

# **Hybrid Cyclicity: Combining The Benefits Of Cyclic And Non-Cyclic Timetables**



The main product of a Train Operating Company is a train timetable.



## What is a timetable?

A railway timetable is defined as a set of arrival and departure times of every train from each of its stopping stations.

# 3 theories of TIME TRAVEL

CREATED BY HARRISON DEMONCHOU

## FIXED TIMELINE

IN A FIXED TIMELINE

EVEN WHEN PARTIES TRAVEL BACK IN TIME... THE FUTURE THEY LEFT CANNOT BE CHANGED. ALL EVENTS REMAIN AS FIXED POINTS IN TIME. THE ACTIONS OF THE TRAVELER IN THE PAST HAVE ALREADY BECOME PART OF HISTORY. THIS IS KNOWN AS THE NOVIKOV SELF-CONSISTENCY PRINCIPLE

**FOR EXAMPLE:** SAY YOU TRAVEL BACK IN TIME IN ORDER TO KILL ADOLF HITLER AS A BABY, IN ORDER TO PREVENT WWII.

YOU REPLACE HIM WITH A ORPHANED BABY, SO THAT THE FAMILY WILL NOT NOTICE. YOU TRAVEL BACK TO THE FUTURE, AND THE REPLACED BABY GROWS UP TO BECOME ADOLF HITLER HIMSELF.

**AS SEEN IN:** THE TERMINATOR 2 AND 3  
HARRY POTTER 3  
12 MONKEYS

## DYNAMIC TIMELINE

IN A DYNAMIC TIMELINE

ALTERED EVENTS IN THE PAST HAVE DEFINITE IMPACTS ON THE PRESENT.

**FOR EXAMPLE:** IF YOU TRAVEL BACK IN TIME AND KILL YOUR GRANDFATHER... YOU ALSO PREVENT YOUR OWN BIRTH, AND YOUR EVENTUAL TRIP BACK IN TIME. IN TURN, YOUR GRANDFATHER IS NEVER KILLED, AND YOU ARE BORN AGAIN, ONLY TO GO BACK IN TIME AND KILL YOUR GRANDFATHER ANYWAY.

THIS LOOP CONTINUES INFINITELY, AND CREATES A

**PARADOX**

**AS SEEN IN:** BACK TO THE FUTURE

## MULTIVERSE

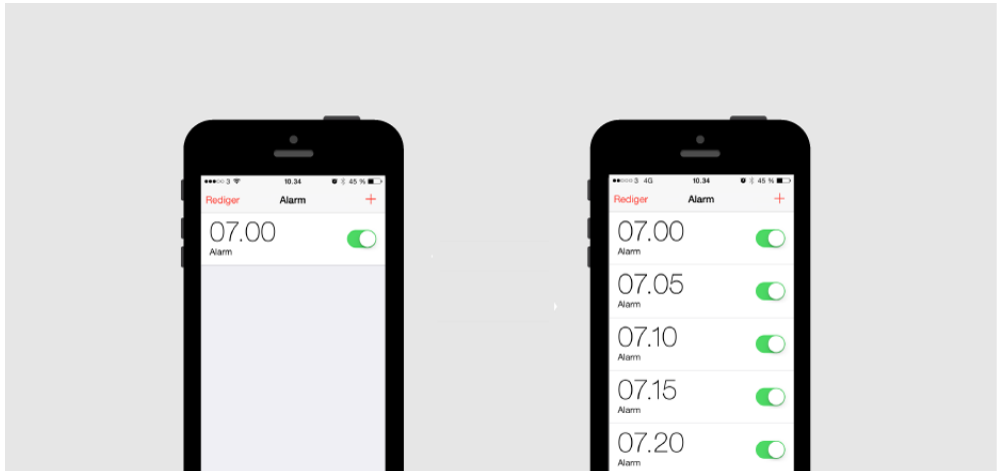
THE CONCEPT OF A MULTIVERSE SUPPORTS ALTERNATE TIMELINES

IN AN INFINITE NUMBER OF PARALLEL UNIVERSES. TRAVELING INTO THE PAST CAUSES A NEW DIVERGENT TIMELINE FROM THE FIRST. BECAUSE OF THIS, THE TRAVELER CAN DO ANYTHING WITH IMPUNITY, AND ONLY THE NEW TIMELINE WILL BE AFFECTED.

