CASPT2015
Conference on Advanced Systems in Public Transport
19-23 July 2015 | nhow hotel, Rotterdam, The Netherlands
Organized by Erasmus School of Economics and Rotterdam School of Management, Erasmus University

# An Offline Framework for Reliability Diagnosis by Automatic Vehicle Location Data

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# Summary

- Introduction
- Related literature
- Methodology
    - Reliability characterization
    - Identification of unreliability sources
        - Sources at terminal
        - Down-streaming sources
        - Time spent at bus stops
        - Speed between bus stops
    - Selection of preventive strategies
- Application in a real case
- Conclusion

# Introduction

- **Reliability definition:**
  - The capability of Public Transport Companies to provide the service as promised
- **Scope:**
  - The stochastic environment of bus service operations
- **Aims:**
  1. Characterizing time reliability over all bus-stops and time periods for each route
  2. Quantifying the occurrence of unreliability sources
  3. Selecting preventive strategies accordingly

# Related literature (1/3)

- **Characterization of the reliability** (***Abkowitz et al., 1978; Cham, 2006***)
  1. Data input (manual or automatic collection)
  2. Output calculation from data input
  3. Service measure (i.e. aggregated metrics)
  4. Threshold for acceptability setting
  5. Final performance report

*e.g. Camus at al., 2005; Lin at al., 2007; Lin and Ruan, 2009; Chen et al., 2009; Mandelzys and Hellinga, 2010; Feng and Figliozzi, 2011; Ma et al., 2014*

Trend toward analysis at all bus stops and time periods

# Related literature (2/3)

## Organization of unreliability sources (by AVL)

Which ones?

1. Improper Service Design,
2. Driver and Supervision Failures
3. Uncertainties in Passengers Volumes
4. Uncontrollable External Factors

} Ceder (2007)

Where?

- At terminals (e.g. *Cham, 2006*)
- At and between time points (e.g. *Mandelzys and Hellinga, 2010; Feng and Figliozzi, 2011*)
- At start terminal and bus stops (e.g. *Hammerle, 2005*)

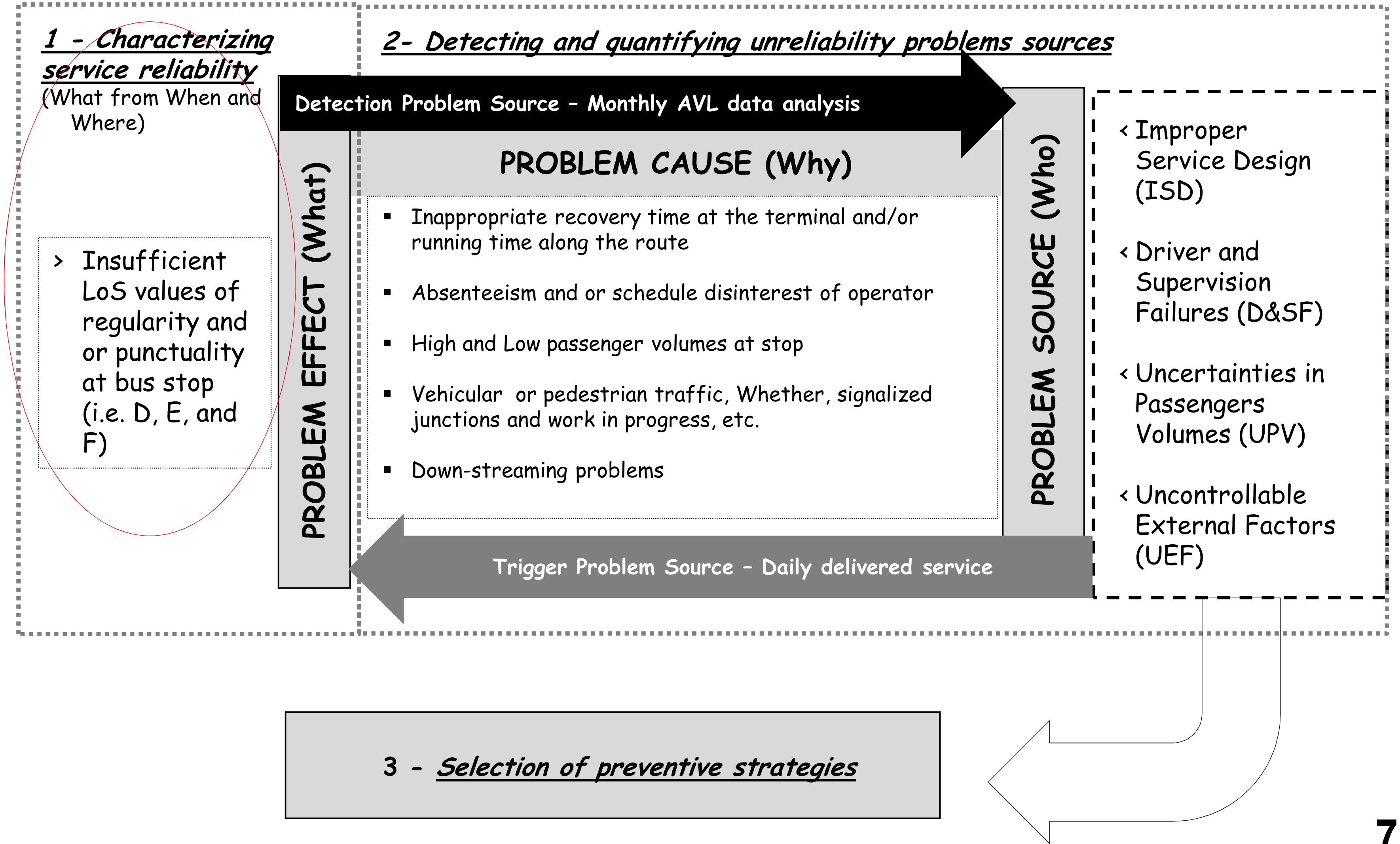
More work on the link between unreliability problems and whomever is in charge of their correction

