TECHNISCHE UNIVERSITÄT DRESDEN

Fakultät Verkehrswissenschaften „Friedrich List"

Professur für Bahnverkehr, öffentlicher Stadt- und Regionalverkehr

Public Transport Operations and Supply

Development of rotating duty rosters

Dipl.-Ing. Steffen Dutsch

Technische Universität Dresden

18 faculties in five schools:

- **Mathematics und Natural Sciences**
- **Humanities and Social Sciences**
- **Medicine**
- **Engineering Sciences**
- **Civil and Environmental Engineering**

  Faculty of Transport and Traffic Sciences „Friedrich List"

  7 institutes, 22 chairs

36.000 students and 6000 employees

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Structure of the faculty

- Institute of Transport Planning and Road Traffic
- Institute of Traffic Telematics
- Institute of Logistics and Aviation
- Institute of Railway Vehicles and Railway Technology
- Institute of Transport & Economics
- Dresden Institute of Automobile Engineering
- **Institute of Railway Systems and Public Transport**

Founded in: 1992
Professors: 22
Students: ≈1500

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Structure of the institute

- Chair of Transportation Systems Engineering
- Chair of Planning and Design of Railway Infrastructure
- **Chair of Rail and Public Urban Transport**
- Chair of Railway Signalling and Transport Safety Technology

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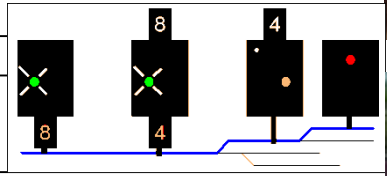
Structure of the chair

- Professional group of railway traffic
- Professional group of railway operation
- Professional group of public urban transport
- Railway Operation Laboratory



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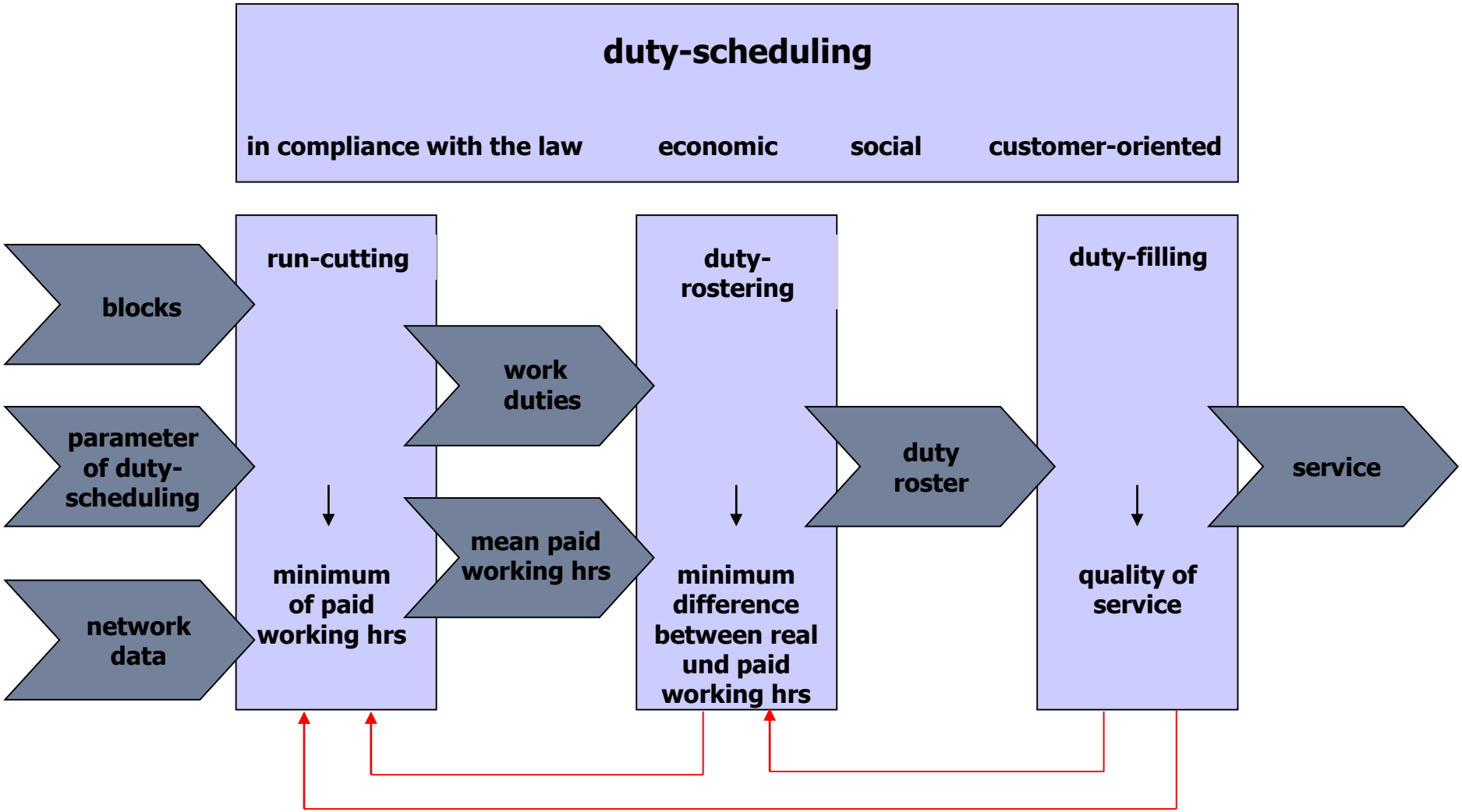
Task and steps of duty-scheduling