**FOR EXAMPLE:** IF YOU TRAVEL BACK IN TIME AND KILL ALL YOUR GRANDPARENTS, NOTHING HAPPENS. THERE IS NO PARADOX, YOU HAVE SIMPLY CREATED A NEW TIMELINE IN WHICH YOU WILL NOT EXIST, BUT THE ORIGINAL TIMELINE IS UNAFFECTED. HOWEVER, YOU CANNOT RETURN TO YOUR ORIGINAL TIMELINE.

**AS SEEN IN:** THE TERMINATOR 2 AND 3  
MISFITS  
STAR TREK (2009)

In our case, the travel times and dwell times are fixed. Therefore, we denote a timetable as a set of departure times of every train from its origin station ( $d_v^l$ ).



Two types of timetables exist: Non-Cyclic and Cyclic.

The cyclic timetable originates from the **Periodic Event Scheduling Problem** (PESP), which was first defined by Serafini and Ukovich (1989).

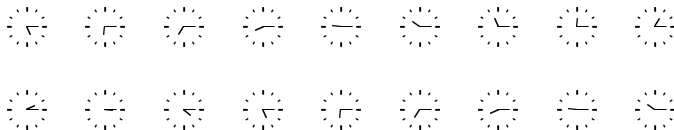
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**The Triennial Symposium  
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A set of events is scheduled in an equally spaced intervals, e.g. TRISTAN - every 3 years.

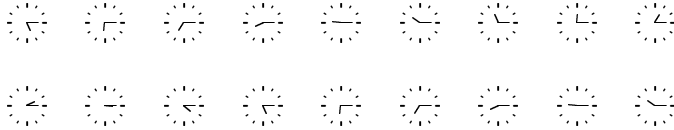
A special subset of cyclicity is the clockfaced timetables:



Event every xx:15.



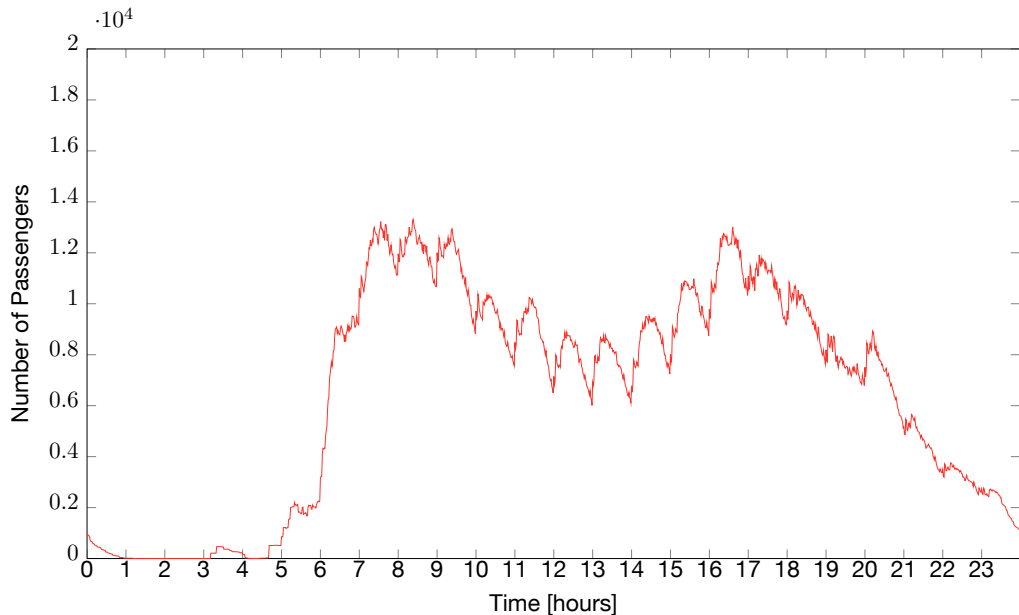
A special subset of cyclicity is the **clockfaced timetables**:



