PRAGUE CITY DATA CONGRESS 2019

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ČESKÉ VYSOKÉ UČENÍ TECHNICKÉ V PRAZE

TRAFFIC DATA PROCESSING ...

... the necessary condition for MAAS functionality

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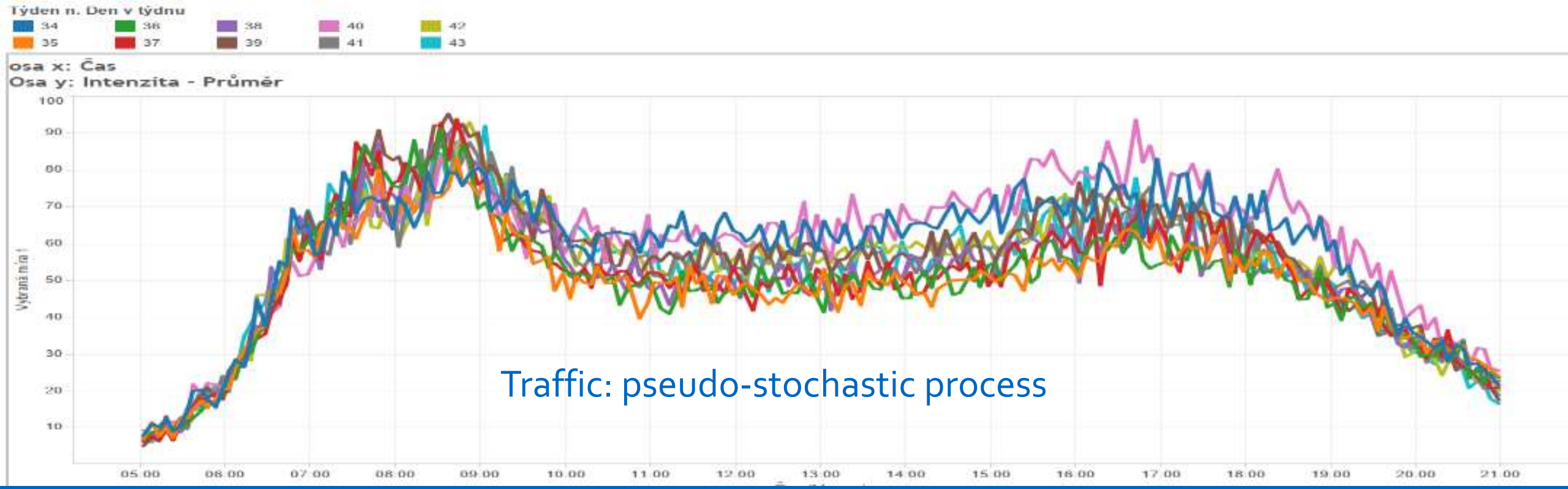
MOTIVATION

- Fields: data processing, traffic management, urban mobility solutions
- To present experience with data in the cities



Traffic: pseudo-stochastic process

MAAS … MOBILITY AS A SERVICE

- Comprehensively implemented as a service
- Combination of public and private providers, no personally owned modes
- Unified approach to the A-B trip, multi-criteria selection, based on travel needs

- MAAS: TRAFFIC MANAGEMENT & PLANNING NECESSARY
  1. Urban mobility plans – strategic level
  2. Traffic flow / service management and optimization – strategic, tactical, operational
  3. Individual travel planning – user-friendly mobility applications

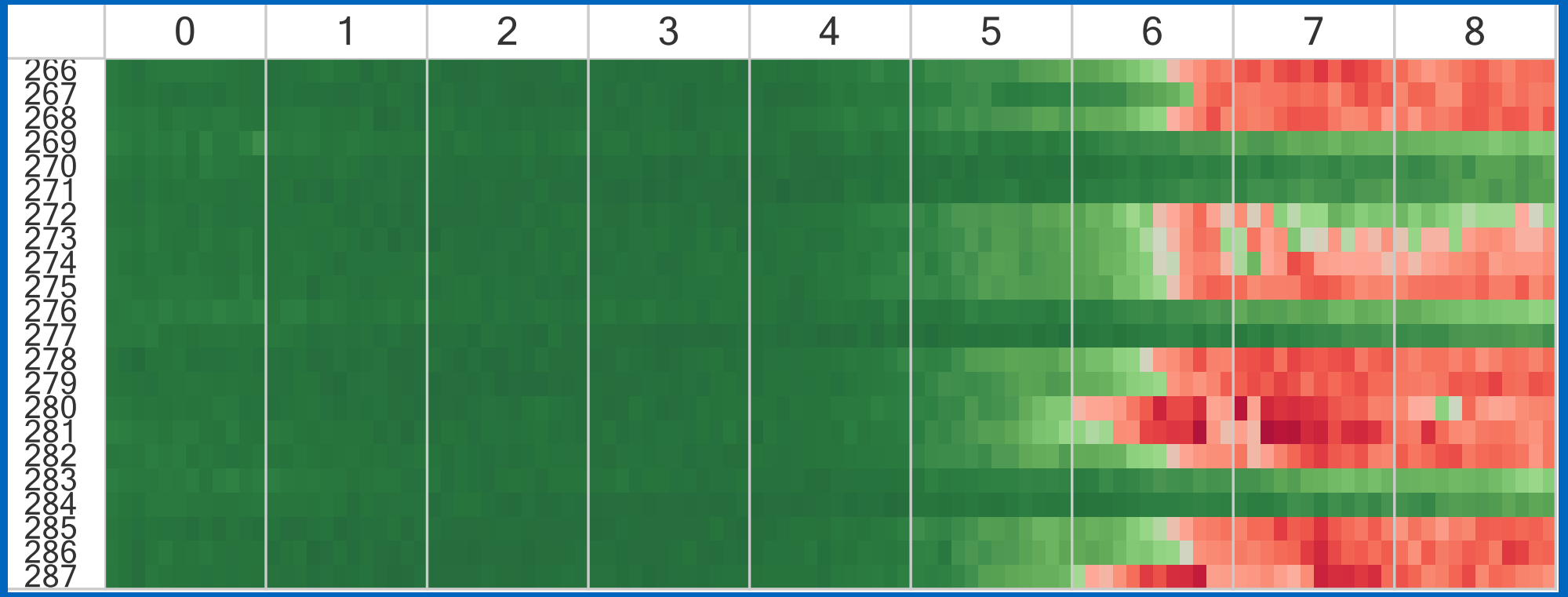
- What is the most important resource?

DATA OF OUR EVERYDAY LIVES

- Data sensing anywhere
- GOAL: PERFECT KNOWLEDGE OF THE TRANSPORT PROCESS
- Data sources:
  - Infrastructure (traffic detectors)
  - Vehicles (FCD, fleet data)
  - Travellers (phone positions, requests)
  - Providers (timetables, billing, service coverage)
- Data is obtained automatically and continuously
  - Possibly one-time and manual for strategic planning

TYPICAL FEATURES OF DATA COLLECTION

- Heterogeneous (sub)systems
- Standardization vs. rapid development



WHAT DOES THE DATA LOOK LIKE?

- Detectors

```
2015-08-17 00:04:30;2015-08-17 00:04:40;193994;0;5;40;0
2015-08-17 00:04:30;2015-08-17 00:04:40;193994;1;5;40;
2015-08-17 00:04:30;2015-08-17 00:04:40;193994;2;0;0;
2015-08-17 00:09:30;2015-08-17 00:09:43;193995;0;7;43;0
2015-08-17 00:09:30;2015-08-17 00:09:43;193995;1;7;43;
2015-08-17 00:09:30;2015-08-17 00:09:43;193995;2;0;0;
```

```
2018-08-17 00:00:00;MUR_BE-BA;1;5;48;
2018-08-17 00:00:00;MUR_BE-BA;2;3;;
2018-08-17 00:00:00;MUR_BG-BM;1;2;;
2018-08-17 00:00:00;MUR_BG-BM;2;10;;
2018-08-17 00:00:00;MUR_BM-KR;1;4;;
```

```
2018-02-01 00:14:04;30;;6
2018-02-01 00:19:05;33;;6
2018-02-01 00:24:06;33;;6
2018-02-01 00:29:08;28;;5
2018-02-01 00:34:09;28;;5
```

WHAT DOES THE DATA LOOK LIKE?

- Vehicles/travellers …

```
12;"";;9;"";1061;"";2018-12-11 05:19:40;1;7;
12;"";;9;"";5491;"";2018-12-11 05:21:49;2;7;
12;"";;9;"";5121;"";2018-12-11 05:23:27;3;7;
12;"";;9;"";4322;"";2018-12-11 05:24:37;4;7;
```

```
$GPGGA,130131,5003.06515,N,01417.26536,E,3,07,1.06,379.86,M,45.64,M,,*77
$GPRMC,130131,A,5003.06515,N,01417.26536,E,37.450,258.160,261009,0.000,E*40
$GPVTG,258.160,T,258.160,M,37.450,N,69.357,K*45
$GPGSV,2,1,7,4,12,37,10,8,8,321,10,11,49,234,12,12,31,195,11*49
$GPGSV,2,2,7,15,45,298,12,18,56,66,12,19,17,70,11*7B
$GPGSA,A,3,04,08,11,12,15,18,19,,,,,,2.0,1.1,1.7*3C
$GPGGA,130132,5003.06258,N,01417.24890,E,3,07,1.06,378.76,M,45.64,M,,*77
```

```
6;"";;427;"";4162;"";2018-12-09 08:08:23;2018-12-09 08:08:35;3;3;0;6;"Unknown";"";3;27;
6;"";;427;"";4182;"";2018-12-09 08:09:15;2018-12-09 08:09:25;6;0;0;6;"Unknown";"";4;27;
6;"";;427;"";1202;"";2018-12-09 08:11:01;2018-12-09 08:11:13;6;2;1;7;"Unknown";"";6;27;
6;"";;427;"";1672;"";2018-12-09 08:12:38;2018-12-09 08:12:49;7;2;0;9;"Unknown";"";7;27;
6;"";;427;"";1192;"";2018-12-09 08:13:26;2018-12-09 08:13:38;9;1;0;10;"Unknown";"";8;27;
```

WHAT DOES THE DATA LOOK LIKE?

- Providers

```
#101011
L1   S5   K1
     3012 04:54
     116  05:07
L1   S6   K1
     116  05:08
     621  05:10
     5281 05:12
     4311 05:14
     51   05:16
     4651 05:17
     4631 05:19
     4601 05:20
     5071 05:22
     5072 05:22
```

```
"Rec;1;101011;"
"Rec;1;101021;"
"Rec;1;101031;"
"Rec;1;101051;"
"Rec;1;101061;"
"Rec;1;101074;"
"Rec;1;101081;"
"Rec;1;101091;"
"Rec;1;101101;"
"Rec;1;101111;"
"Rec;1;101121;"
```

DATA + METADATA

WORKING WITH DATA

- Typical assumptions
  - Big data
  - Open data format

```
"2017-09-01 00:00:00","MUR_BG-BM","1","6","55"
"2017-09-01 00:00:00","MUR_BG-BM","2","18","53"
"2017-09-01 00:05:00","MUR_BG-BM","1","5","55"
"2017-09-01 00:05:00","MUR_BG-BM","2","22","51"
"2017-09-01 00:10:00","MUR_BG-BM","1","4","56"
"2017-09-01 00:10:00","MUR_BG-BM","2","17","52"
"2017-09-01 00:15:00","MUR_BG-BM","1","5","57"
"2017-09-01 00:15:00","MUR_BG-BM","2","14","53"
"2017-09-01 00:20:00","MUR_BG-BM","1","7","57"
"2017-09-01 00:20:00","MUR_BG-BM","2","19","56"
"2017-09-01 00:25:00","MUR_BG-BM","1","5","59"
```

- Process:
  1. Loading
  2. Pre-processing
     - Incl. cleaning, filtration, integration, transformation, reduction
  3. Analysis
     - Incl. modelling, classification
  4. Interpretation

Which part of the process takes the most time?