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Tasks and problems of duty-rostering

Task:

group all duties and days-off into a roster, that is

- with exactly one employee per duty each day
- in compliance with the law
- as social as possible

Problems:

- Different number of duties at different days (monday to friday, saturday and sunday)
- minimal rest period: 10 hours
  maximal number of duties without days-off: 6 duties
  minimal number of free sundays per year: 15 sundays
- Number of cycledays, sum of duties and days-off should be between 4 and 8 days but never 7 days

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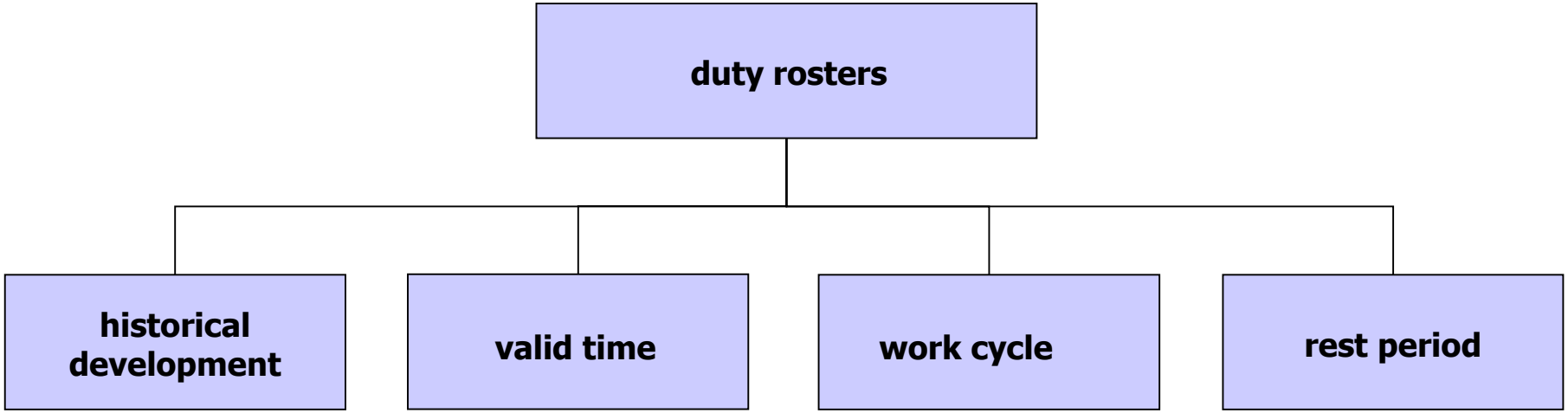
types of duty rosters



- entire duty roster for all employees
- different duty rosters often with main and side rotation
- chooce duty roster
- request duty roster

- monthly duty roster
- duty roster for schedule period

- duty roster with fixed cycle
- duty roster with weekly cycle

- shift similarly duty roster
- duty roster with fast rotation
- duty roster with slow rotation