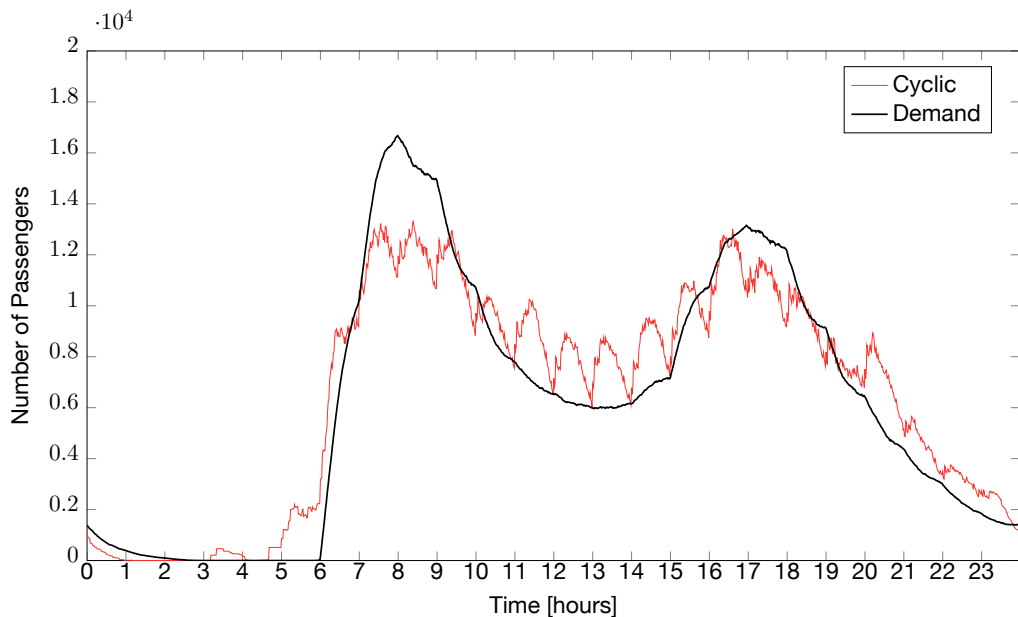
Event every xx:15. Especially popular within:



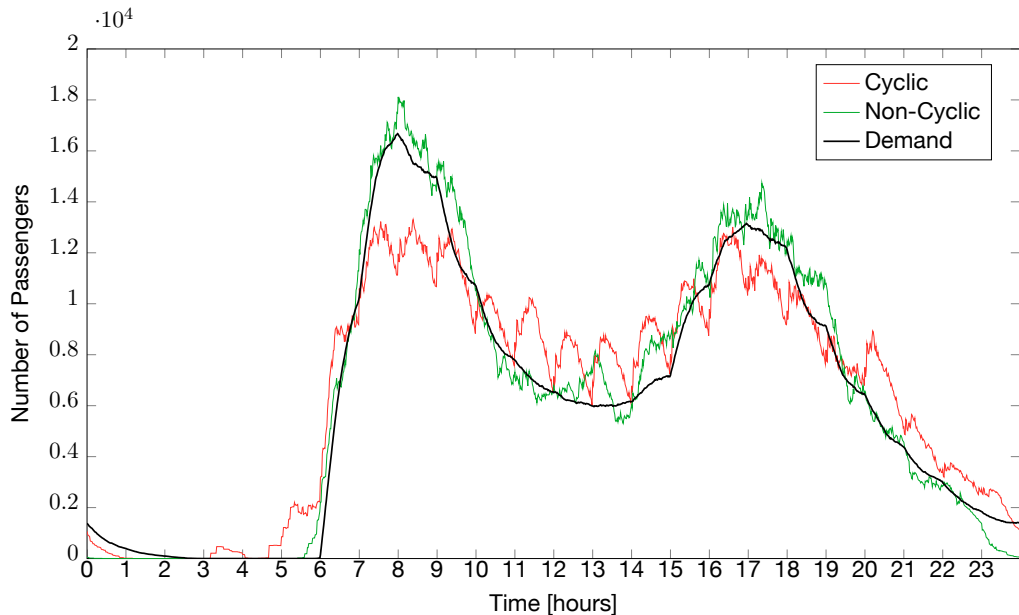
**Issue:** The demand is not uniformly distributed.



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Passengers find the regularity of a timetable easier to be memorized (Wardman et al. (2004), Johnson et al. (2006)).

Therefore one is not superior to the other.

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Why not both?