# Related literature (3/3)

- **Selection of strategies** (inspired by Abkowitz et *al., 1978; Cham, 2006*):

| Type of strategy | Sub-type of strategy | Preventive | Corrective |
|---|---|---|---|
| Priority | Exclusive lanes (Bus only streets, busways, with and contra flow bus lane) | • | |
| | Route Design | • | |
| | Signal Priority | • | • |
| Operational | Reserve vehicle and operators | • | • |
| | Operator training | • | |
| | Operator incentives and penalties | • | |
| | Schedule adjustments | • | |
| | Supervision | • | |
| | Improve vehicle access (e.g. fare collection, device for boarding/alightings) | • | • |
| Control | Holding (Scheduled-based or Headway-based) | | • |
| | Overtaking | | • |
| | Expressing (Full expressing, Limited stops, Alighting only) | | • |
| | Short- Turning | | • |
| | Deadheading | | • |
| | Exchanging vehicle shift | | • |
| | Adding a reinforce shift | | • |
| | Providing in-vehicle message | | • |
| | Operator self-regulation | | • |

# Methodology (1/11)



# Methodology (2/11)

- **Characterization of the reliability:**

1. Pick up data from AVL and scheduled services (e.g. date, route, trip number, bus stop code, arrival (or departure) time, etc.)
2. Handle AVL data to recognize and address bus overtaking and missing data points (technical failures or incorrect operation in service) – *Barabino et al., 2013*

3. & 4. High Frequency Services

Compute actual and scheduled headway as the difference between to consecutive bus arrivals (or departures)

Compute the $C_{vh}$ for bus stops and time periods

Link the $C_{vh}$ to a Los (e.g. Kittelson and Associates, 2003).