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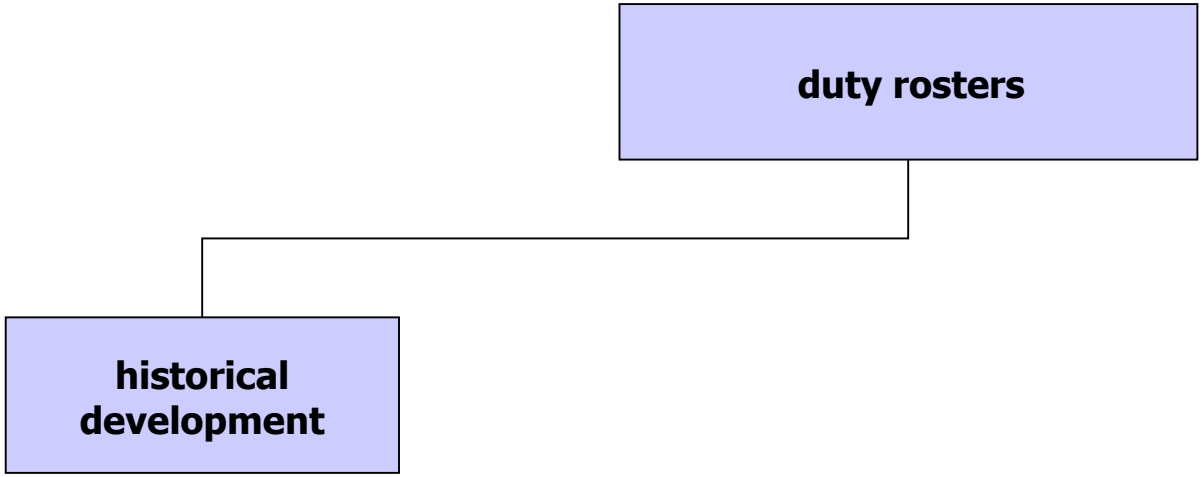
types of duty rosters



- **entire duty roster for all employees**	one duty roster for all employees each employee should do all the duties	all employees have the same working time
- **main rotation and side rotation**	consists of popular duties consists of unpopular duties (two parts)	seldom a free weekend often a free weekend
- **chooce duty roster**	one rotation with early duties one rotation with late duties	at all times early duty at all times late duty
- **request duty roster**	one basic duty roster for all employees with possibility to wish duties	every employee has for example 10 points monthly

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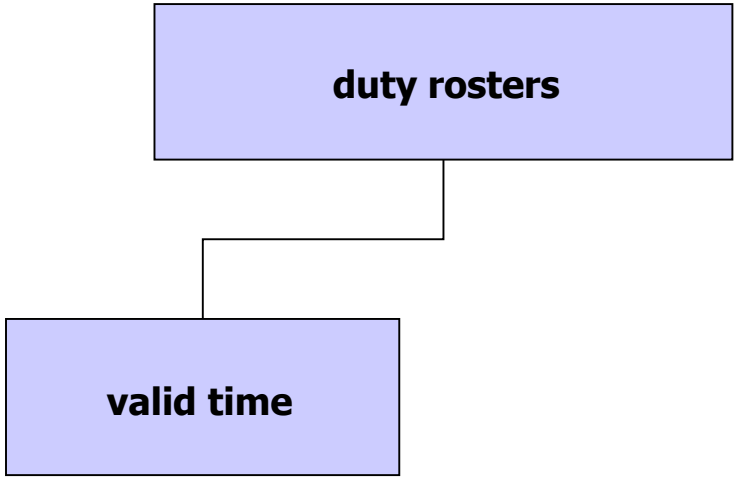
types of duty rosters



- **monthly duty roster** →
  - regional transport, public urban transport in small networks
  - whithout any cycle
  - possibility to take bank holidays, special features ore wishes into account
- **duty roster for schedule period** →
  - rail transport, public urban transport in large networks
  - whith fixed ore weekly cycle
  - no possibility to take bank holidays, special features ore wishes into account;
    this possibility exists only in the step duty-filling

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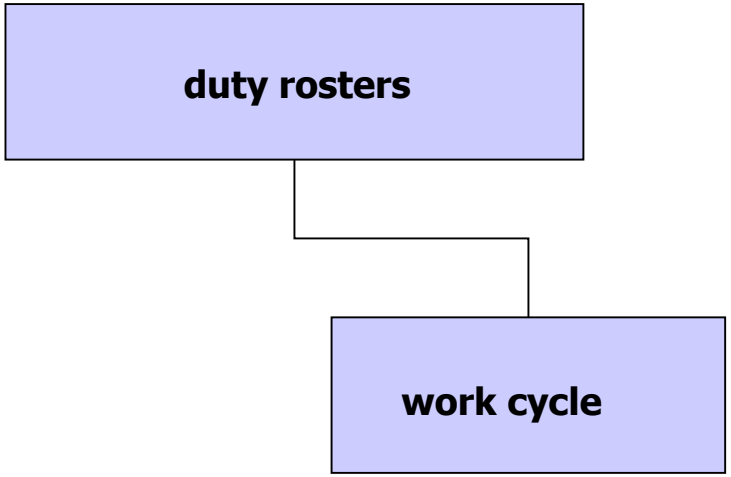
types of duty rosters



- **duty roster with fixed cycle** → Lehner methodologie
- **duty roster with weekly cycle** → Rüger methodologie