What we want to combine and how:



Figure: Ursus Wehrli

Regularity: Taken care of by the design



What we want to combine and how:

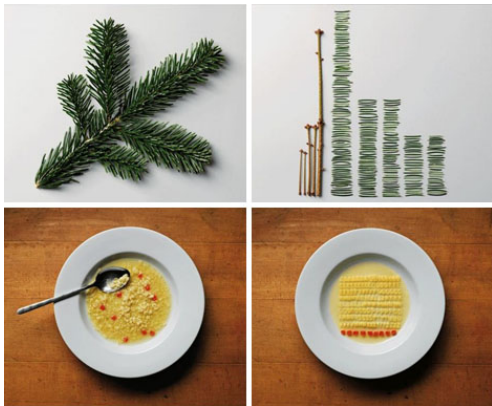
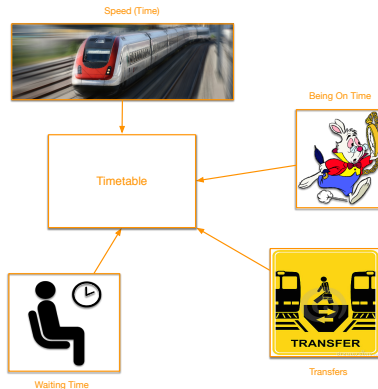


Figure: Ursus Wehrli

**Regularity:** Taken care of by the design



**Flexibility:** Passenger satisfaction, maximized by solving the Passenger Centric Train Timetabling Problem

$$S_i^{tp} = -VOT \cdot \left( \sum_{\ell \in L^p} r_i^{p\ell} + \beta_W \cdot w_i^{tp} + \beta_T \cdot (|L^p| - 1) + \beta_E \cdot \delta_{ip}^t + \beta_L \cdot \gamma_{ip}^t \right), \quad \forall i \in I, \forall t \in T_i, \forall p \in P_i,$$

$r_i^{p\ell}$

– running time/ in-vehicle time

$w_i^{tp}$

– waiting time

$|L^p| - 1$

– number of transfers

$\delta_{ip}^t$

– early schedule passenger delay

$\gamma_{ip}^t$

– late schedule passenger delay

$-VOT$

– value of time

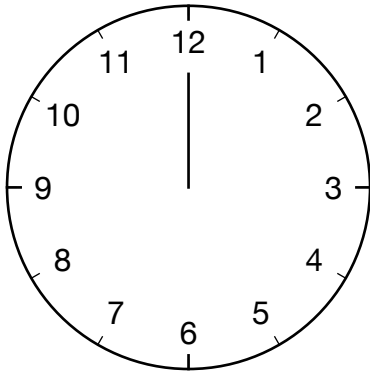
$\beta_W, \beta_T, \beta_E, \beta_L$

– estimates from literature

**What are the combinations?**



## $\theta$ Shifted Cyclic Timetable

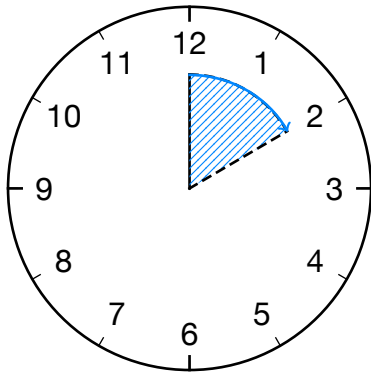


$$\Delta_v^\ell \in \langle -\theta, \theta \rangle$$

For a cycle of 60 minutes:

- $\theta = 0$  is equivalent to the cyclic timetable
- $\theta = 30$  is the maximum deviation without overlapping trains
- We test values between 0 and 30 in 3 minute intervals

## $\theta$ Shifted Cyclic Timetable

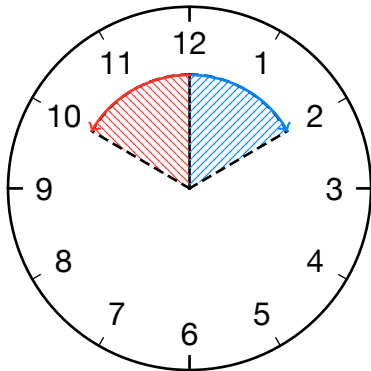


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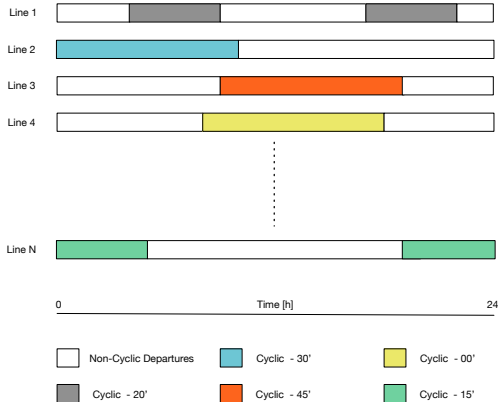


$$\Delta_v^\ell \in \langle -\theta, \theta \rangle$$

For a cycle of 60 minutes:

- $\theta = 0$  is equivalent to the cyclic timetable
- $\theta = 30$  is the maximum deviation without overlapping trains
- We test values between 0 and 30 in 3 minute intervals

# § Partially Cyclic Timetable



$$\eta = \max(|V^\ell|) \cdot \frac{\xi}{100}$$

$\eta$  trains per line have a cyclic departure time, the rest is free

For a cycle of 60 minutes:

- $\xi = 100$  is equivalent to the cyclic timetable
- $\xi = 0$  is equivalent to the non-cyclic timetable
- We test values between 0 and 100 in 10% intervals

# Hybrid Cyclic Timetable

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
0	0	0	0	0	0	1	2	2	1	2	1	1	0	1	1	1	1	0	2	0	1	1	0	0
0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	0	1
0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	3	2	2	1	0	0	2	0	1	1	2	1	0	0	0	1	0	0	0
0	0	0	0	0	0	1	1	2	0	1	1	0	1	1	3	1	2	0	1	1	0	1	0	0
0	0	0	0	0	0	1	0	1	1	0	1	1	0	1	1	1	1	0	1	1	0	1	0	0
0	0	0	0	0	0	1	1	3	2	0	0	0	0	0	0	1	1	2	0	0	0	0	0	0
0	0	0	0	0	0	1	3	0	2	0	0	0	0	0	2	2	1	0	2	0	0	0	0	0
0	0	0	0	0	0	2	1	3	0	2	0	0	0	2	0	1	1	0	0	0	0	0	0	0
0	0	0	0	0	0	2	2	2	1	1	1	0	0	1	1	1	1	1	1	0	0	0	0	0
0	0	0	0	0	0	0	2	1	0	0	0	2	1	2	1	2	1	2	1	0	0	1	0	0
0	0	0	0	0	0	1	1	3	1	1	0	2	1	1	1	2	1	3	0	0	0	0	0	0
0	0	0	0	0	0	1	1	1	2	1	1	1	1	1	1	2	1	1	1	1	0	0	0	0
0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
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0	0	0	0	0	0	1	1	0	1	0	0	0	0	0	0	1	0	0	2	1	0	0	0	0
0	0	0	0	0	0	1	2	0	0	1	1	0	0	0	0	1	0	0	0	0	1	0	0	0
0	0	0	0	0	0	2	1	1	1	0	1	0	1	2	1	3	1	1	1	1	0	1	0	0
0	0	0	0	0	0	2	3	1	1	1	0	2	0	0	1	1	1	2	2	0	1	0	0	0
0	0	0	0	0	0	1	1	2	0	0	1	3	1	0	3	1	1	1	1	0	0	0	0	0
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0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	1	0	3	0	0	0	0	0
0	0	0	0	0	0	0	2	1	1	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	1	0	0	1	0	1	1	1	1	1	0	0	0	1	1	0
0	0	0	0	0	0	2	2	0	0	0	1	0	1	1	1	0	0	1	0	0	0	0	0	1

A cycle can have:

- no train
- a cyclic train
- a cyclic train and one or more non-cyclic ones



# Model

- max satisfaction* (1)
- satisfaction function* (2)
- at most one path per passenger* (3)
- link trains with paths* (4)
- cyclicity* (5)
- train scheduling* (6)
- train capacity* (7)
- schedule delay* (8)
- waiting time* (9)