3. & 4. Low Frequency Services

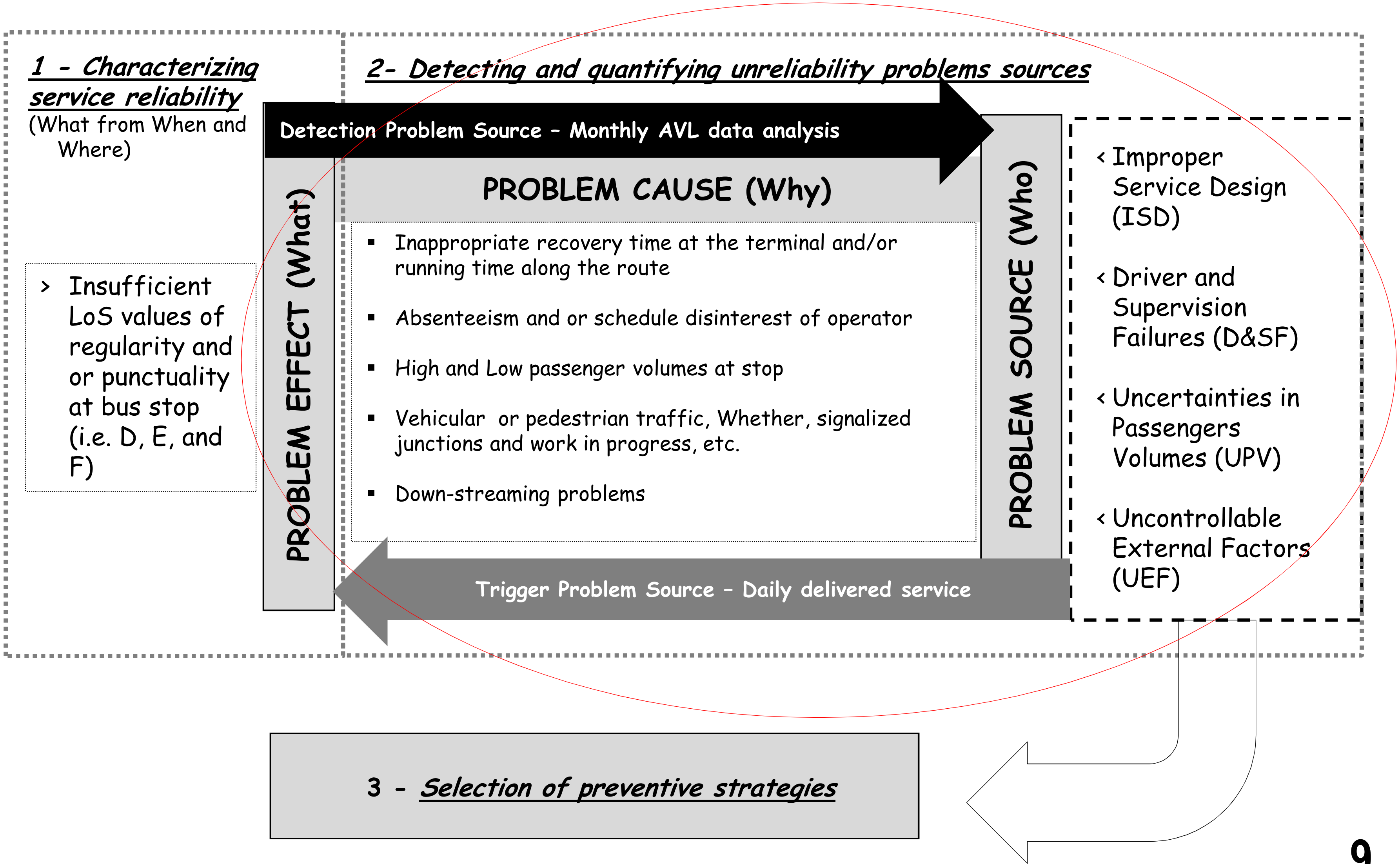
Compute the schedule deviation as the difference between actual and scheduled arrival (or departure)

Compute the % of Punctual buses for bus stops and time periods

Link the % of Punctual buses to a Los (e.g. Kittelson and Associates, 2003)

5. Investigate unreliability sources, in case of insufficient LoS

# Methodology (3/11)



# Methodology (4/11)

- **Analysis of unreliability:**

Which ones?

- Improper Service Design,
- Driver and Supervision Failures
- Uncertainties in Passengers Volumes
- Uncontrollable External Factors

Where and how?

- At terminals by recovery times
- In the remaining bus stops by down-streaming sources and time spent
- In the leg between consecutive bus stops by speed analysis

Selection and representation of the most frequent source by control dashboards

# Methodology (5/11)

- **Identification of unreliability sources:**
  - Sources at terminals

$J$ = set of runs $A$ = Set of terminals

$T_a^j$ = time deviation of run $j \in J$ at terminal $a \in A$.

$RDT_a^j$ = real departure time of run $j \in J$ at terminal $a \in A$.

$SDT_a^j$ = scheduled departure time of run $j \in J$ at terminal $a \in A$.

$ART_a^j$ = available recovery time of run $j \in J$ at terminal $a \in A$.