Point 2

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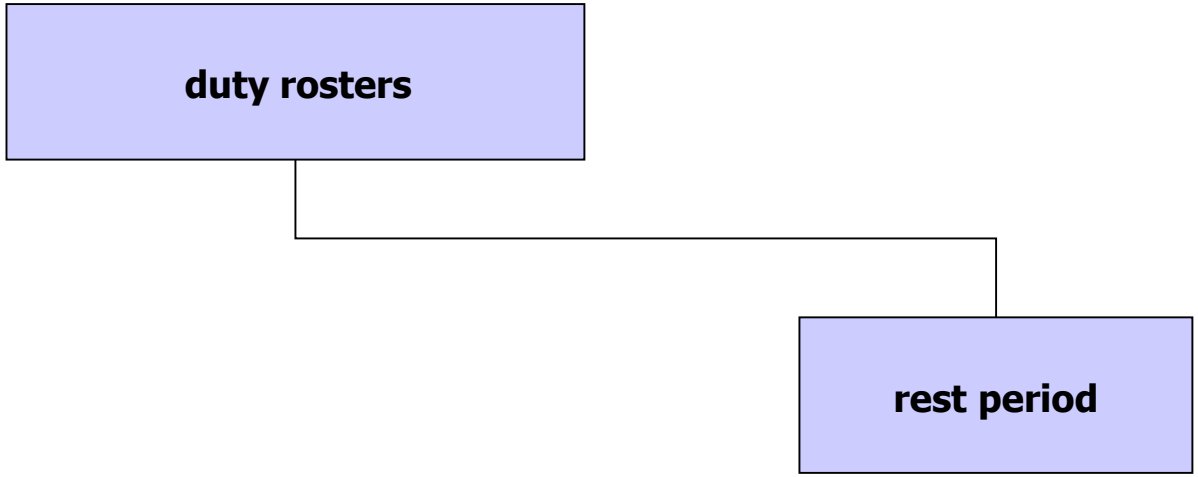
types of duty rosters



second duty begins and ends about 24 hours after the first
best possibility for families with children
← - **shift similarly duty roster**

second duty begins and ends less than 24 hours after the first
popular with young people
← - **duty roster with fast rotation**

second duty begins and ends more than 24 hours after the first
best possibility for elderly employees [1)]
← - **duty roster with slow rotation**

[1)] reference:
Tarifvertrag zur Bewältigung des demografischen Wandels im Nahverkehr.- Vereinigung der kommunalen Arbeitgeberverbände (VKA), 2013

[1)] reference:
collective agreement to overcome demographic change in public transport.- Union of Employers' Associations, 2013
enacts Janurary,1 2014

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Transportation systems (M. Sc.)

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Duty roster with fixed cycle

4 working days and 2 days-off

weekday	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7
cycleday	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
staff no. 1	■	■					■	■					■	■					■	■					■	■					■	■					■	■						
staff no. 2		■	■					■	■					■	■					■	■					■	■					■	■					■	■					
staff no. 3			■	■					■	■					■	■					■	■					■	■					■	■					■	■				
staff no. 4				■	■					■	■					■	■					■	■					■	■					■	■					■	■			
staff no. 5					■	■					■	■					■	■					■	■					■	■					■	■					■	■		
staff no. 6	■					■	■					■	■					■	■					■	■					■	■					■	■					■	■	

4 working days and 1 day-off

weekday	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su
cycleday	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
staff no. 1	■					■					■					■					■					■					■				
staff no. 2		■					■					■					■					■					■					■				
staff no. 3			■					■					■					■					■					■					■			
staff no. 4				■					■					■					■					■					■					■		
staff no. 5					■					■					■					■					■					■					■

weekday	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su
cycleday	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
staff no. 1					■					■					■					■					■					■					■
staff no. 2	■					■					■					■					■					■					■				
staff no. 3		■					■					■					■					■					■					■			
staff no. 4			■					■					■					■					■					■					■		
staff no. 5				■					■					■					■					■					■					■

Mo	Tu	We	Th	Fr	Sa	Su
				■		
		■				
■					■	
	■					

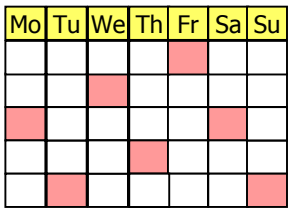
■ day-off

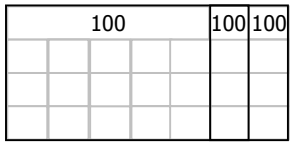
□ duty

■■□□□□ cycle basis group of 6 days

Duty roster with fixed cycle

4 working days and 1 day-off





Z_{sa}	Z_{so}	t_X
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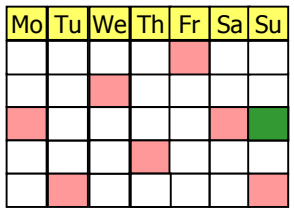