DATA PRE-PROCESSING PROCESS

- Prerequisite – understanding the data
- THERE ARE ERRORS IN ANY DATA
- Error finding and analysis
- The need for error selection and the search for the cause
- Common causes:
  1. Measurement/input method
  2. Data transmission
  3. Input system processing
- Getting experience
- Knowledge of context often necessary

Time	In	On	Off	Out
4.12.2018 16:02	3	0	1	2
4.12.2018 16:04	2	0	3	-1
4.12.2018 16:06	-1	0	3	-4
4.12.2018 16:07	-4	0	0	-4
4.12.2018 16:09	-4	5	0	1
4.12.2018 16:11	1	1	0	2

TYPICAL ERRORS – DETECTORS

2015-08-18 17:19:57;2015-08-18 17:20:01;164593;0;72;45;9
2015-08-18 17:19:57;2015-08-18 17:20:01;164593;1;72;45;
2015-08-18 17:19:57;2015-08-18 17:20:01;164593;2;0;0;

Speed error

Flow error

2015-10-23 20:09:12;2015-10-23 20:09:13;157872;0;19;38;2
2015-10-23 20:14:12;2015-10-23 20:14:13;157873;0;765;116;20
2015-10-23 20:19:12;2015-10-23 20:19:13;157874;0;1097;117;28

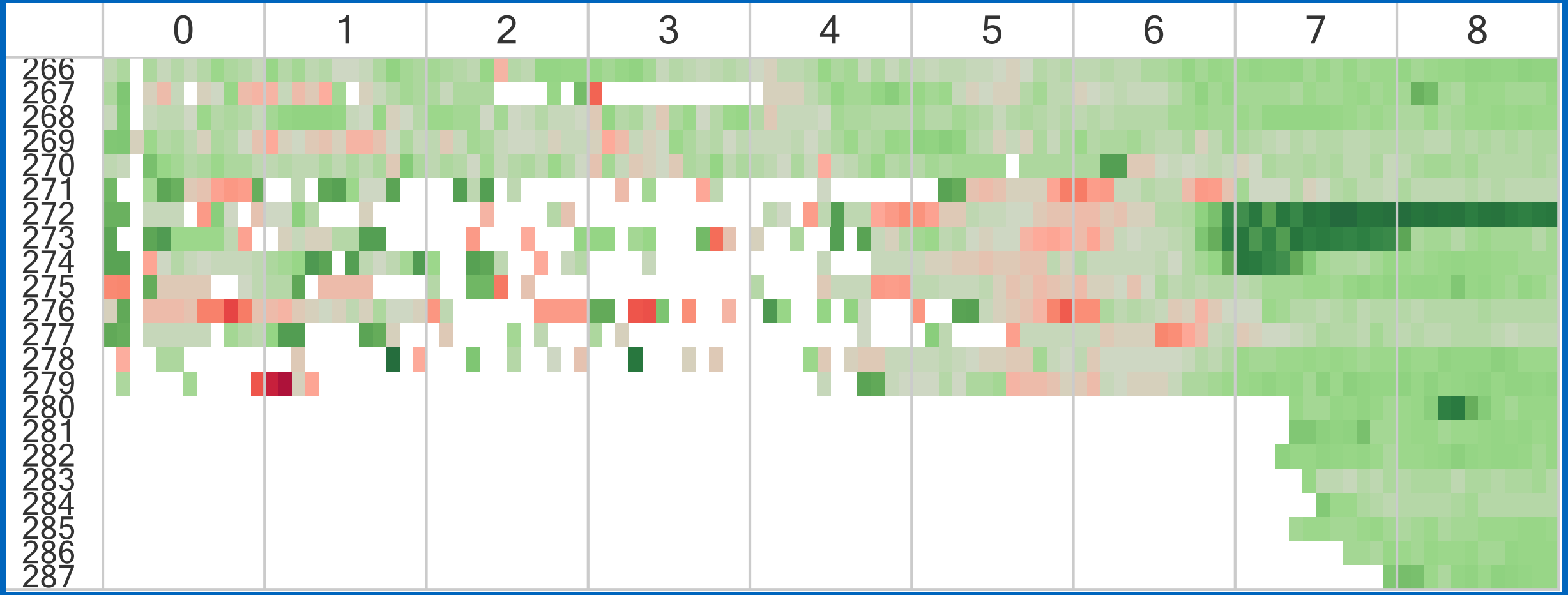
2015-09-24 09:25:12;2015-09-24 09:25:45;15338;0;52;;85
2015-09-24 09:29:39;2015-09-24 09:29:51;15594;0;51;;86

Time interval inaccuracy

Timestamp error

2015-09-24 14:57:40;2015-09-24 14:57:56;49335;0;40;;6
2015-09-24 14:58:20;2015-09-24 14:53:08;49079;0;40;;34
2015-09-24 15:02:42;2015-09-24 15:03:24;49591;0;41;;5

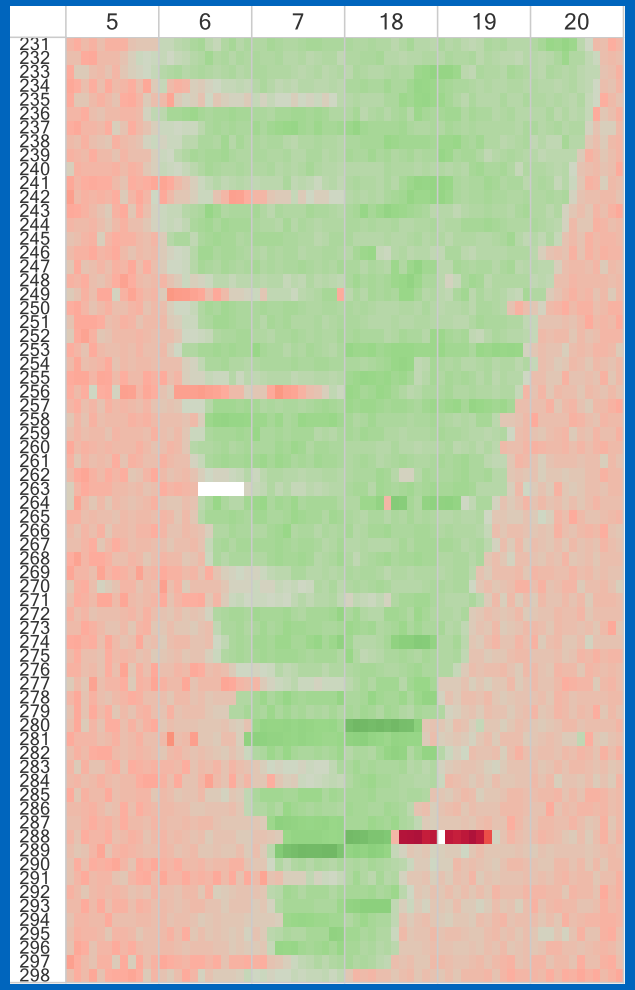
MEASUREMENT OUTAGES

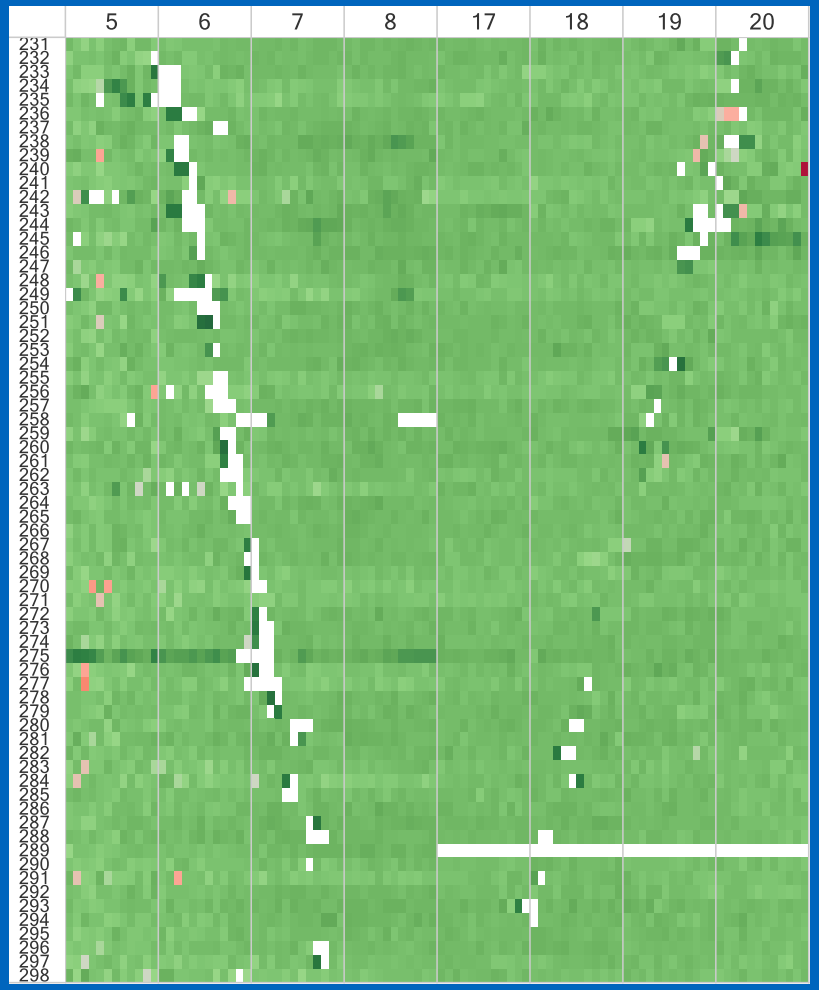


SPECIFIC ERRORS & PERFORMANCE

- IS IT ALWAYS POSSIBLE TO RECOGNIZE THE ERROR?

- Performance measures
  - Reliability (% time)
  - Accuracy (% value)
  - Availability (acquisition speed)
  - Continuity (without interruption)
  - Integrity (validity information)

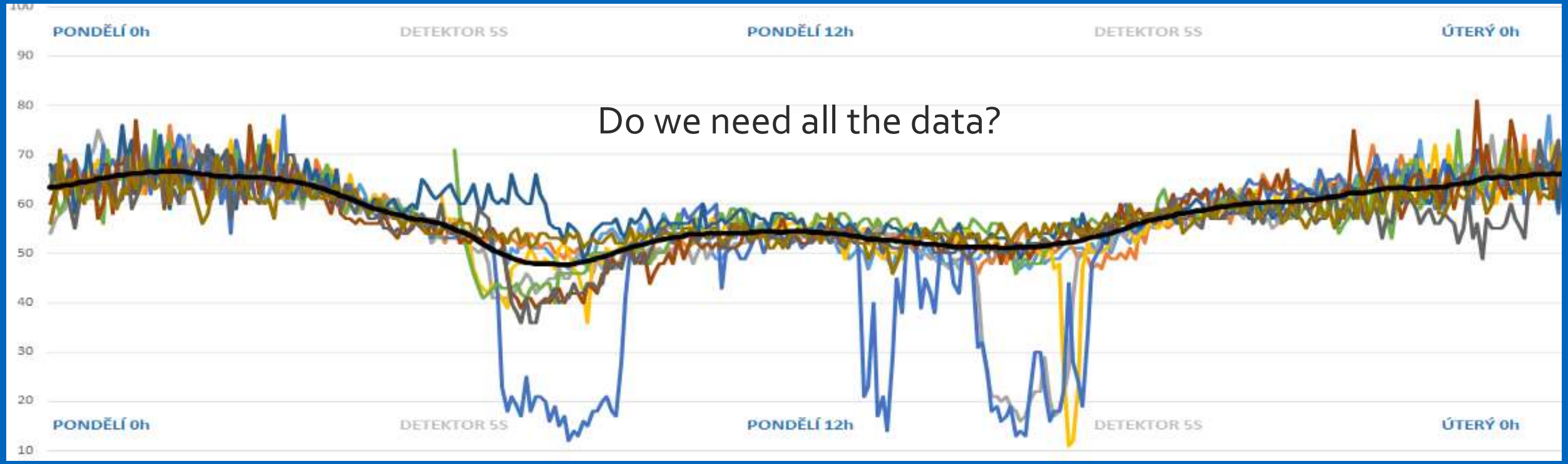




WHAT TO DO WITH ERRORS?

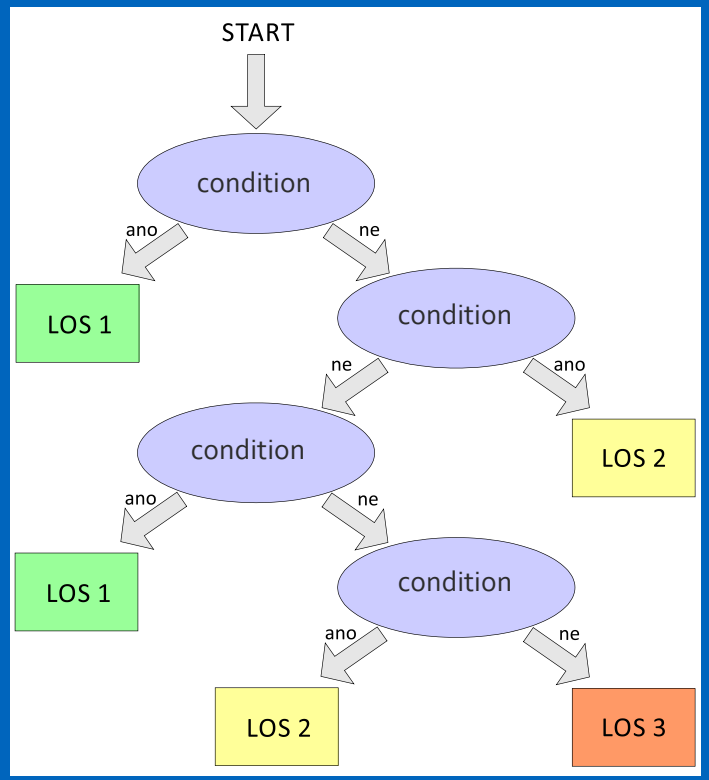
- Some data may be discarded
- Data smoothing, filtration