$RAT_a^{j-1}$ = real arrival time of run j-1 ∈ J at terminal a ∈ A.

$$T_a^j = RDT_a^j - SDT_a^j$$

$$ART_a^j = SDT_a^j - RAT_a^{j-1}$$

# Methodology (6/11)

- **Identification of unreliability sources:**
  - Sources at terminals

**Detect Down-streaming sources by comparing $T_a^j$ and $ART_a^j$**

| $ART_a^j$ \ $T_a^j$ | $<0$ | $\approx 0$ | $>0$ |
|---|---|---|---|
| $<0$ | n/a | n/a | ISD |
| $\approx 0$ | ok | ok | D&SF and ISD |
| $>0$ | D&SF | ok | D&SF |

**The notation $T_a^j$ and $ART_{aj} \approx 0$ must be read as:**

$\alpha \leq T_a^j \leq \beta$

$\gamma \leq ART_a^j \leq \delta$

# Methodology (7/11)

- **Identification of unreliability sources:**
  - Down-streaming sources

$J$ = set of runs $I$ = Set *of bus stops (different from terminals)*

$T_i^j$ = time deviation of run $j \in J$ at bus stop $i \in I/A$.

$RAT_i^j$ = real arrival time of run j ∈ J at bus stop $i \in I/A$.

$SAT_a^j$ = scheduled arrival time of run $j \in J$ at bus stop $i \in I/A$.

$RDT_a^j$ = real departure time of run $j \in J$ at bus stop $i \in I/A$.

$SDT_a^j$ = scheduled departure time of run $j \in J$ at bus stop $i \in I/A$.

**Detect Down-streaming sources by comparing $T^j_i$ to $T^j_{i-1}$**

*If $T^j_i \leq 0$ & $T^j_{i-1} \leq 0$ -→ early arrivals at bus stops i and i-1*
*If $T^j_i \geq 0$ & $T^j_{i-1} \geq 0$ -→ late arrivals at bus stops i and i-1*

**Compute the relative occurences of these two situations**

# Methodology (8/11)

- **Identification of unreliability sources:**
  - Time spent at bus stops

$J$ = set of runs $I$ = Set *of bus stops (different from terminals)*

$N$ = maximum number of scheduled times spent at bus stop $i \in I/A$

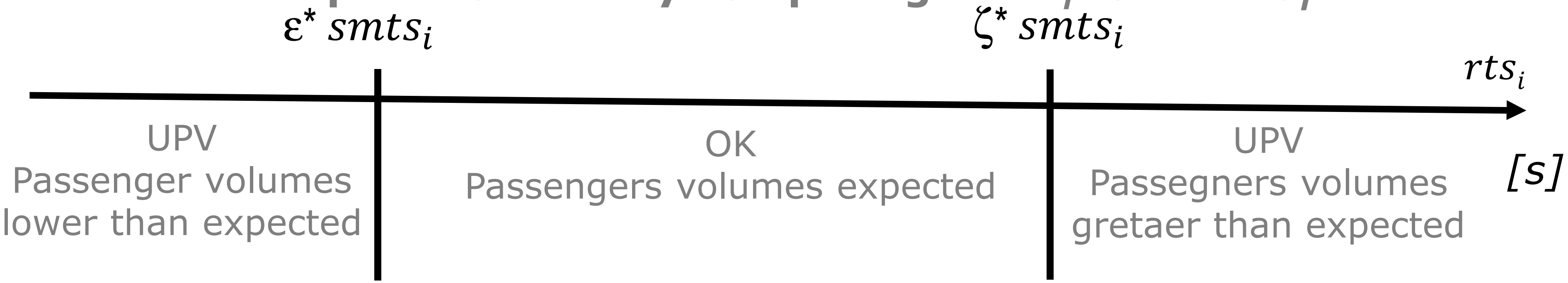
$smts_i$ = scheduled time mean spent at bus stop $i \in I/A$.

$$smts_i \; \frac{\sum_{j=1}^{N} sts_{i,j}}{N}$$

$sts_i^j$ = scheduled time spent by run $j \in J$ at bus stop $i \in I/A$

$rts_i^j$ = real time spent by run $j \in J$ at bus stop $i \in I/A$

**Detect Time spent sources by comparing *smts$^j_i$* to the *rts$_i^j$***




**Compute the relative occurences of these three situations**

# Methodology (9/11)

- **Identification of unreliability sources:**
  - Speed between bus stops

$J$ = set of runs $I$ = Set of bus stops (different from terminals)