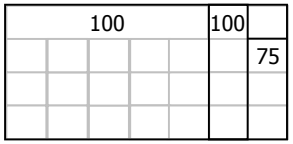

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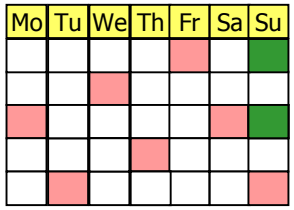

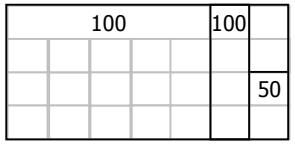

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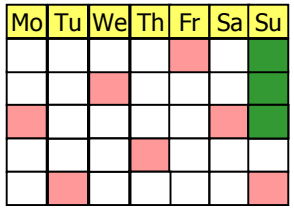

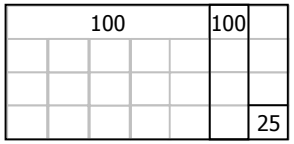

Z_{sa}	Z_{so}	t_X
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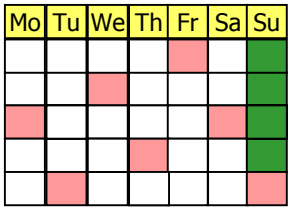

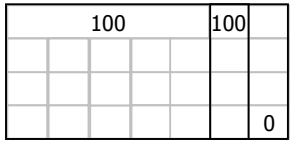

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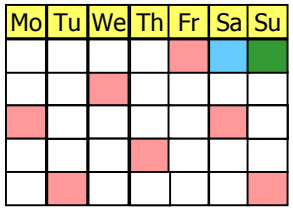
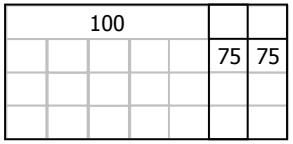
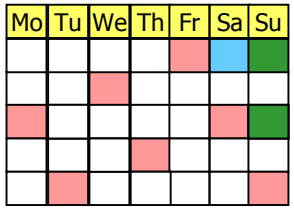
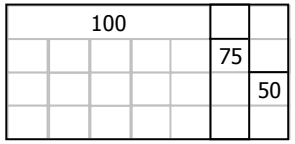




Z_{sa}	Z_{so}	t_X
1	1	7,42





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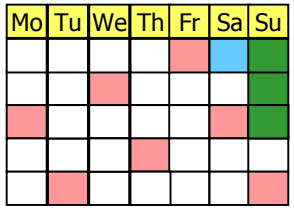
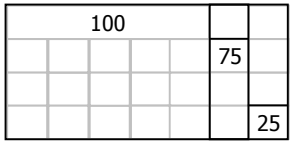
1	2	8,00





Z_{sa}	Z_{so}	t_X
1	3	8,20

reference:
Verkehrsrhythmus und Turnus im Fahrdienst.-
Ausschuss für Personalwirtschaft des Verbandes Öffentlicher Verkehrsbetriebe (VÖV), 1986

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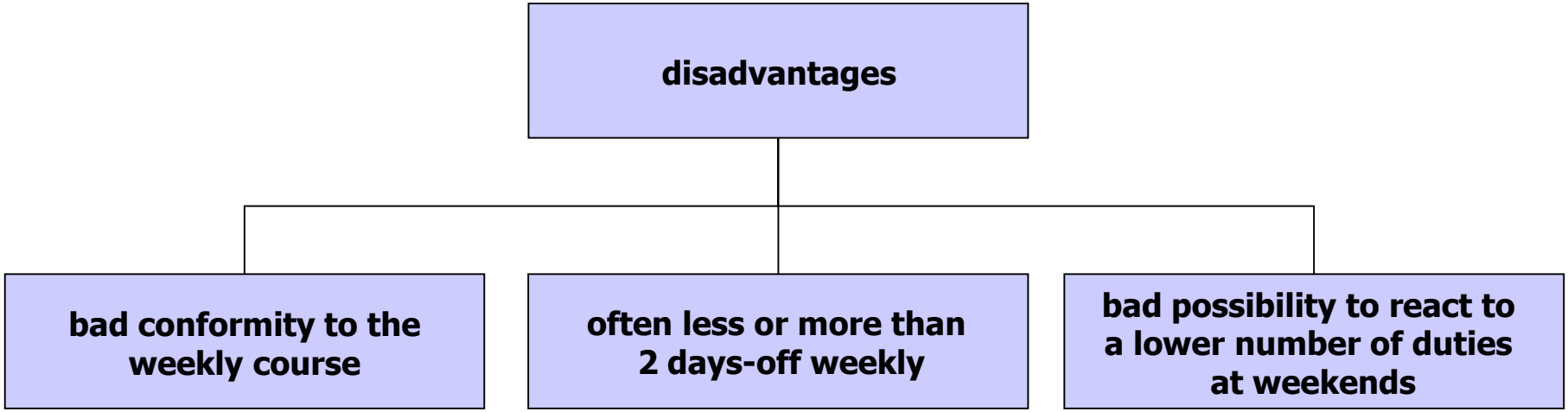
Duty roster with fixed cycle



- wife, husband
- children
- leisure time activities
- opening times ...