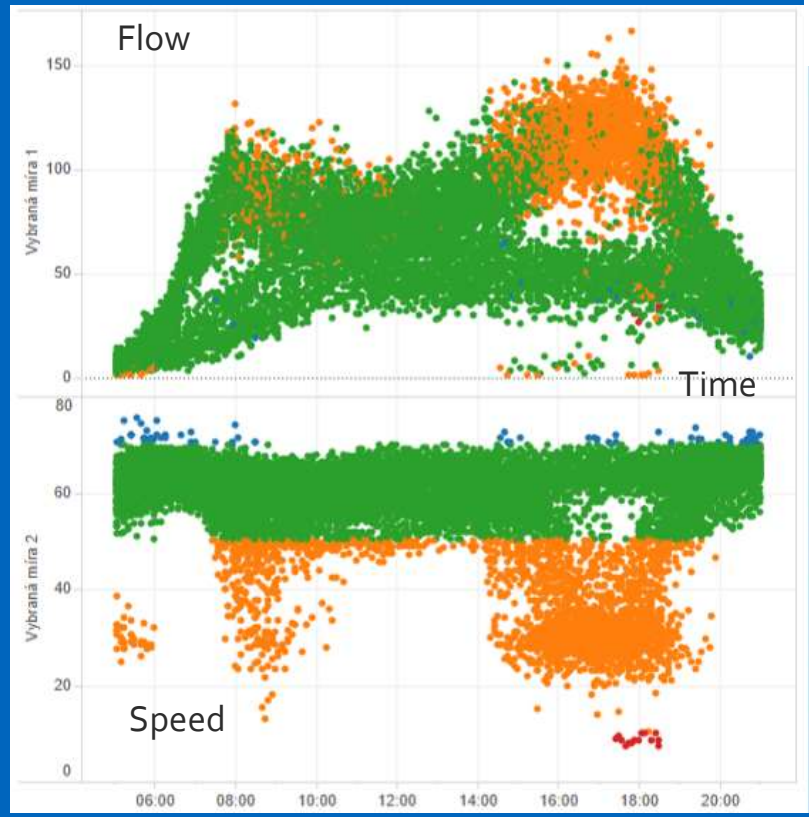
- Some data need to be corrected
  - Estimation
  - Using historical model (typical values)

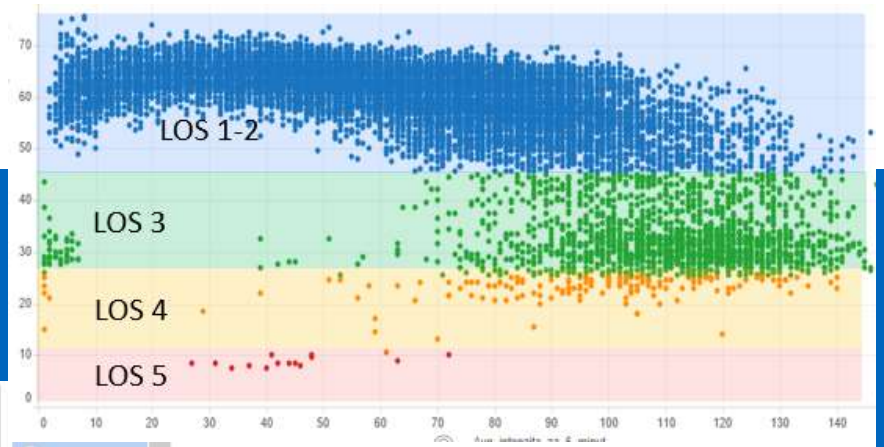


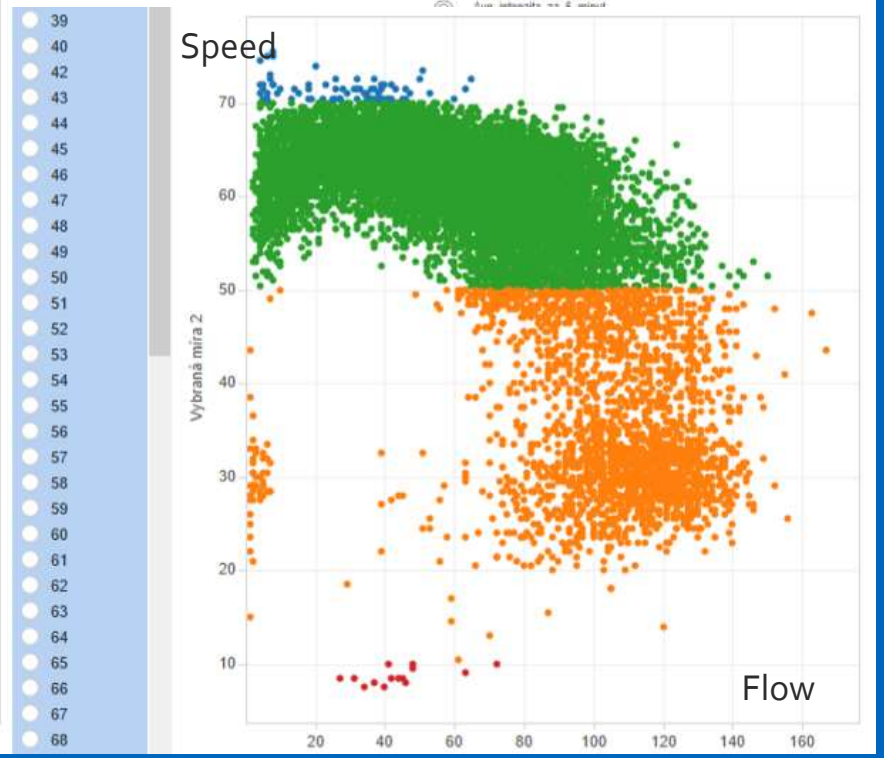
DATA CLASSIFICATION

- k-NN
- DT



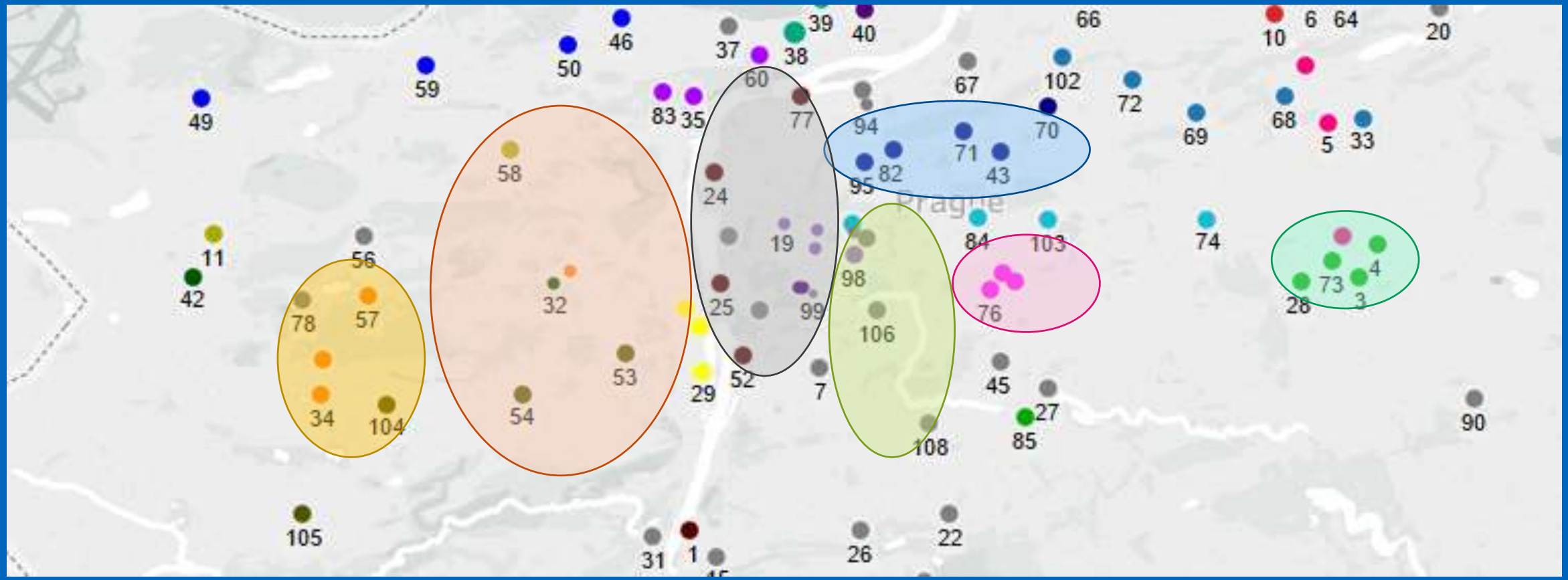






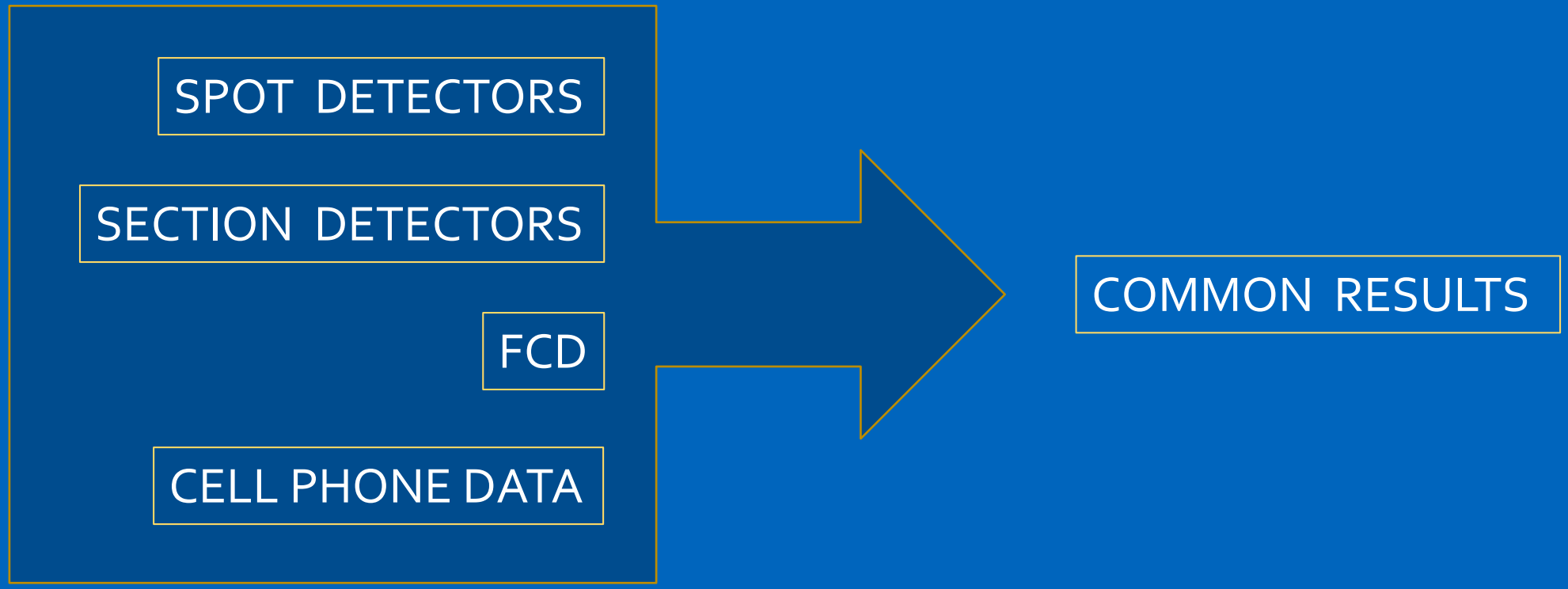
DATA REDUCTION

- Clusters, PCA, ...



DATA INTEGRATION

- Data unification – different systems usually provide different formats
- DATEX?

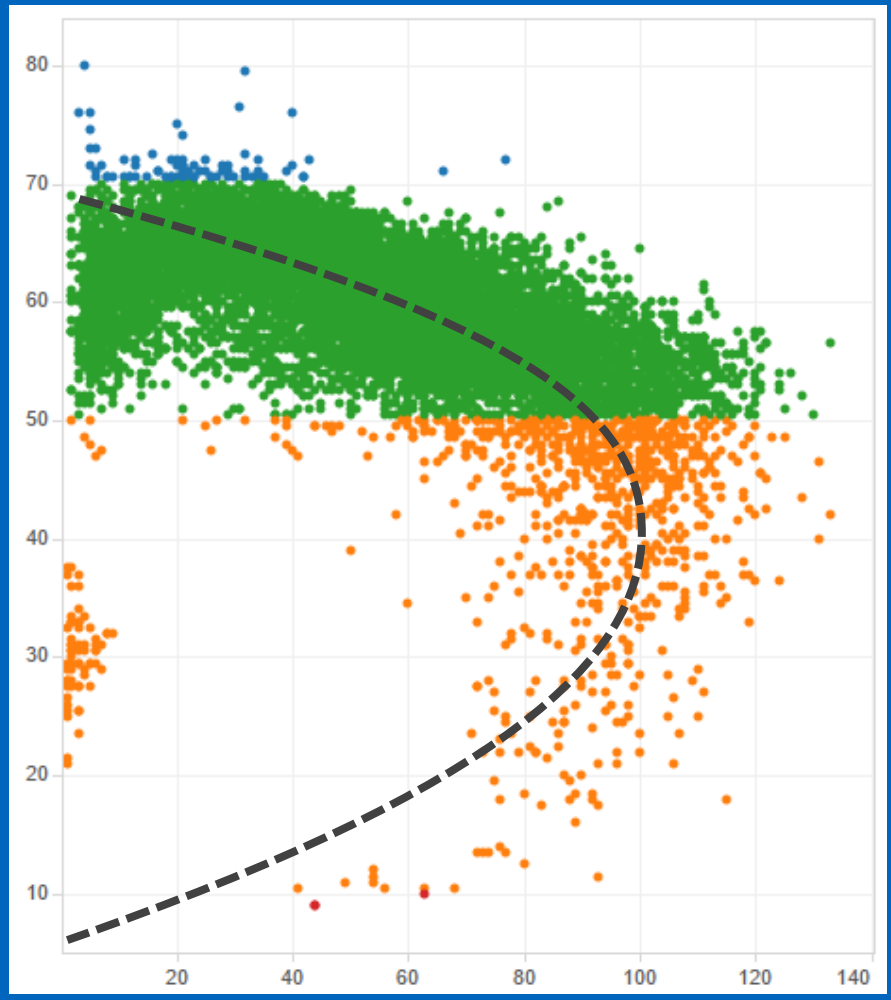


THE MODELLING

- Helps to get or correct missing values
- Helps to estimate unknown quantities
- Helps to find space-time dependencies

