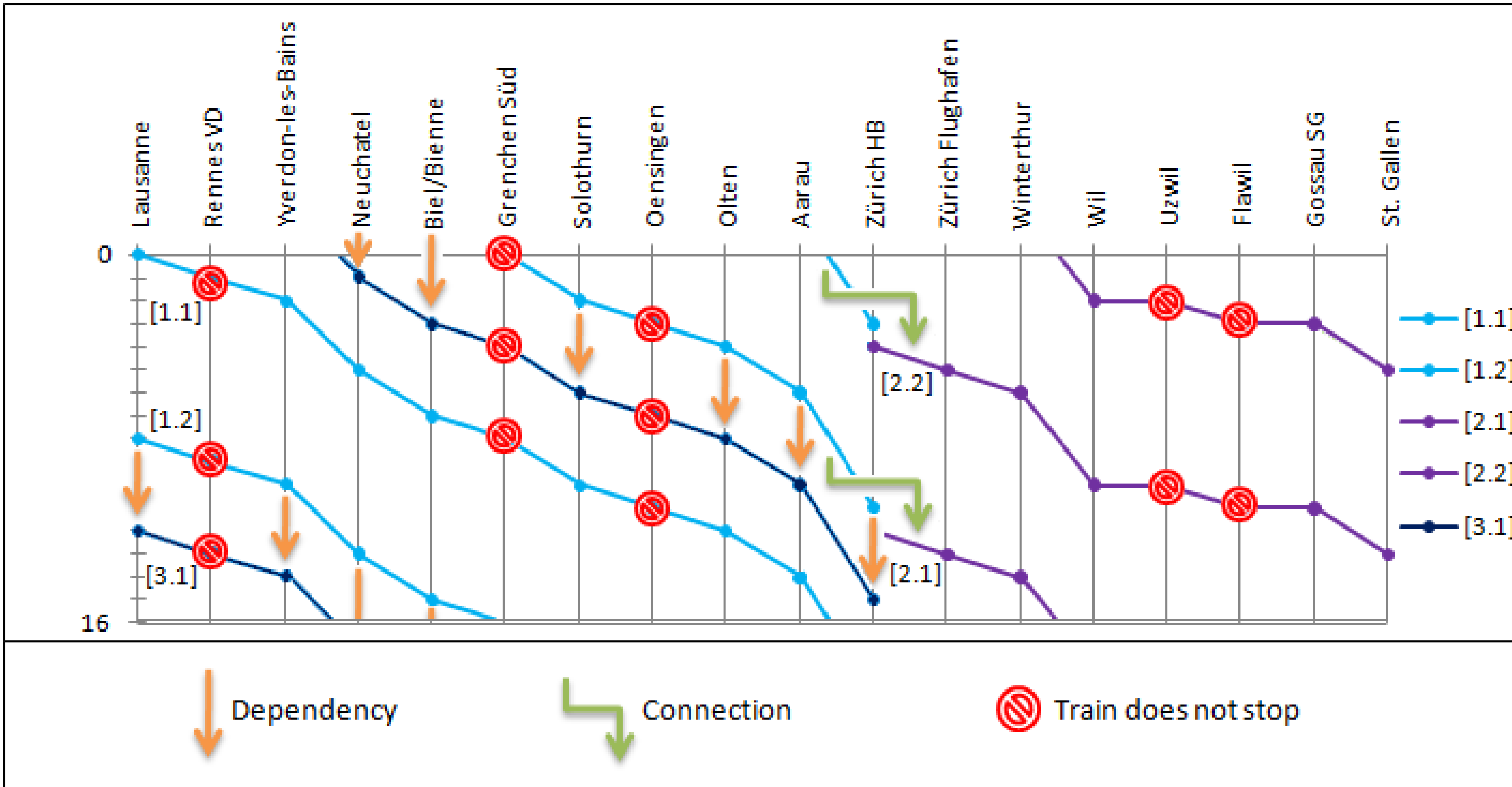
Example


Lausanne
Rennes VD
Yverdon-les-Bains
Neuchatel
Biel/Bienne
Grenchen Süd
Solothurn
Oensingen
Olten
Aarau
Zürich HB
Zürich Flughafen
Winterthur
Wil
Uzwil
Flawil
Gossau SG
St. Gallen
0
16
32
48
1.1
1.2
1.3
1.4
2.1
2.2
3.1
Dependency
Connection
Train does not stop