## Methodology: Simulated Annealing



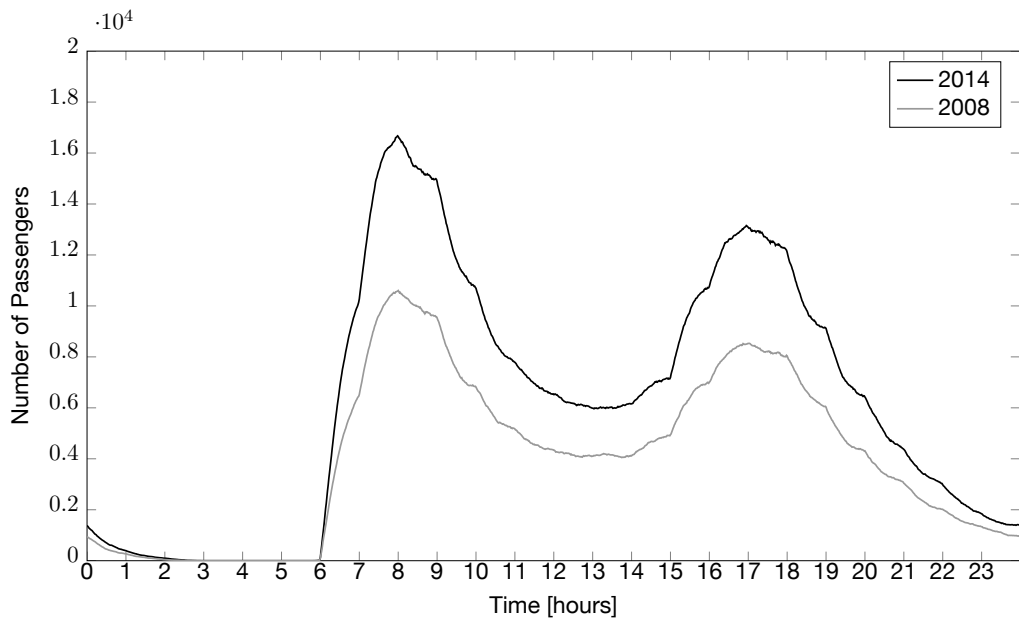
# Case Study



# Israel 2008



- OD Matrix for an average working day (Sunday to Thursday) in Israel during 2008
- 47 Stations
- 2162 ODs
- 34 (unidirectional) lines
- 380 trains
- Min. transfer – 4 mins
- VOT – 21.12 NIS per hour
- 126 036/193 886 Passengers

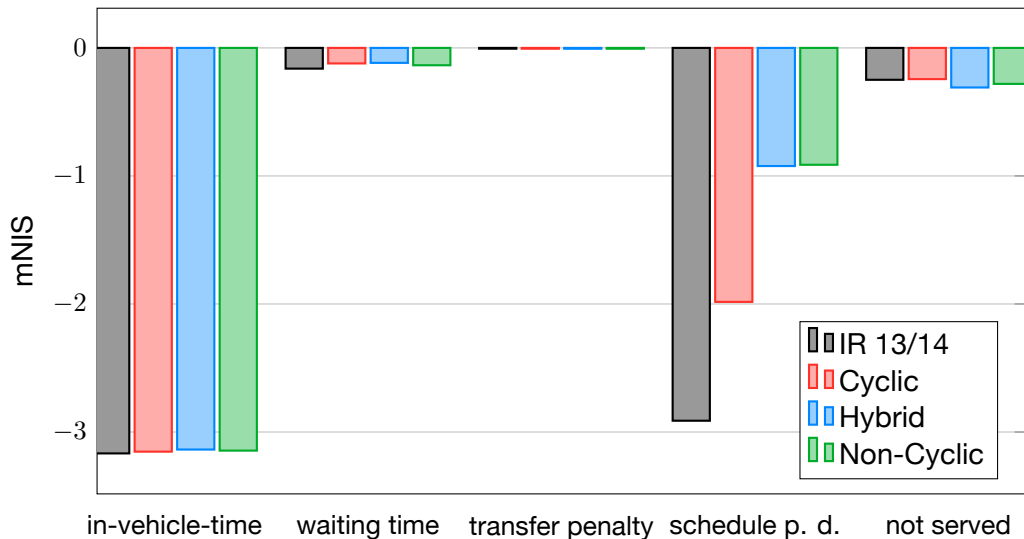


	IR 13/14 as Strictly Cyclic	IR 13/14	cyclic	non-cyclic	perfect service
satisfaction [NIS]	-704 904	-537 503	-476 774	-424 529	-2 089 049
drivers [-]	470	388	388	388	48 960
rolling stock [-]	940	776	776	776	48 960
covered [%]	100	100	100	100	100
time [sec]	12	6	24 997	25 613	1