- Tools
  - Mathematical tools in combination with GIS
  - Training and test data set
  - Model and measured data calibration
  - Expert methods, risk analysis

- TREND: GLOBAL TRAFFIC MODEL OF THE CITY



THE "WIRE" MODEL

- Modelling of missing inputs; dissemination of phenomena in space and time

DATA INTERPRETATION: SUPPLY, DEMAND, QUALITY

- GOAL: To extract useful information and knowledge from data, especially
  1. Space-time information on supply and demand
  2. Data on quality of service
- CLARITY COMES FIRST, REGARDING THE USER

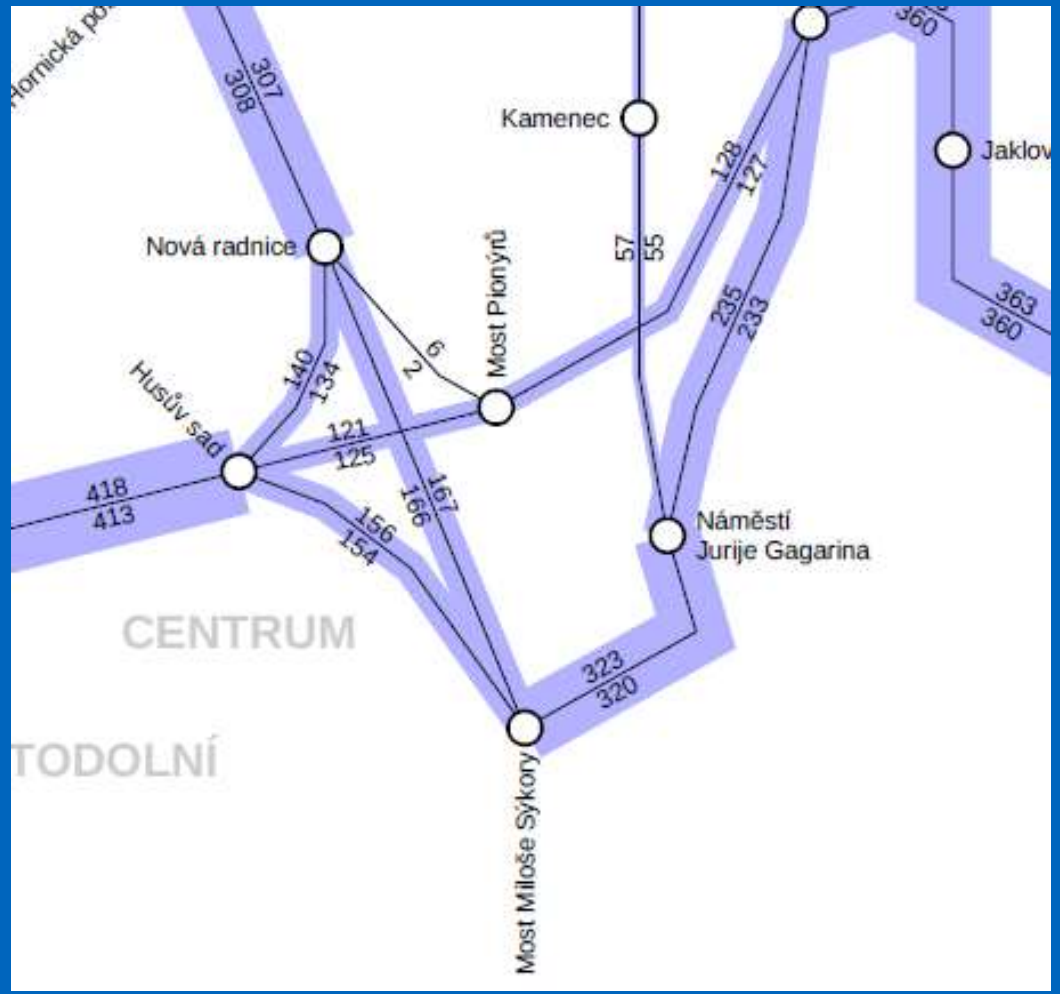
- Supply parameters
  - Number of vehicles / spaces
  - Flow of vehicles (time interval)
  - Vehicle capacity
  - Shared vehicles position
  - Price of a service

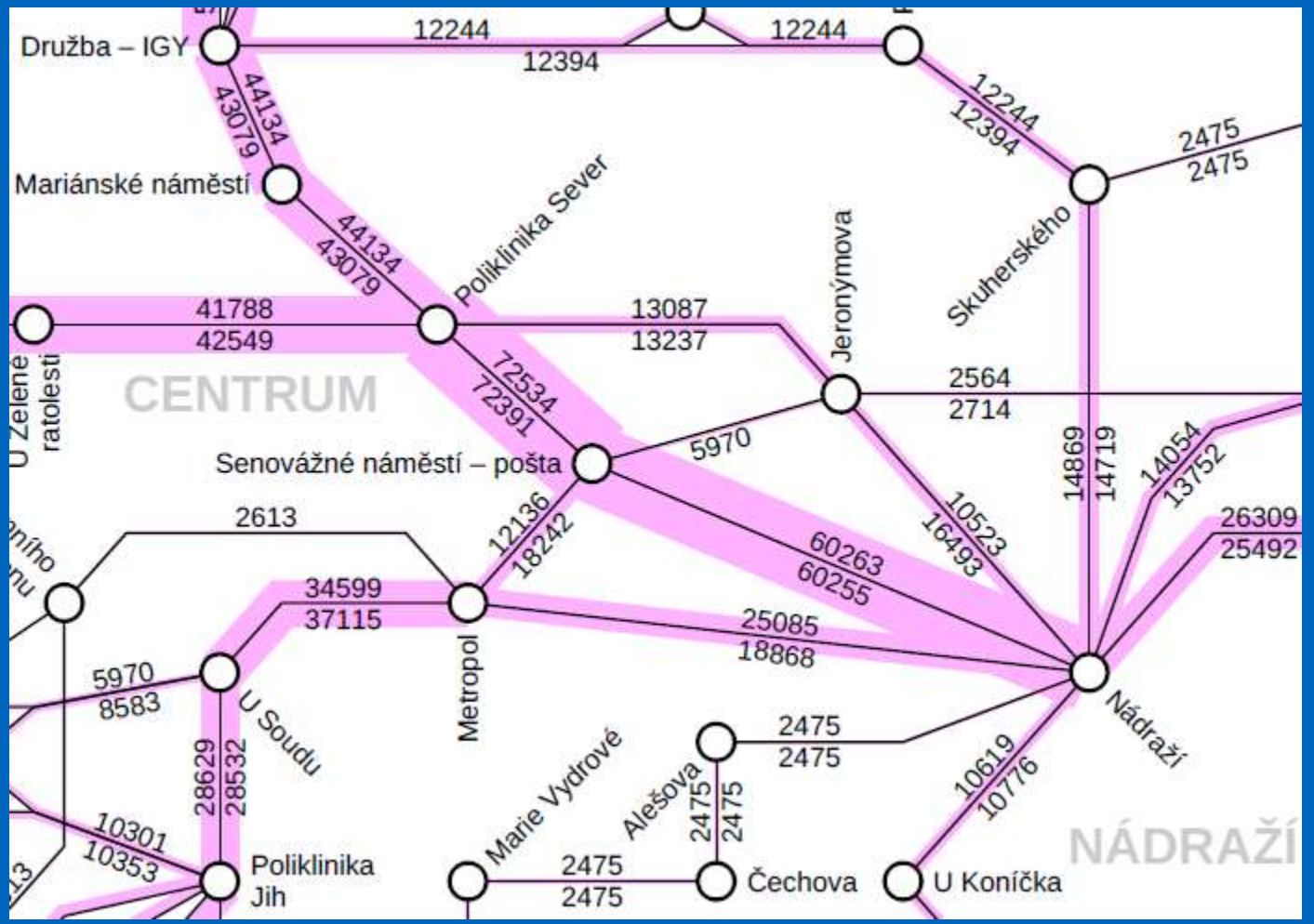
  etc.

- Demand parameters
  - Traveller requests
  - Number of travellers per time
  - Number of travellers per vehicle
  - Density of individual vehicles
  - Travelling directions

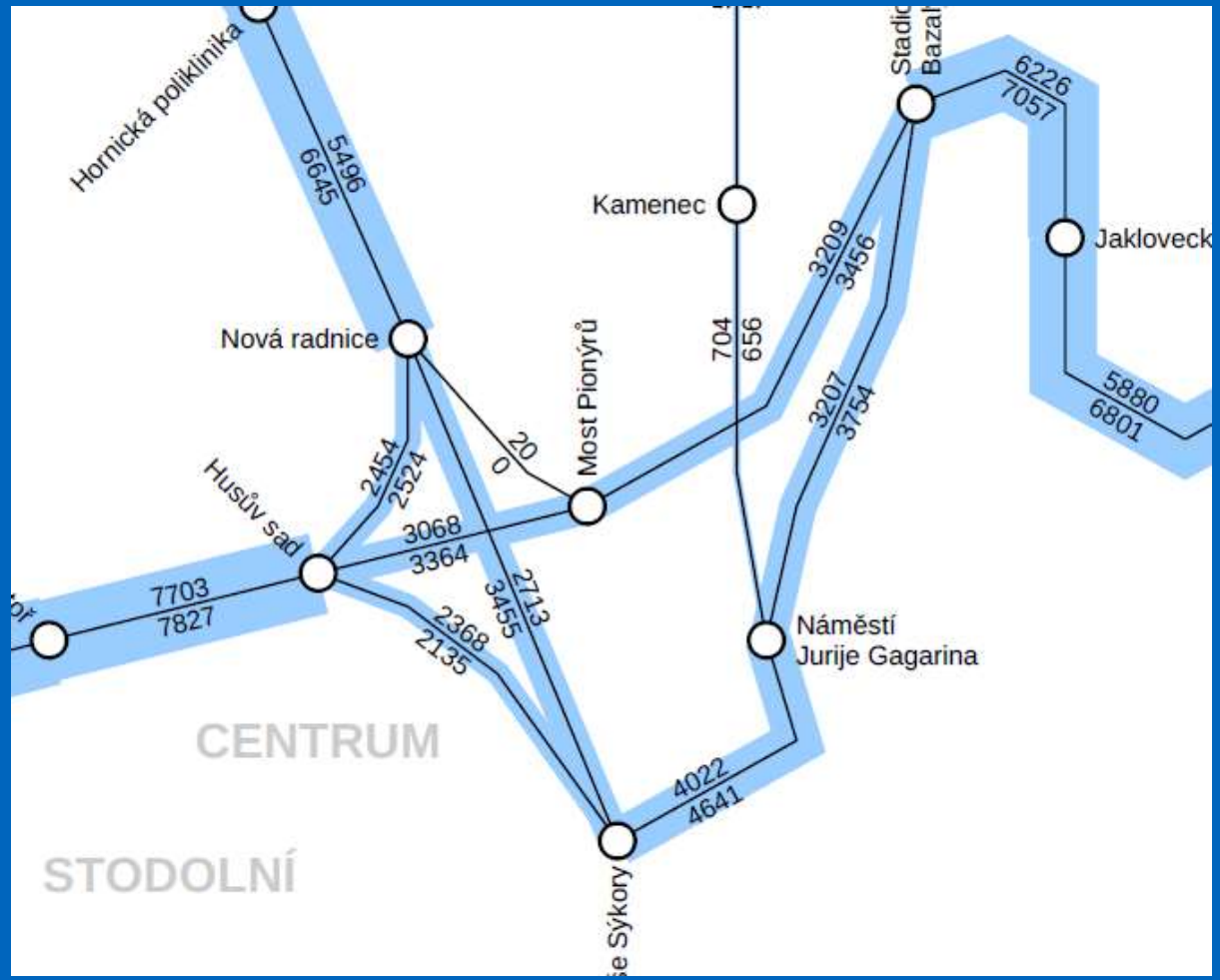
  etc.