Solution approach: basic idea



Projection: example



Model for projected problem

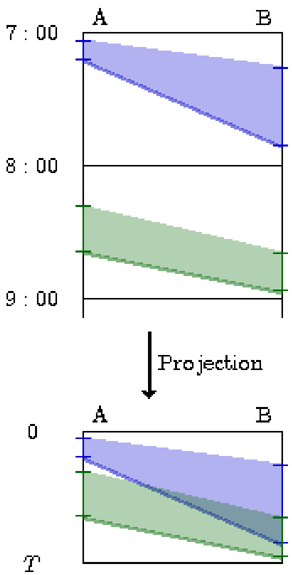
- Projected problem is modeled as a Periodic Event Scheduling Problem (PESP)
- Decision variables are event times (departure and arrival) of projected equivalence classes
- Train service constraints are easily modeled in PESP
- Headway constraints are different than classical PESP

Introduction (or not) of headway constraints

- If projection does not need headway
  → do not introduce headway constraint
- If projection needs headway
  → check original train service intention

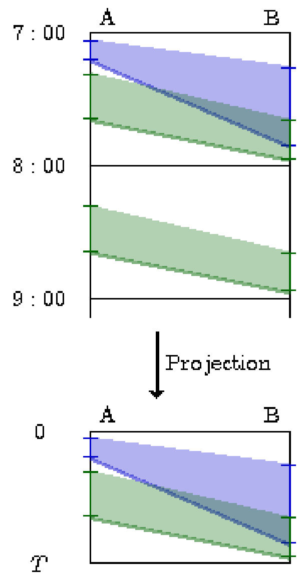
Introduction (or not) of headway constraints

- Headway necessary in the original version?



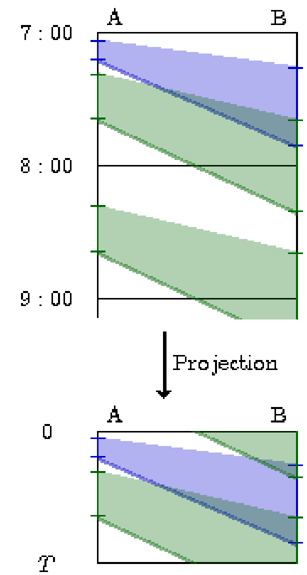
(a)

No → No headway



(a)

Yes → headway



(a)

Once yes and once no
→ special situation (*)