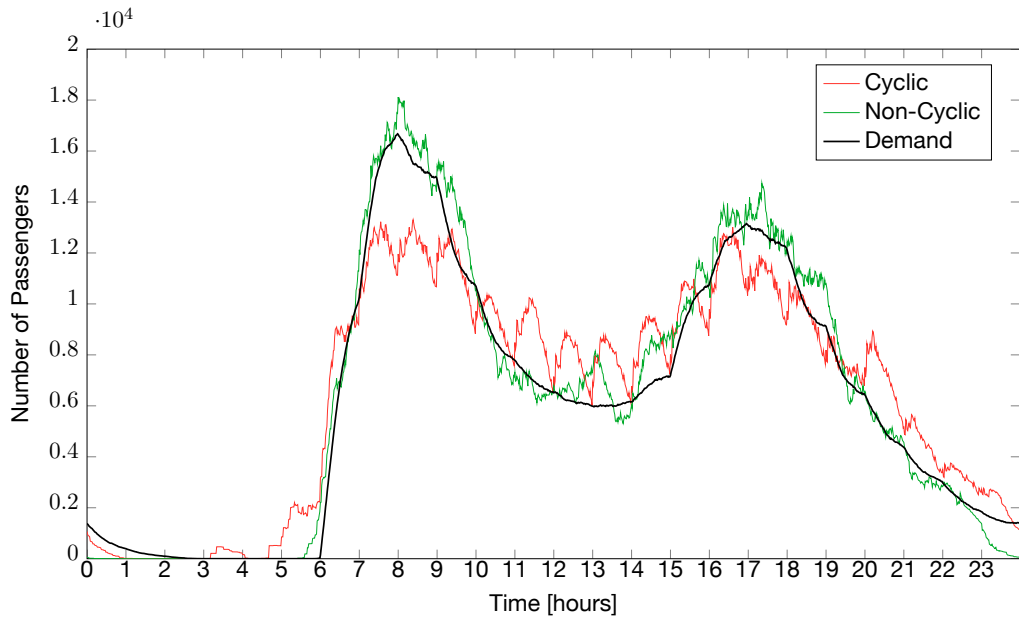
**Table:** *Computational results of the existing timetables for the 2008 demand*

	IR 13/14 as Strictly Cyclic	IR 13/14	cyclic	non-cyclic	perfect service
satisfaction [NIS]	-3 792 733	-3 379 596	-2 392 909	-1 365 779	-3 171 721
drivers [-]	470	388	388	388	48 960
rolling stock [-]	940	776	776	776	48 960
covered [%]	99.17	99.32	99.32	99.23	100
time [sec]	11	8	86 627	88 342	2

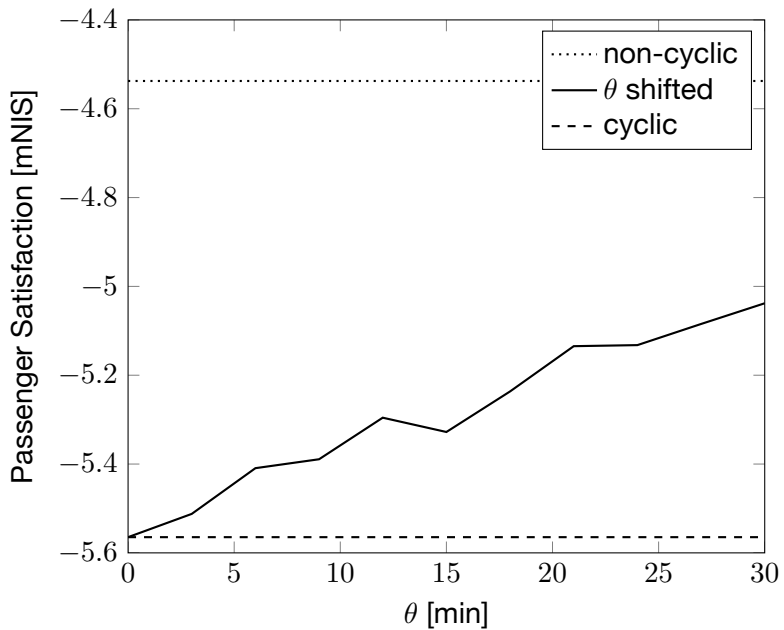
**Table:** *Computational results of the existing timetables for the 2014 demand*