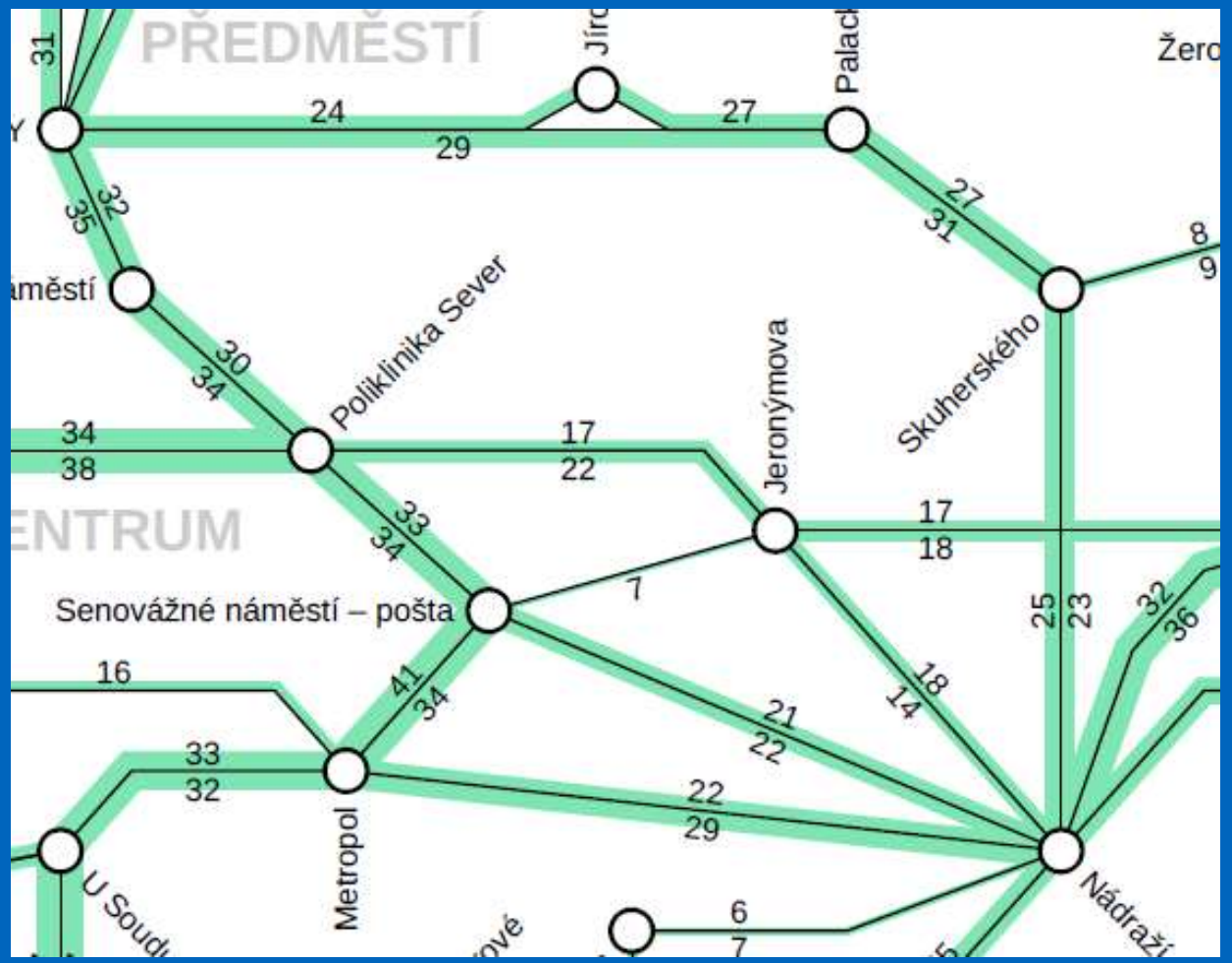
SUPPLY – VEHICLES AND SPACES



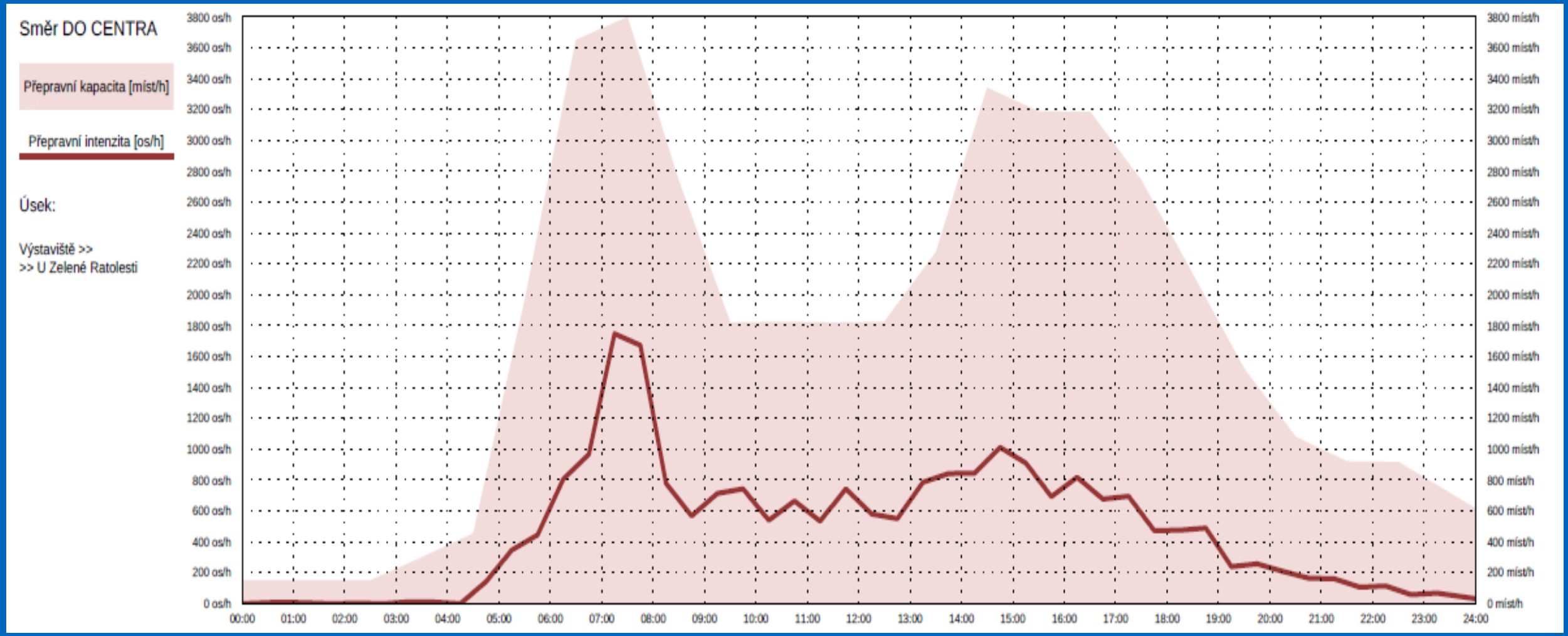


DEMAND – OVERALL AND / OR AVERAGE PER VEHICLE

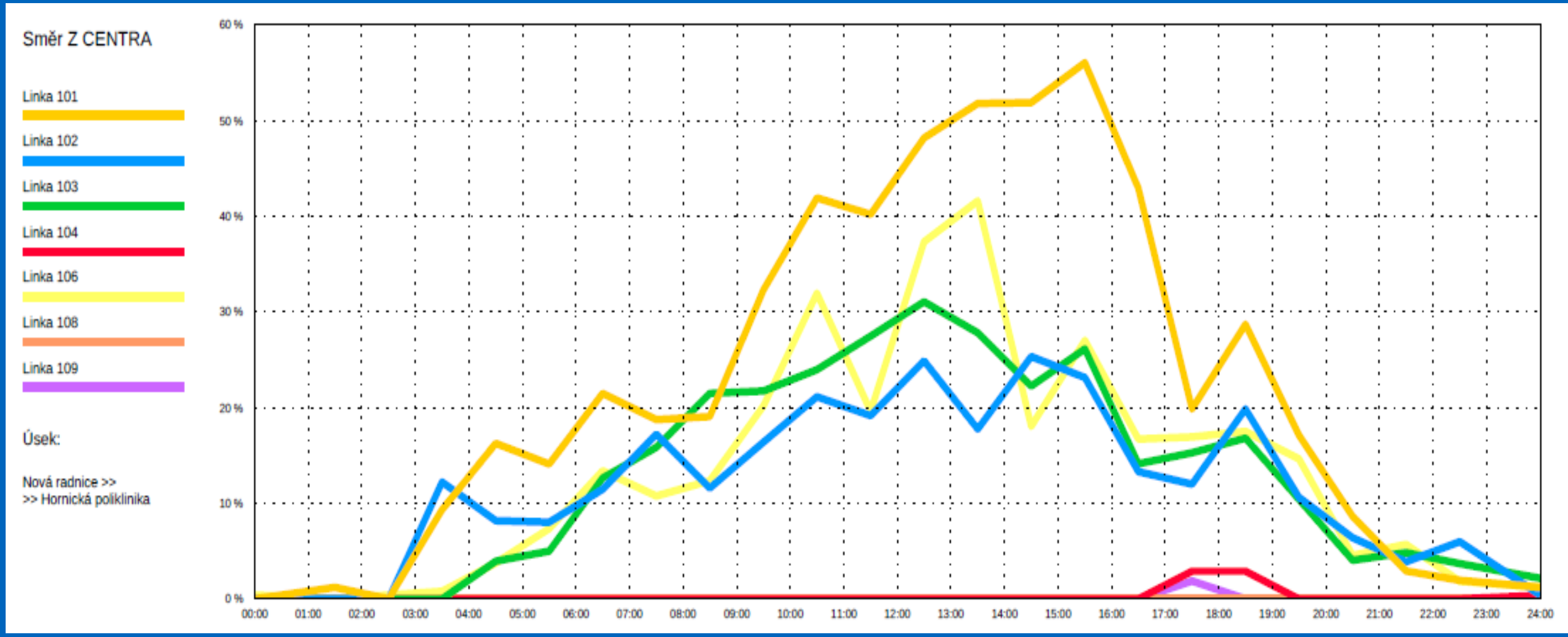




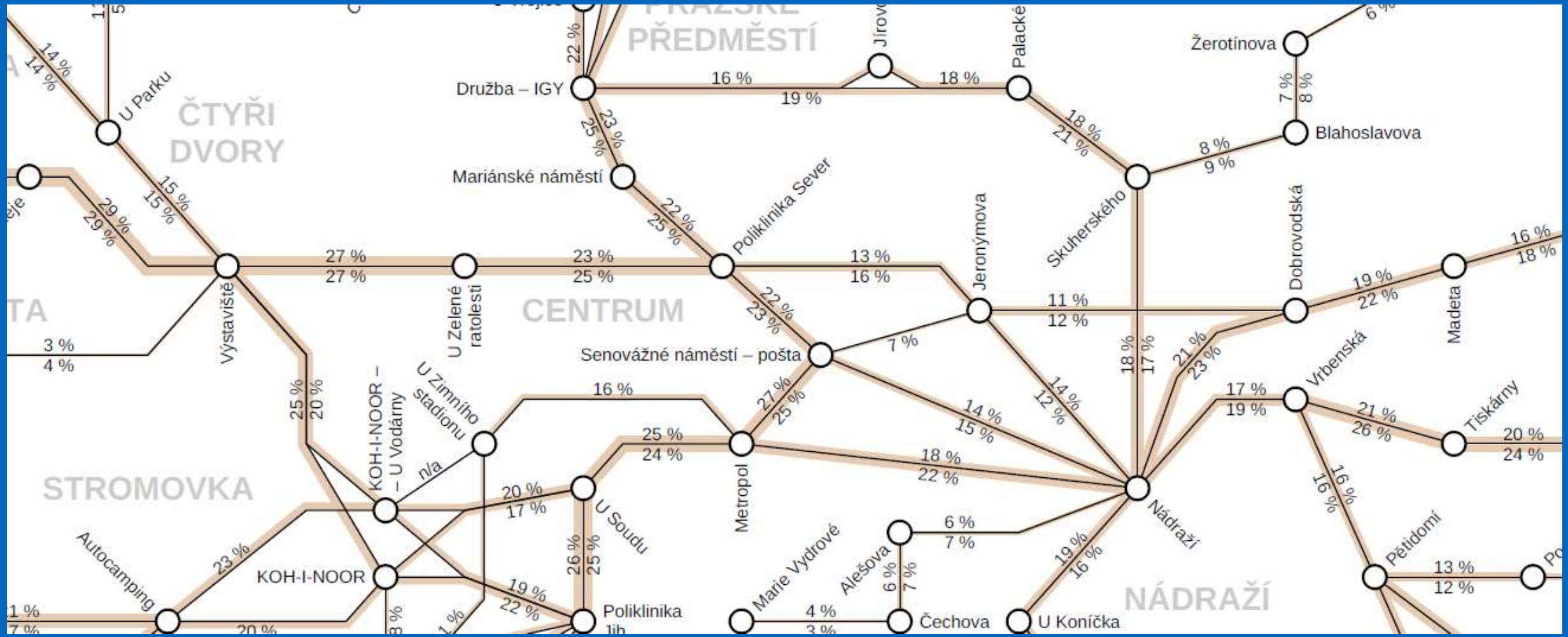
SUPPLY AND DEMAND – A PROFILE VIEW



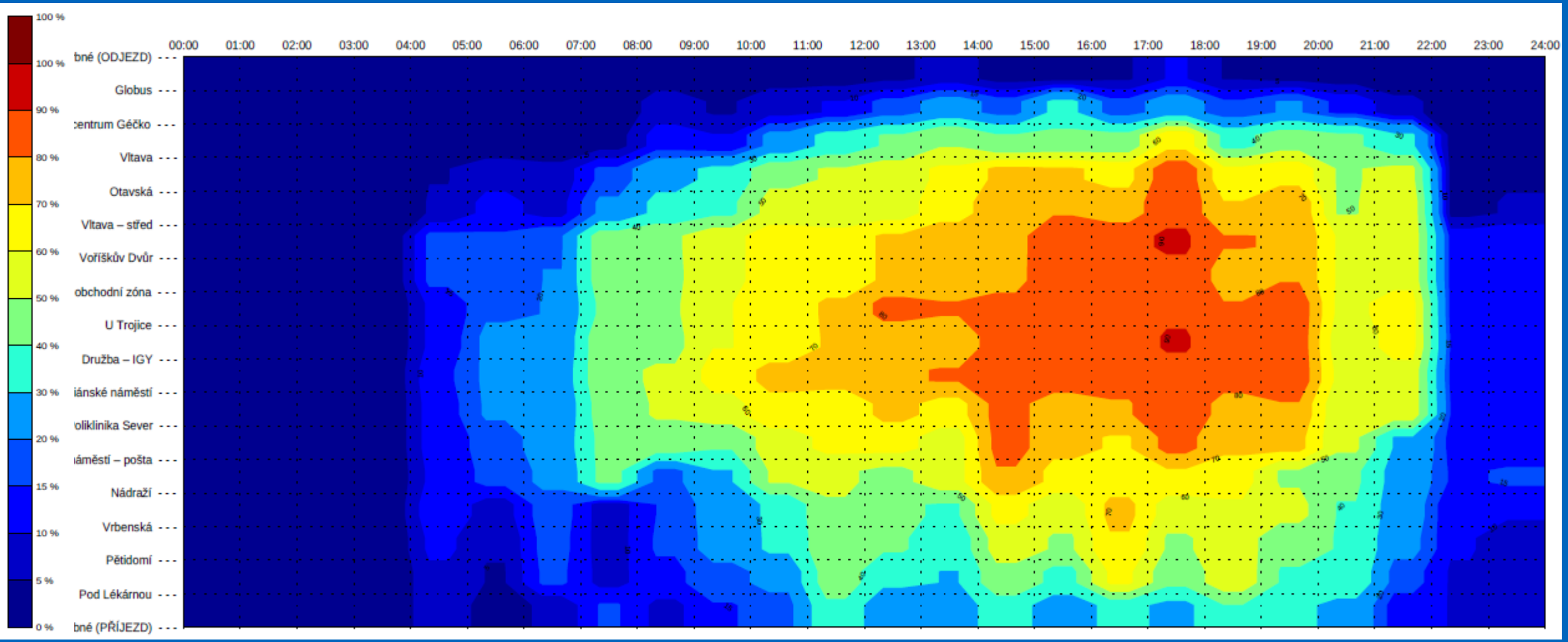
RELATIVE RATIO OF SUPPLY AND DEMAND – A PROFILE VIEW



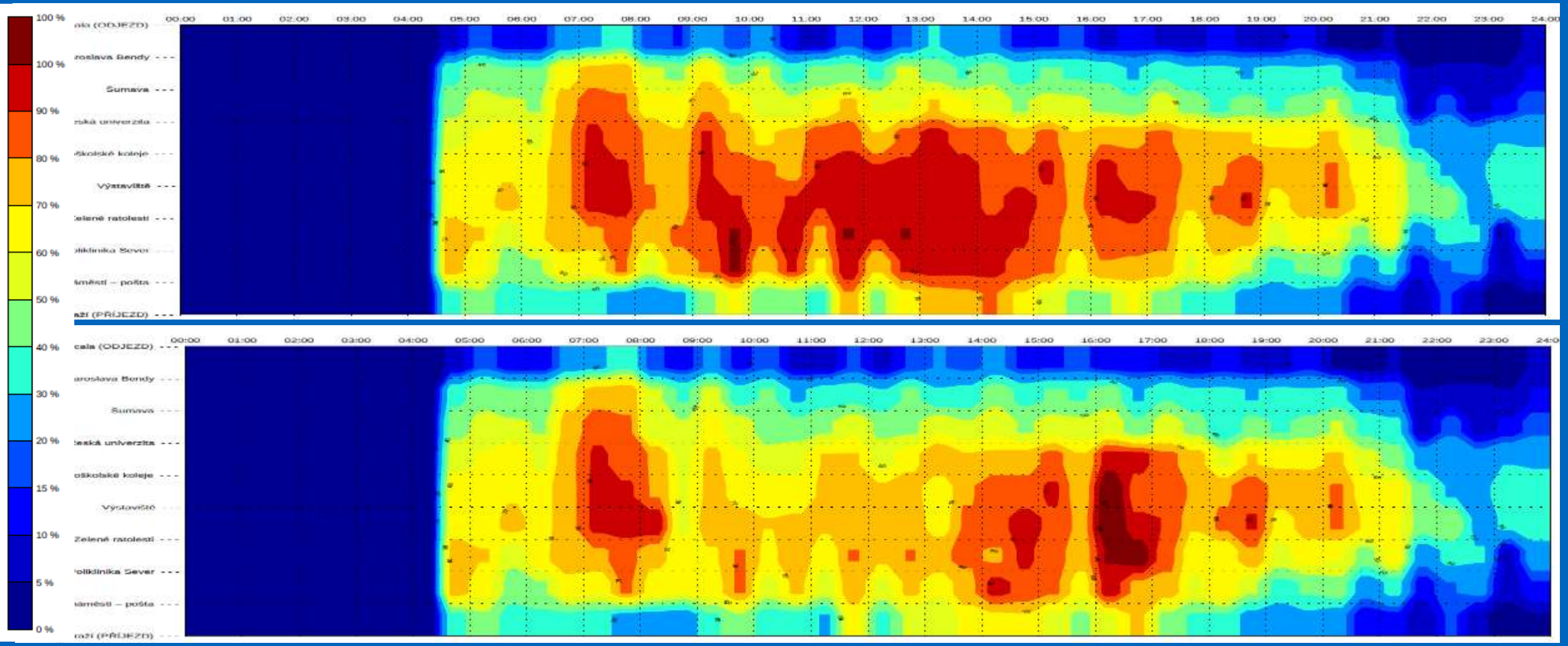
RELATIVE RATIO OF SUPPLY AND DEMAND – A SPACE VIEW



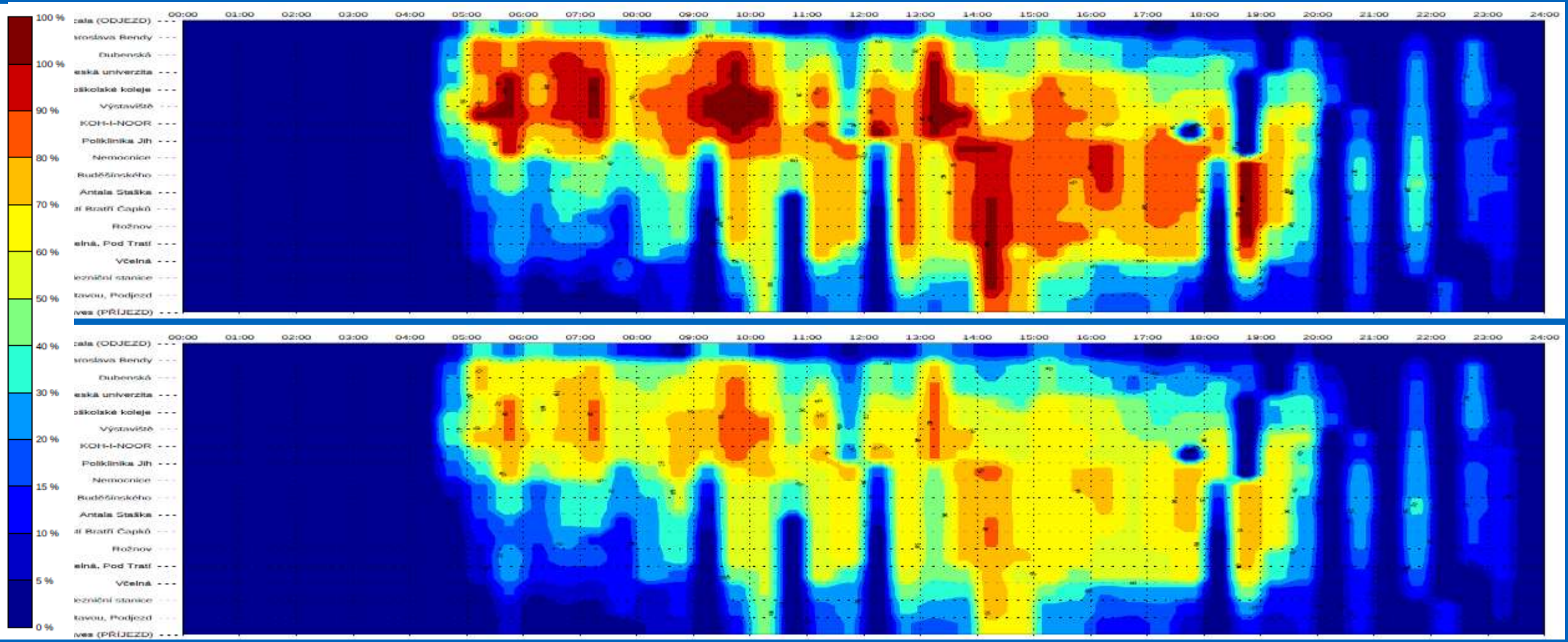
SPACE-TIME RELATIVE RATIO OF SUPPLY AND DEMAND → QUALITY OF SERVICE



MODEL INTERPRETATION COMPUTING TIMETABLE CHANGE → QUALITY CHANGE



MODEL INTERPRETATION COMPUTING A NEW VEHICLE TYPE → QUALITY CHANGE



TRAFFIC QUALITY FOR ANY ROAD USER → LEVELS OF SERVICE

- Output classification: Common quality levels … LOS

20	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT
detektor	6	6	6	6	6	6	6	6	6	6	6	6	7	7	7	7	7	7	7	7	7	7	7	7	8	8	8	8	8	8	8	8	8	8	8	8	9	9	9	9	9	9	9	9	9	9	9	9	10	10	10	10	10	10	10	10	10	10	10	10