headway

Equivalence of the problem

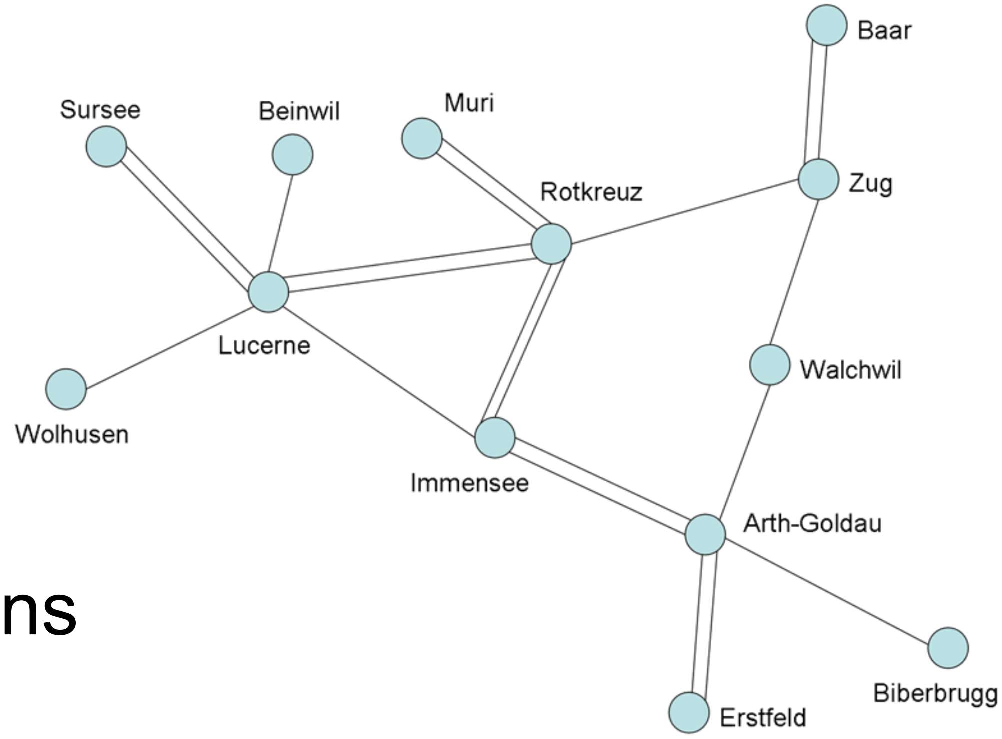
- If (situation (*) does not occur) and (all time slots have size < T), then:

Original Problem
is equivalent to
Projected Problem

- i.e. Solution Spaces are equivalent

Test scenario

- Central Switzerland: Zug – Lucerne – ArthGoldau
- Reverse-Engineering from 2008 SBB-Schedule
- Trains:
  intercity, local, cargo
- Compare with fully periodic variant
  without peak hours
  or late evening exeptions



Computational results

Scenario	T	# variables	# integer	# constraints	CPU time [s]
Partial periodic SI	60 120 No	2206 2936 12 122	963 1278 5168	3449 4594 19 076	24# 23 130
Fully periodic	60 120 No	802 1344 10 732	341 568 4544	1263 2120 16 920	6 2 70

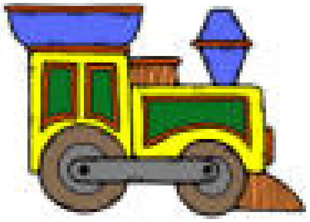
Situation (*) occurred, resulting in infeasible problem

In all other tests situation (*) did not occur

Conclusions

- Formalise partial periodicity, which is most common situation in practice
- Projection method enables the use of established methods for periodic timetabling
- The stronger the periodicity, the larger the size reduction
- Optimises over whole day, no need for post-processing

Thank You!



Time for questions!

Problem definition

- INPUT
  - Train service intention (incl. periodicity properties)
  - Railway network
  - Dynamic properties of rolling stock
- OUTPUT
  - Conflict-free train schedule
  - Fulfilling service intention

Connection

Service Intention
- Train run
- Connection
- Time dependency

- Connects 2 train runs at a common station
- Minimum changing time from station layout
- Maximal changing time from service intention
- Periodicity
- First recurrence
- Number of recurrences

Time dependency

Service Intention
- Train run
- Connection
- Time dependency

- Between two 2 train runs
- Lower and upper bound for departure time difference
- e.g. to enhance the service during peak hours, or coordinate two different train runs on same (sub-)line

Solution approach: basic idea

1. Project all train runs on the periodic time [0,T]
   - Create equivalence classes of train runs
2. Apply existing solvers for periodic scheduling
3. Roll out the created timetable on the complete day

- Reduces problem size

Train service intention

- List of train services offered to the customers, including:
  - Train lines with stop and frequencies
  - Interconnection possibilities
  - Rolling stock
- TSI can be generated by planners manually or partially automatic (e.g. line planning)