- extra short duties
- extra long duties

- to much employees on Saturday and Sunday
- not enough employees from Monday to Friday

→ duty roster with weekly cycle

→ consists of frame basic groups with two days-off weekly

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Duty roster with weekly cycle

B 1 (1 week, 1 cycle basis group, 2 days-off)

Number of week	su	mo	tu	we	th	fr	sa
1.	day-off						day-off

B 3 (3 weeks, 4 cycle basic groups, 6 days off)

1.	(day-off)				day-off	day-off	
2.				day-off	↓		
3.		day-off	day-off				(day-off)

↓

B 4 (4 weeks, 5 cycle basic groups, 8 days-off)

1.	day-off					day-off	(day-off)
2.				day-off	day-off		
3.			day-off	↓			
4.	(day-off)	day-off					day-off

B 6 (5) (6 weeks, 5 cycle basic groups, 12 days-off)

1.	day-off	day-off					
2.		day-off	day-off				
3.			day-off	day-off			
4.				day-off	day-off		
5.					day-off	day-off	
6.						day-off	day-off

B 6 (7) (6 weeks, 7 cycle basic groups, 12 days off)

1.	<day-off>				<day-off>	day-off	<day-off>
2.				<day-off>	day-off	<day-off>	
3.			<day-off>	day-off	<day-off>		
4.		<day-off>	day-off	<day-off>			
5.	<day-off>	day-off	<day-off>				<day-off>
6.	day-off	<day-off>				<day-off>	day-off

(day-off) extra day-off, either Saturday or Sunday

day-off ↓ day-off, with the possibility to move it in the next week

<day-off> extra day-off, take only 5 from there

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Example for a shift similarly duty roster

number of week	shift	su	mo	tu	we	th	fr	sa
B_e								
1.	e	day-off	e	e	e	e	e	day-off
B_l								
1.	l	day-off	l	l	l	l	l	day-off
$B_{el/el}$								
1.	e	day-off	e	e	e	e	day-off	l
2.	l/e	l	l	l	day-off	day-off	e	e
3.	l	e	day-off	day-off	l	l	l	l
$B_{le/le}$								
1.	l	l	l	l	l	day-off	day-off	e
2.	e/l	e	e	e	day-off	l	l	l
3.	e	l	day-off	day-off	e	e	e	day-off

e early shift
l late shift

it goes:

$n_{Be} = n_{emf} - k$
$n_{Bl} = n_{lmf} - k$
$n_{Bel/el} = n_{lsa} - k$
$n_{Ble/le} = n_{lsu} - k$
$k = 1/5(n_{esa} + n_{lsa} + n_{esu} + n_{lsu})$

boundary conditions:

n_{emf} ; n_{lmf} ; n_{esa} ; n_{lsa} ; n_{esu} ; $n_{lsu} \geq 0$ (a whole number)
n_{emf} ; $n_{lmf} \geq k$
n_{esa} ; $n_{esu} = k$
$k \leq n_{lsa}$; $n_{lsu} \leq 2k$
$n_{esa} + n_{lsa} + n_{esu} + n_{lsu} \equiv 0 \pmod 5$

k	[-]	a whole constant
n_B	[-]	number of basic groups
n_{mf}	[-]	number of duties on every monday to friday
n_{sa}	[-]	number of duties on saturday
n_{su}	[-]	number of duties on sunday and public holiday

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Example for a duty roster with fast rotation

number of week	su	mo	tu	we	th	fr	sa
B 1							
1.	day-off						day-off
B 6 (5)							
1.	day-off	day-off					
2.		day-off	day-off				
3.			day-off	day-off			
4.				day-off	day-off		
5.					day-off	day-off	
6.						day-off	day-off

it goes:

$n_{B1} = n_{mf} - 4\, n_{B6(5)}$
$n_{B6(5)} = 1/5\, n_{sa} = 1/5\, n_{su}$

boundary conditions:

n_{mf} ; n_{sa} ; $n_{su} \geq 0$ (a whole number)
$n_{mf} \geq 4/5\, n_{sa}$
$n_{mf} \geq 4/5\, n_{su}$
n_{sa} ; $n_{su} \equiv 0 \pmod 5$

n_B	[-]	number of basic groups
n_{mf}	[-]	number of duties on every monday to friday
n_{sa}	[-]	number of duties on saturday
n_{su}	[-]	number of duties on sunday and public holiday

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Public Transport Operations and Supply