1J	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1S	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3	3	3	3	3	2	3	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2J	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2S	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	3	3	2	2	1	2	2	2	3	3	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
3V	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
3Z	1	1	1	1	1	1	2	2	2	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	3	3	3	3	2	2	2	1	1	2	1	1	1	1	2	2	2	1
4V	1	1	1	1	2	2	2	2	2	2	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	2	2	2	2	2	2	2
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5J	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	1	2	2	2	2	2	2	2	2	2	3	2	2	2	2	2	2	2	2	1	1	1	1	2	2	2	2	2	1	2	2	2	1	2	1	1	1	1	1	1	1
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6J	1	2	2	2	2	2	2	2	2	3	3	3	3	2	2	3	3	3	3	3	3	3	3	3	3	3	3	3	2	3	3	3	2	3	3	3	3	3	3	3	3	3	3	3	2	3	3	3	3	3	3	3	3	2	3	3	3	2	1	1
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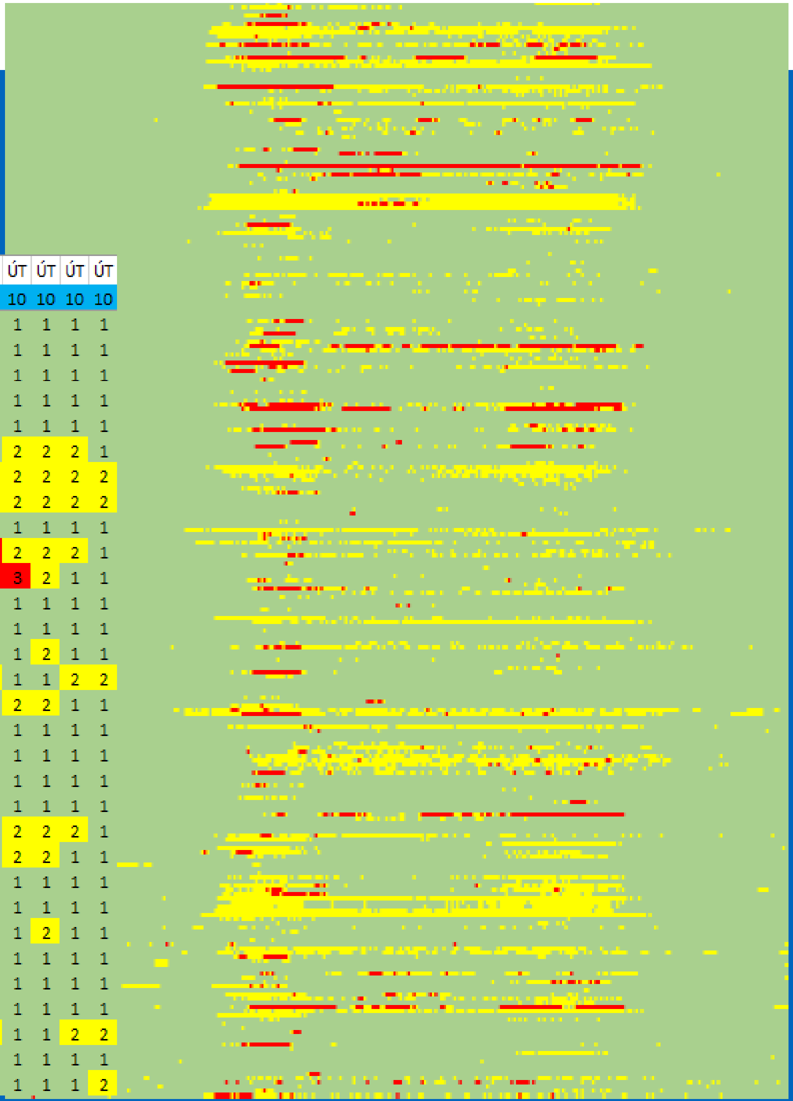
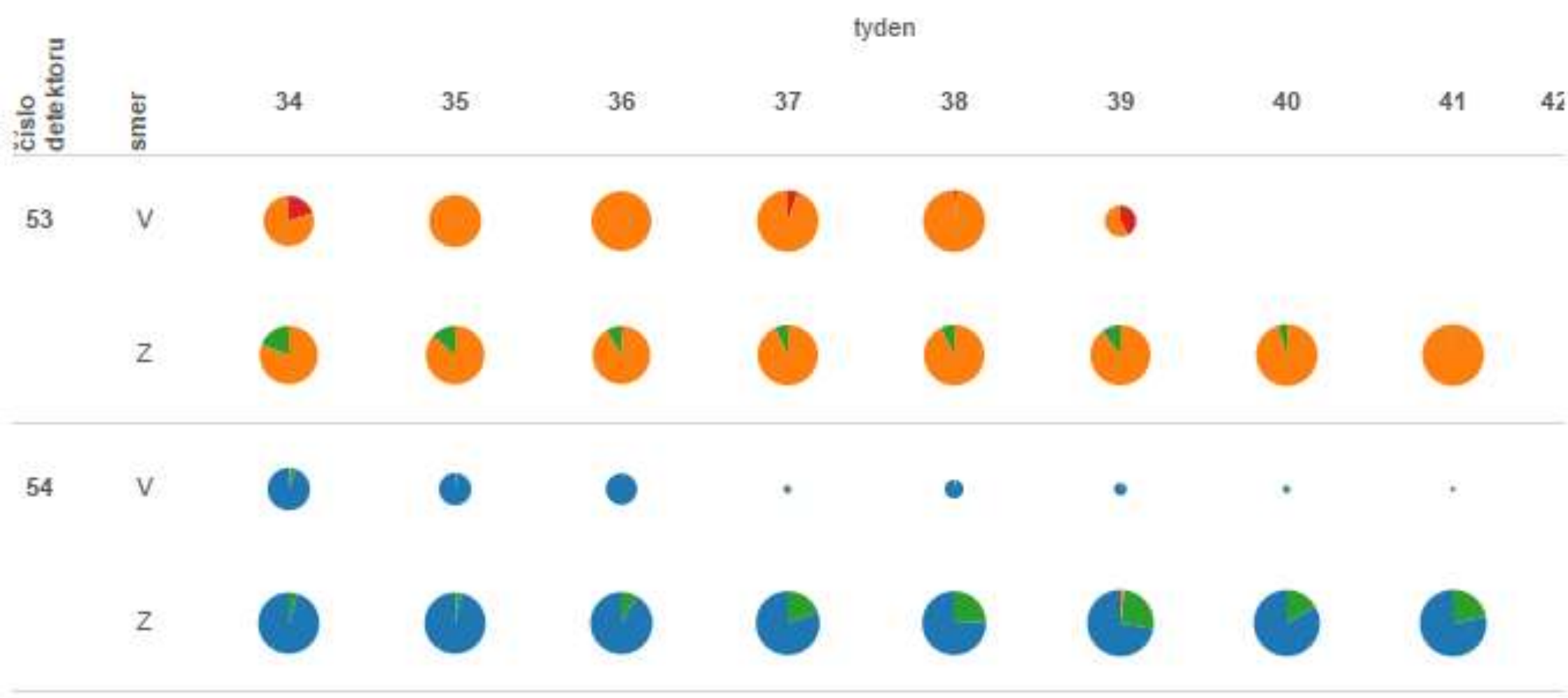