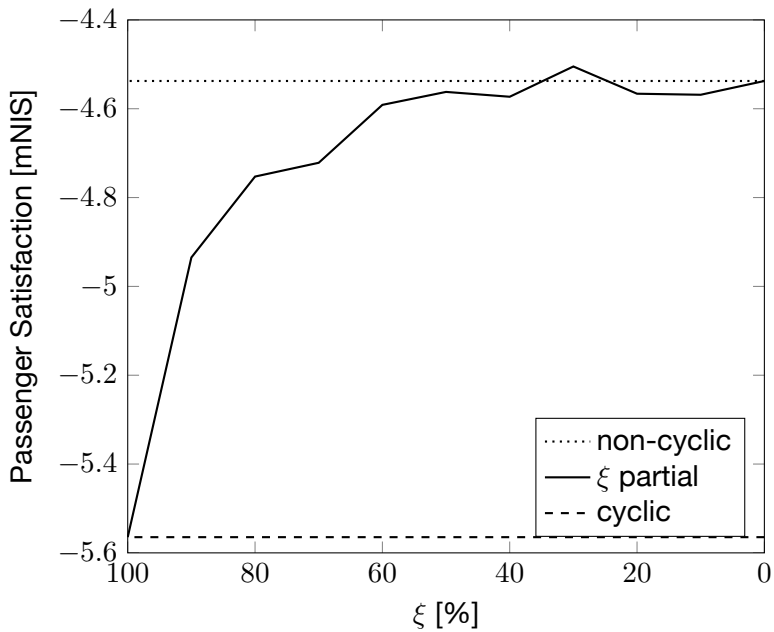


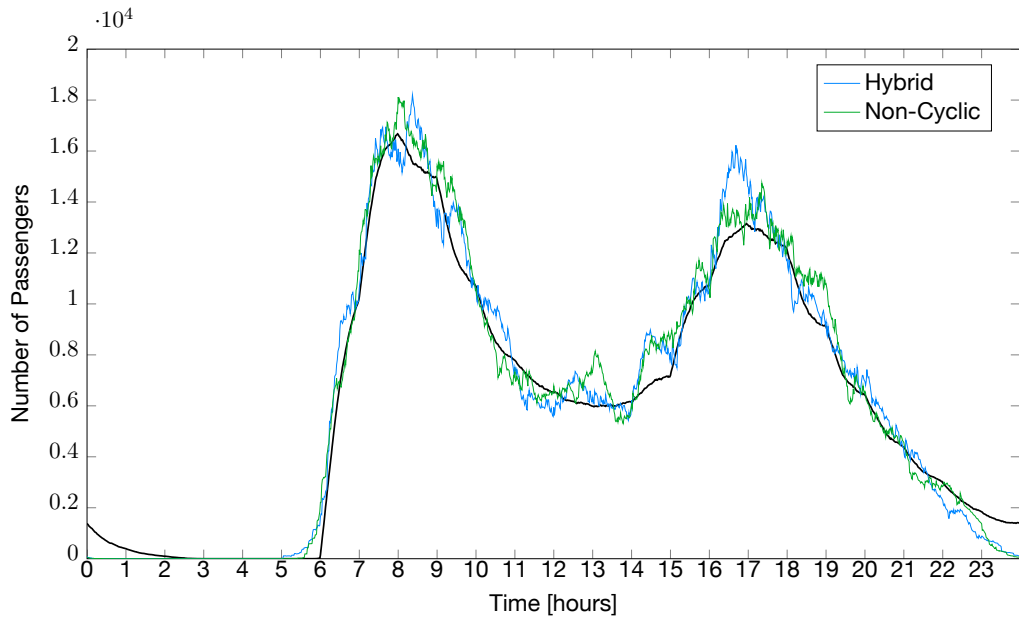
**Figure:** Breakdown of the passenger satisfaction for various timetables under the 2014 demand











## Conclusion

## Case Study

- Difference in Pax. Sat. between cyclic and non-cyclic timetable: 18.5%
- $\theta$  Shifted Timetable can reduce the difference to a half
- $\xi$  Partially Cyclic can diminish the difference already at  $\xi = 60$  with a train ratio 3:1
- Hybrid Cyclic finds the same ratio, provides good level of service

## General

- As the demand is time dependent, purely cyclic timetable is not a good option
- Hybrid cyclic timetable can diminish the impact of the cyclicity constraints

## **Future Work**

- Elastic Demand
- Need of an opt-out
- Maximize Profit
- Adapt Pricing Scheme



The regularity of a habit is generally in proportion  
to its absurdity.

(Marcel Proust)

izquotes.com

**Thank you for your attention.**



## References

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- Serafini, P. and Ukovich, W. (1989). A mathematical model for periodic scheduling problems, *SIAM J. Discret. Math.* **2**(4): 550–581.
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