Development of rotating duty rosters

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Exercise

monday – friday:

duty no.	train	begin and end working time	working time
1	1/3.	3.56 – 12.06	8:10
2	1/6.	4.14 – 12.51	8:37
3	1/7.	4.34 – 13.06	8:32
4	1/8.	4.49 – 13.04	8:15
5	11/1. + 1/7.	4.56 – 7.59 + 12.56 – 16.49	6:56
6	11/2. + 11/3.	5.11 – 8.14 + 15.11 – 18.14	6:06
7	11/3. + 1/6.	5.26 – 7.44 + 12.41 – 16.51	6:28
8	1/3.	11.56 – 19.49	7:53
9	11/1.	14.41 – 18.29	3:48
10	1/8.	12.54 – 19.04	6:10
11	11/2. + 1/3.	14.56 – 18.44 + 19.39 – 0.11	9:15
12	1/7.	16.39 – 1.18	8:39
13	1/6.	16.41 – 0.48	8:07
14	1/8.	18.54 – 4.21	9:27

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Exercise

saturday, sunday:

duty no.	train	begin and end working time	working time
21	1/3.	3.56 – 12.06	8:10
22	1/6.	4.14 – 12.51	8:37
23	1/7. + 1/8.	4.34 – 8.49 + 8.49 – 13.04	8:30
24	1/7.	8.39 – 17.06	8:27
25	1/3.	11.56 – 17.49	5:53
26	1/6.	12.41 – 18.34	5:53
27	1/8.	12.54 – 19.04	6:10
28	1/7.	16.56 – 1.18	8:22
29	1/3.	17.39 – 0.11	6:32
30	1/6.	18.24 – 0.48	6:24
31	1/8.	18.54 – 4.21	9:27

You have the duties number 1 to 14 and 21 to 31. Create a duty roster with weekly cycle. The first duty after days-off has to start as late as possible, the last one before days-off has to end as early as possible. The rest period between two duties may never be smaller than 10 hours.

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Exercise

Steps:

Selektion

-select the type of duty roster divided by rest period (**shift similarly**, **fast rotation** or **slow rotation**)

Calculation

- divide the duties evenly into **early** and **late** duties and include the necessary **buffer duties**

- calculate the **number of** 3, 4 or 6 weekly **basic groups** based on the number of weekend-duties

- include the missing duties Monday - Fryday by including a sufficient number of one week basic groups

- compose the **whole duty roster**

Putting down

- **group the duties**, pay attention to the minimal rest period between two duties

- correct the whole duty roster, if necessary

- put all **duties into the finished roster**

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Exercise

monday – friday:

duty no.	train	begin and end working time	working time
1	1/3.	3.56 – 12.06	8:10
1.1	on-call duty	3.56 – 12.06	8:10
1.2	spare duty	(3.56 – 13.06)	7:37
2	1/6.	4.14 – 12.51	8:37
3	1/7.	4.34 – 13.06	8:32
4	1/8.	4.49 – 13.04	8:15
5	11/1. + 1/7.	4.56 – 7.59 + 12.56 – 16.49	6:56
6	11/2. + 11/3.	5.11 – 8.14 + 15.11 – 18.14	6:06
7	11/3. + 1/6.	5.26 – 7.44 + 12.41 – 16.51	6:28
8	1/3.	11.56 – 19.49	7:53
8.1	on-call duty	11.56 – 19.15	7:19
8.2	spare duty	(11.56 – 4.21)	7:37
9	11/1.	14.41 – 18.29	3:48
10	1/8.	12.54 – 19.04	6:10
11	11/2. + 1/3.	14.56 – 18.44 + 19.39 – 0.11	9:15
12	1/7.	16.39 – 1.18	8:39
13	1/6.	16.41 – 0.48	8:07
14	1/8.	18.54 – 4.21	9:27

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Exercise

saturday, sunday:

duty no.	train	begin and end working time	working time
21	1/3.	3.56 – 12.06	8:10
21.1	on-call duty	3.56 – 13.04	9:08
21.2	spare duty	(3.56 – 17.06)	7:37
22	1/6.	4.14 – 12.51	8:37
23	1/7. + 1/8.	4.34 – 8.49 + 8.49 – 13.04	8:30
24	1/7.	8.39 – 17.06	8:27
25	1/3.	11.56 – 17.49	5:53
25.1	on-call duty	11.56 – 19.24	7:28
25.2	spare duty	(11.56 – 4.21)	7:37
26	1/6.	12.41 – 18.34	5:53
27	1/8.	12.54 – 19.04	6:10
28	1/7.	16.56 – 1.18	8:22
29	1/3.	17.39 – 0.11	6:32
30	1/6.	18.24 – 0.48	6:24
31	1/8.	18.54 – 4.21	9:27