TRAFFIC QUALITY FOR ANY ROAD USER → QUALITY LEVELS DISTRIBUTION



ERRORS IN MODELS?

- Not only the input data involve errors
- ALSO THE MODELS NEED TO BE TESTED AND ADJUSTED!
- Typical problem for traffic detectors: low flow, low speed

20	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT	ÚT
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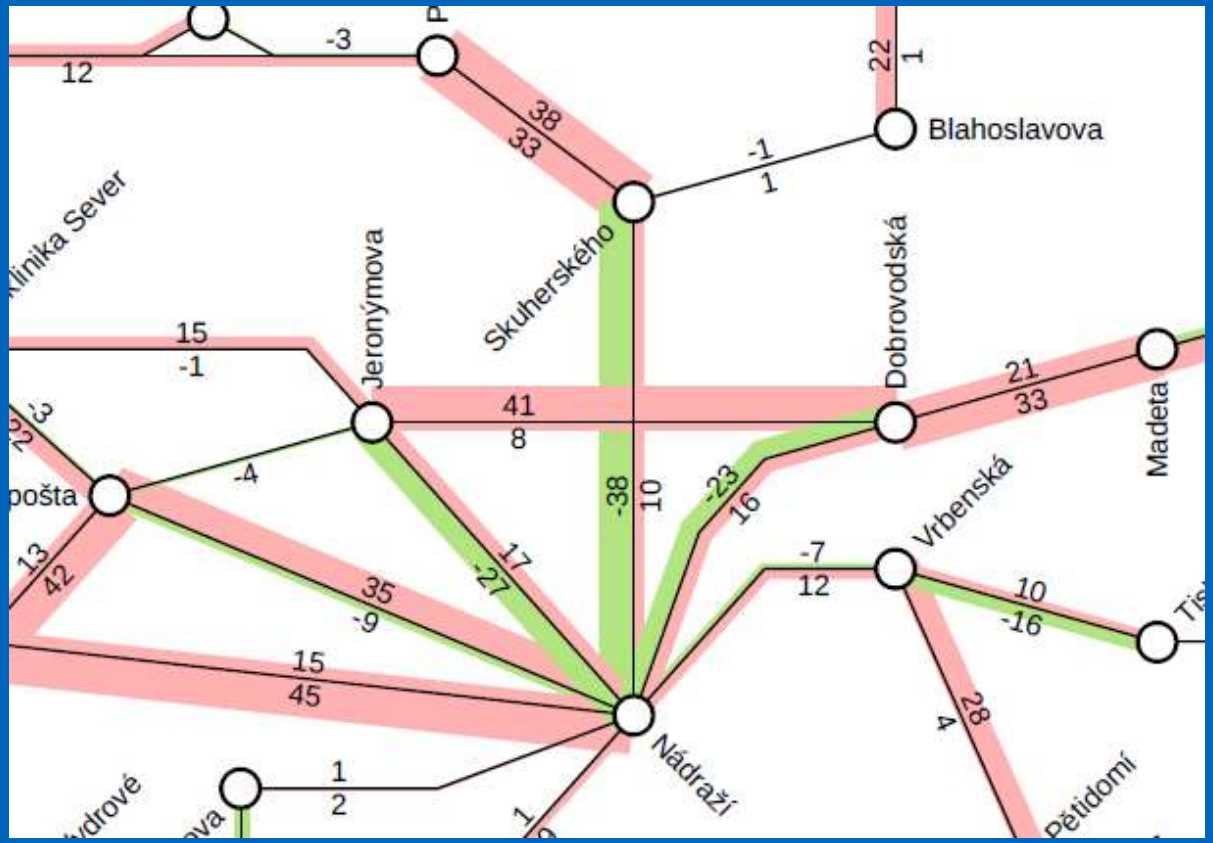
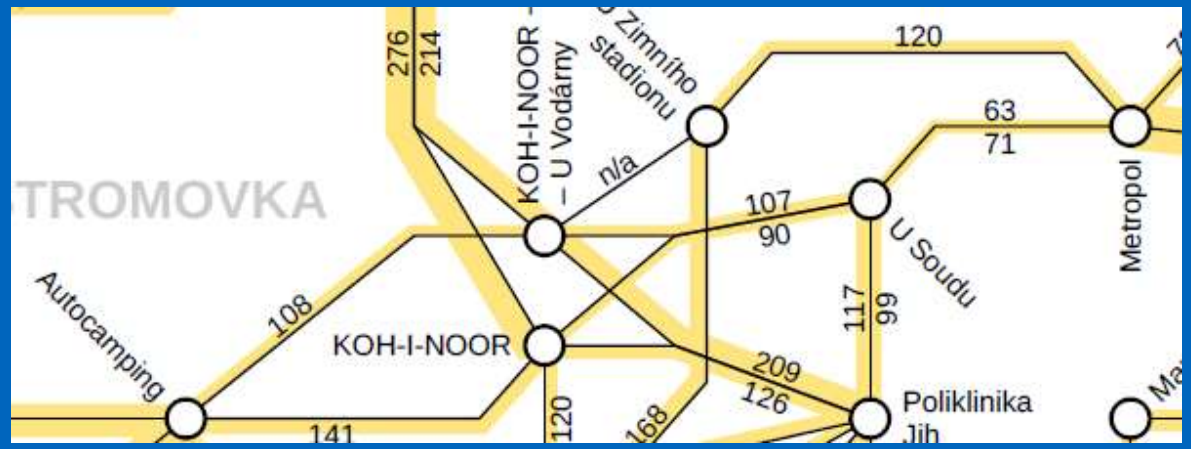
OTHER SERVICE QUALITY VALUES