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number of week	su	mo	tu	we	th	fr	sa
1.	day-off						day-off
2.	day-off	day-off					
3.		day-off	day-off				
4.			day-off	day-off			
5.				day-off	day-off		
6.					day-off	day-off	
7.						day-off	day-off
8.	day-off						day-off
9.	day-off						day-off
10.	day-off	day-off					
11.		day-off	day-off				
12.			day-off	day-off			
13.				day-off	day-off		
14.					day-off	day-off	
15.						day-off	day-off
16.	day-off						day-off
17.	day-off						day-off
18.	day-off	day-off					
19.		day-off	day-off				
20.			day-off	day-off			
21.				day-off	day-off		
22.					day-off	day-off	
23.						day-off	day-off
24.	day-off						day-off

number of week	su	mo	tu	we	th	fr	sa
1.	day-off						day-off
2.	day-off	day-off					
3.		day-off	day-off				
4.			day-off	day-off			
5.				day-off	day-off		
6.					day-off	day-off	
7.						day-off	day-off
8.	day-off						day-off
9.	day-off						day-off
10.	day-off	day-off					
11.		day-off	day-off				
12.			day-off	day-off			
13.				day-off	day-off		
14.					day-off	day-off	
15.						day-off	day-off
16.	day-off						day-off
17.	day-off						day-off
18.	day-off	day-off					
19.		day-off	day-off				
20.			day-off	day-off			
21.				day-off	day-off		
22.					day-off	day-off	
23.						day-off	day-off
24.	day-off						day-off

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number of week	su	mo	tu	we	th	fr	sa
1.	day-off						day-off
2.	day-off	day-off					
3.	day-off	day-off	day-off				
4.			day-off	day-off			
5.				day-off	day-off		
6.					day-off	day-off	
7.						day-off	day-off
8.							day-off
9.	day-off						day-off
10.	day-off	day-off					
11.	day-off	day-off	day-off				
12.			day-off	day-off			
13.				day-off	day-off		
14.					day-off	day-off	
15.						day-off	day-off
16.							day-off
17.	day-off						day-off
18.	day-off	day-off					
19.	day-off	day-off	day-off				
20.			day-off	day-off			
21.				day-off	day-off		
22.					day-off	day-off	
23.						day-off	day-off
24.							day-off

Exercise

3 groups with ever 6 duties Monday to Friday and ever 5 duties Saturday and Sunday:

I	II	III	IV	V	VI
18.54 14 4.21	14.56 11 0.11	11.56 8.1 19.15	5.26 7 16.51	4.34 3 13.06	4.14 2 12.51
18.54 31 4.21	16.56 28 1.18	12.54 27 19.04	8.39 24 17.06	3.56 21.1 13.04	
16.41 13 0.48	(11.56) 8.2 (4.21)	14.41 9 18.29	4.56 5 16.49	(3.56) 1.2 (13.06)	3.56 1 12.06
18.24 30 0.48	(11.56) 25.2 (4.21)	12.41 26 18.34	4.34 23 13.04	3.56 21 12.06	
16.39 12 1.18	11.56 8 19.49	12.54 10 19.04	5.11 6 18.14	4.49 4 13.04	3.56 1.1 12.06
17.39 29 0.11	11.56 25.1 19.24	11.56 25 17.49	(3.56) 21.2 (17.06)	4.14 22 12.51	

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number of week	su	mo	tu	we	th	fr	sa
1.	day-off	14	11	8.1	7	3	day-off
2.	day-off	day-off	13	8.2	9	5	21
3.	day-off	day-off	day-off	12	8	10	21.2
4.	22	1.1	day-off	day-off	14	11	27
5.	24	3	2	day-off	day-off	13	25.2
6.	26	5	1.2	1	day-off	day-off	29
7.	25.1	10	6	4	1.1	day-off	day-off
8.	31	11	8.1	7	3	2	day-off
9.	day-off	13	8.2	9	5	1.2	day-off
10.	day-off	day-off	12	8	10	6	22
11.	day-off	day-off	day-off	14	11	8.1	24
12.	21.1	2	day-off	day-off	13	8.2	26
13.	23	1.2	1	day-off	day-off	12	25.1
14.	25	6	4	1.1	day-off	day-off	31
15.	28	8.1	7	3	2	day-off	day-off
16.	30	8.2	9	5	1.2	1	day-off
17.	day-off	12	8	10	6	4	day-off
18.	day-off	day-off	14	11	8.1	7	21.1
19.	day-off	day-off	day-off	13	8.2	9	23
20.	21	1	day-off	day-off	12	8	25
21.	21.2	4	1.1	day-off	day-off	14	28
22.	27	7	3	2	day-off	day-off	30
23.	25.2	9	5	1.2	1	day-off	day-off
24.	29	8	10	6	4	1.1	day-off

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