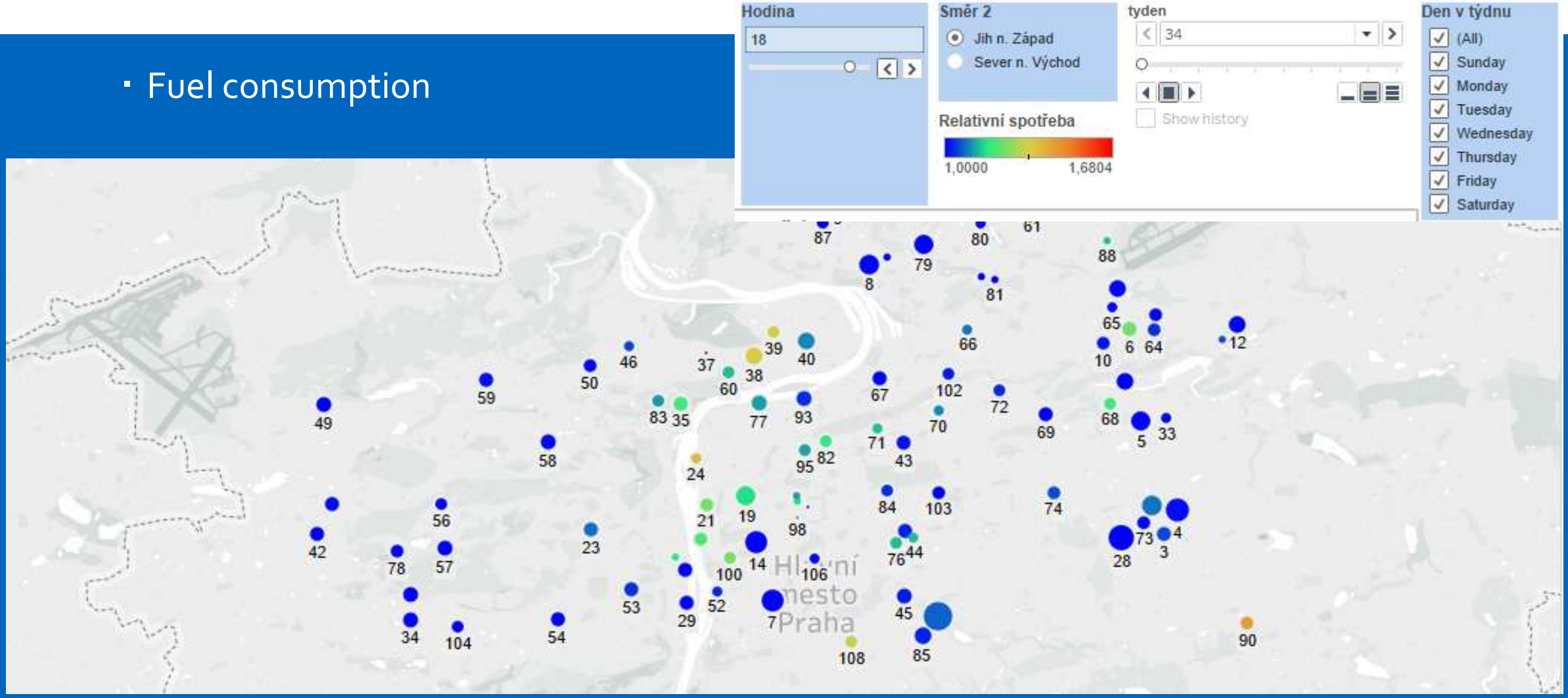
- Delays, travel time, travel speed





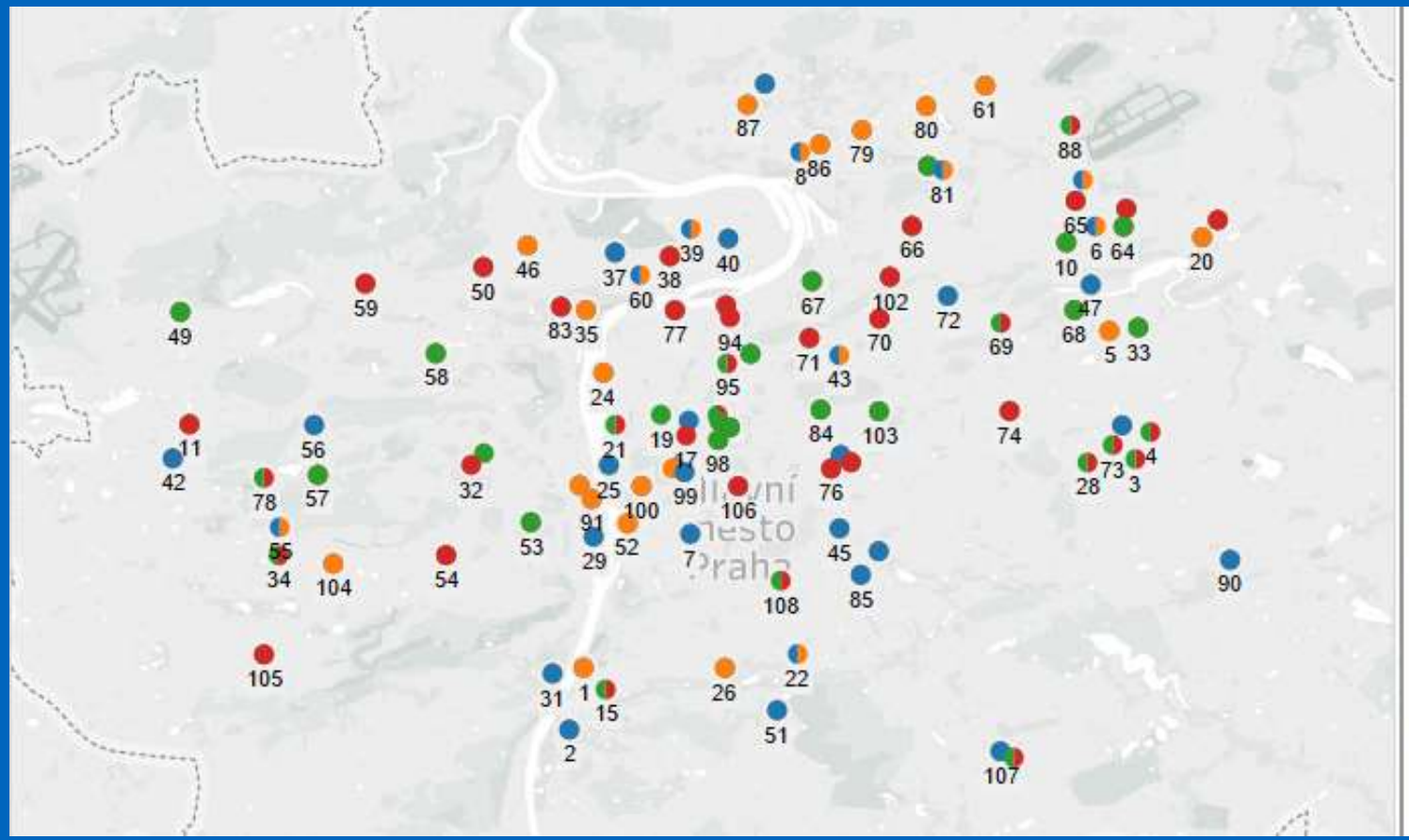
OTHER SERVICE QUALITY VALUES ECOLOGICAL FACTORS

- Fuel consumption

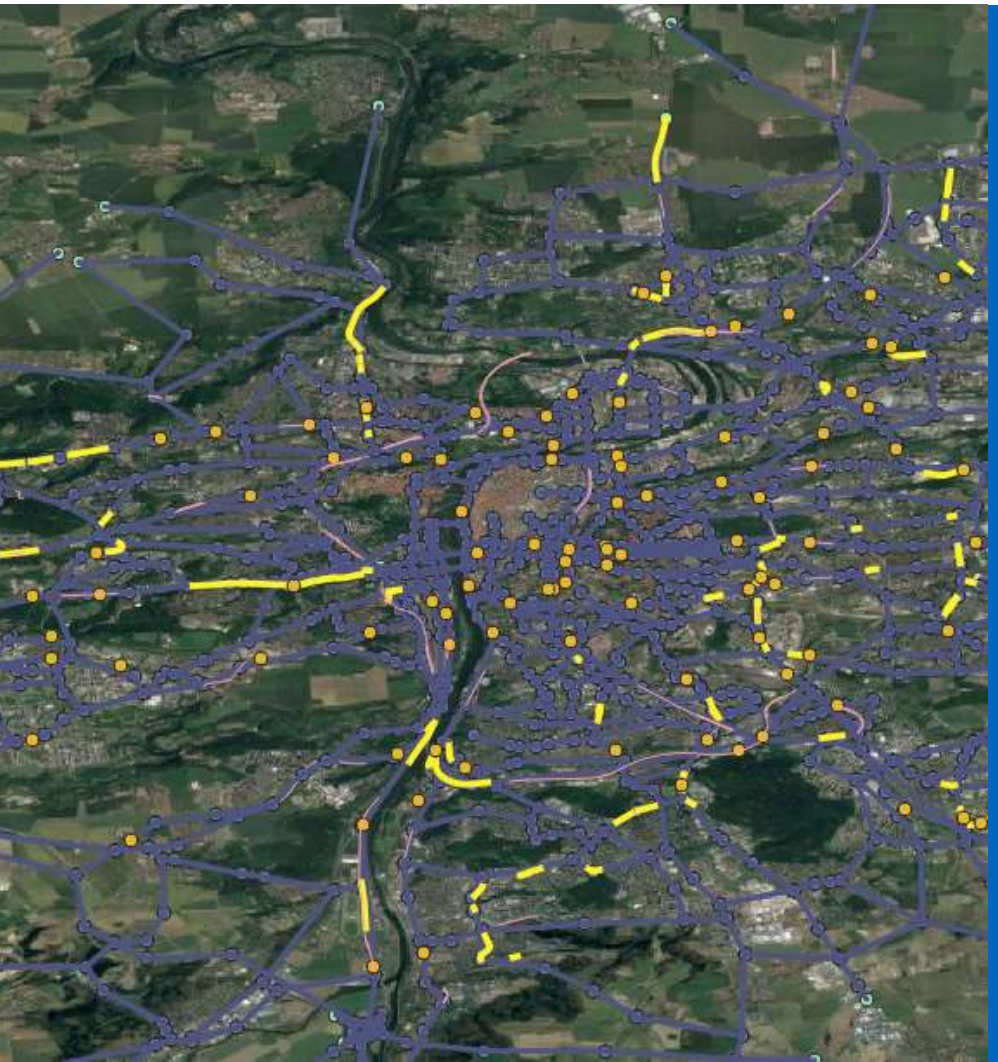


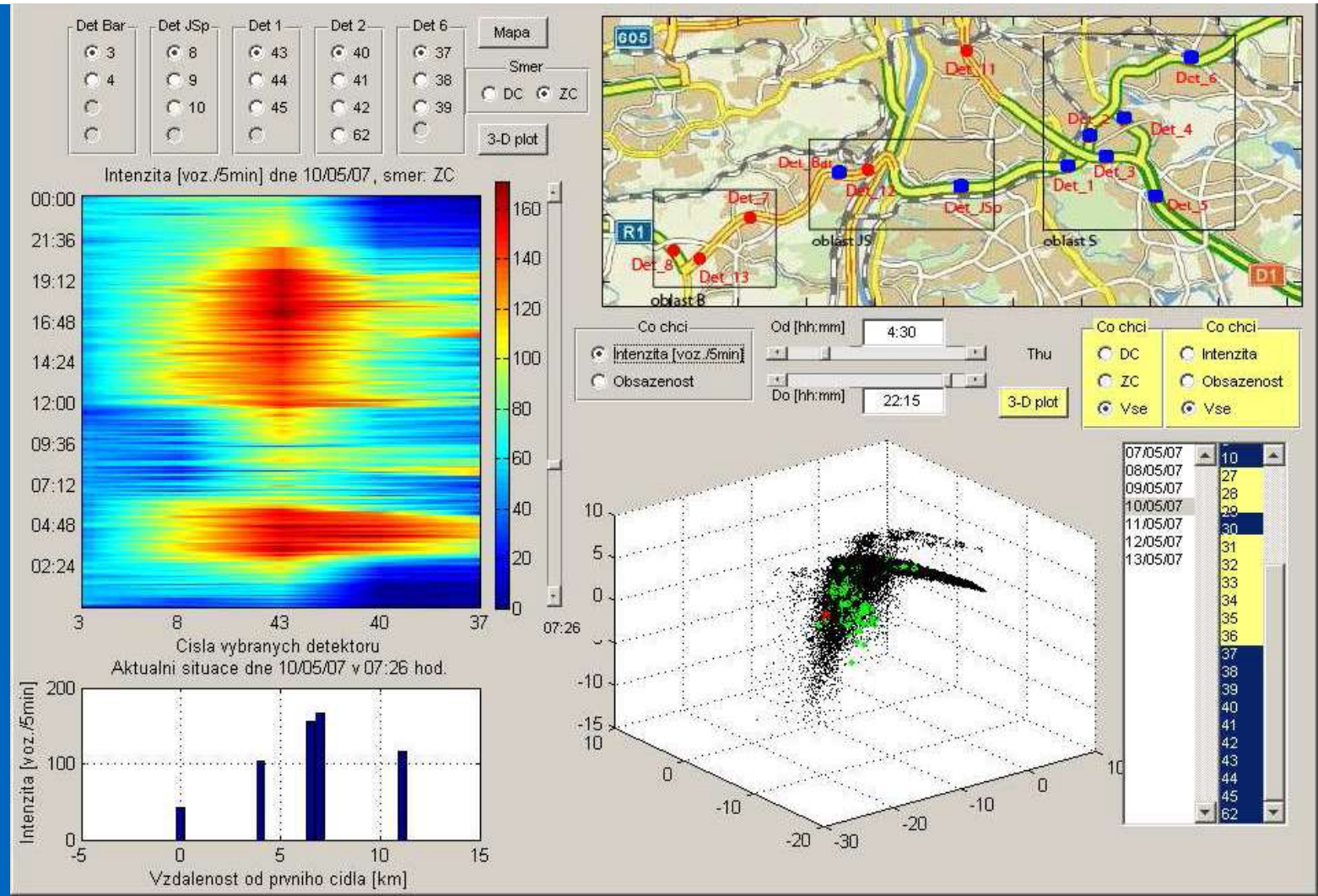
SW TOOLS?

- Programming + GIS + dynamic visualization



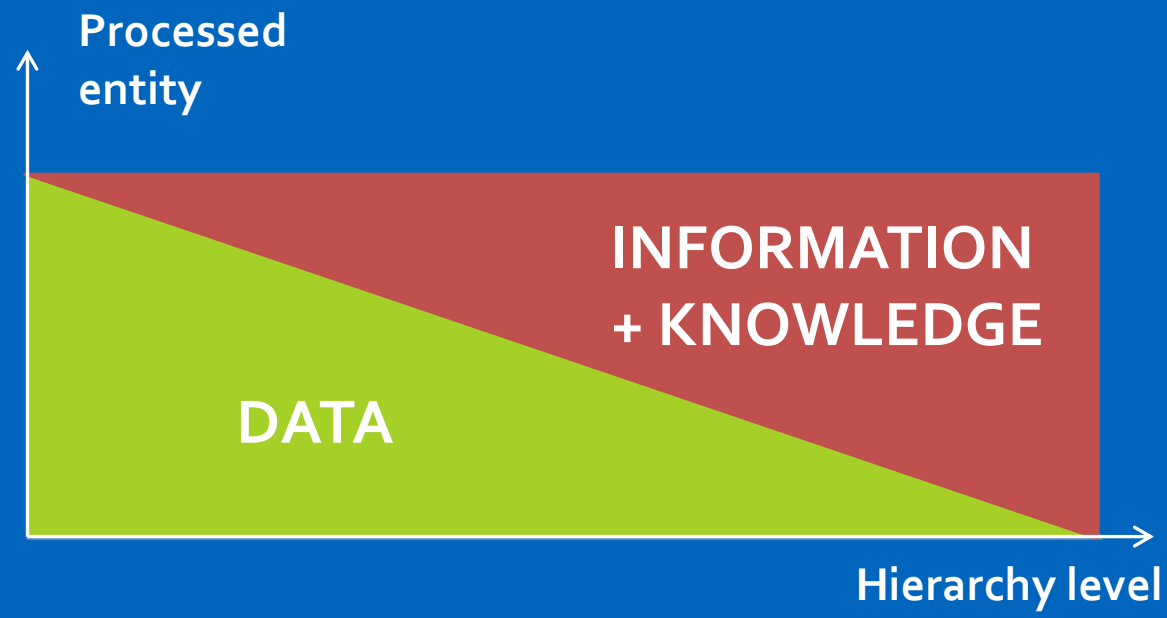
INTEGRATED TRAFFIC VIEWERS

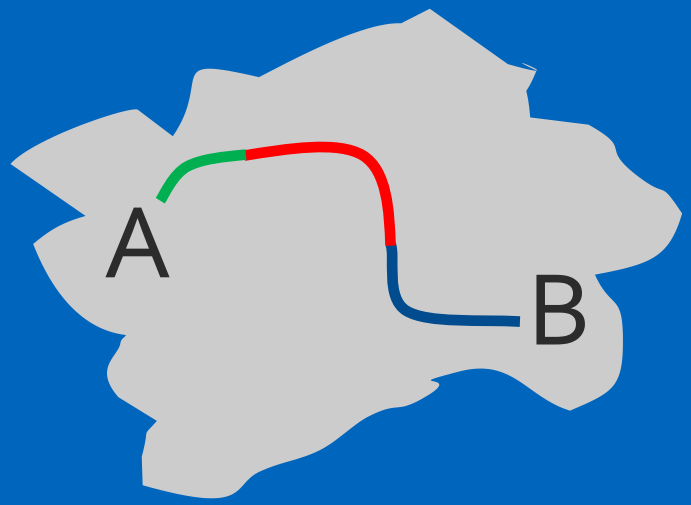




ON-LINE DATA PROCESSING

- MAAS necessity
- Dealing with unexpected errors
- Towards higher levels, data must be transformed into information and knowledge





THANK YOU ...

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