N = maximum number of scheduled running times, which are recorded j ∈ J on the leg between stops i ∈ I/A and i-1 ∈ I/A

$l_{i-1,i}$ =lenght of the leg between stops i ∈ I/A and i-1 ∈ I/A

$rs^{j}_{i-1,i}$ = real speed between stops i ∈ I/A and i-1 ∈ I/A

$sms_{i-1,i}$ = scheduled mean speed between stops i ∈ I/A and i-1 ∈ I/A

$rrt_{i-1,i}^{j}$ = real running time between stops i ∈ I/A and i-1 ∈ I/A

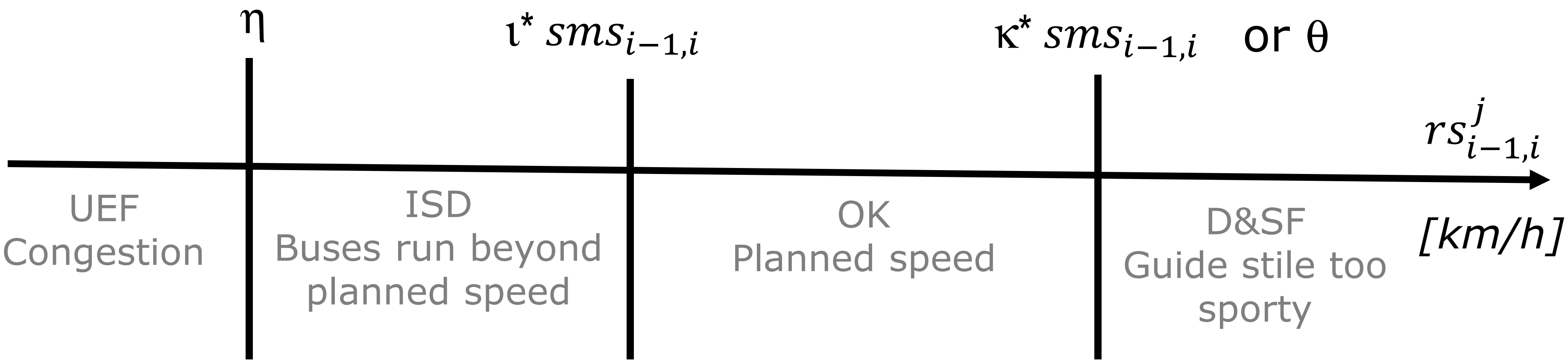
$srt_{i-1,i}^{j}$ = scheduled running time of run j ∈ J between stops i ∈ I/A and i-1 ∈ I/A

# Methodology (10/11)

- **Identification of unreliability sources:**
  - Speed between bus stops (J = set of runs I = Set of bus stops)

$$rs^j_{i-1,i} = \frac{l_{i-1,i}}{rrt^j_{i-1,i}} \quad \forall i \in I, \forall j \in J \qquad sms_{i-1,i} = \frac{l_{i-1,i}}{\frac{\sum_{j=1}^{N} srt_{(i-1,i)j}}{N}} \quad \forall i \in I, \forall j \in J$$

**Detect Speed sources by comparing $rs^j_{i-1,i}$ to the $smts_{i-1,i}$**




**Compute the relative occurences of these four situations**

# Methodology (11/11)

- **Systematization of sources**
  - Improper Service Design **(ISD)**
  - Driver **(D)** and Supervision Failures **(SF)**
  - Uncertainties in Passengers Volumes **(UPV)**
  - Uncontrollable External Factors **(UEF)**
- **Selection of strategies:**

| Unreliability source | Type of strategies | Sub-Type of strategies |
|---|---|---|
| UEF | Priority | Exclusive lanes |
| UEF | | Route re-design |
| UEF | | Signal Priority |
| ISD | Operational | Reserve vehicle and operators |
| D | | Operator training |
| D | | Operator incentives and penalties |
| ISD, UPV | | Schedule adjustments |
| D&SF | | Supervision |
| UPV | | Improving vehicle access (e.g. fare collection, device for boarding/alightings) |

# Case study (1/5)

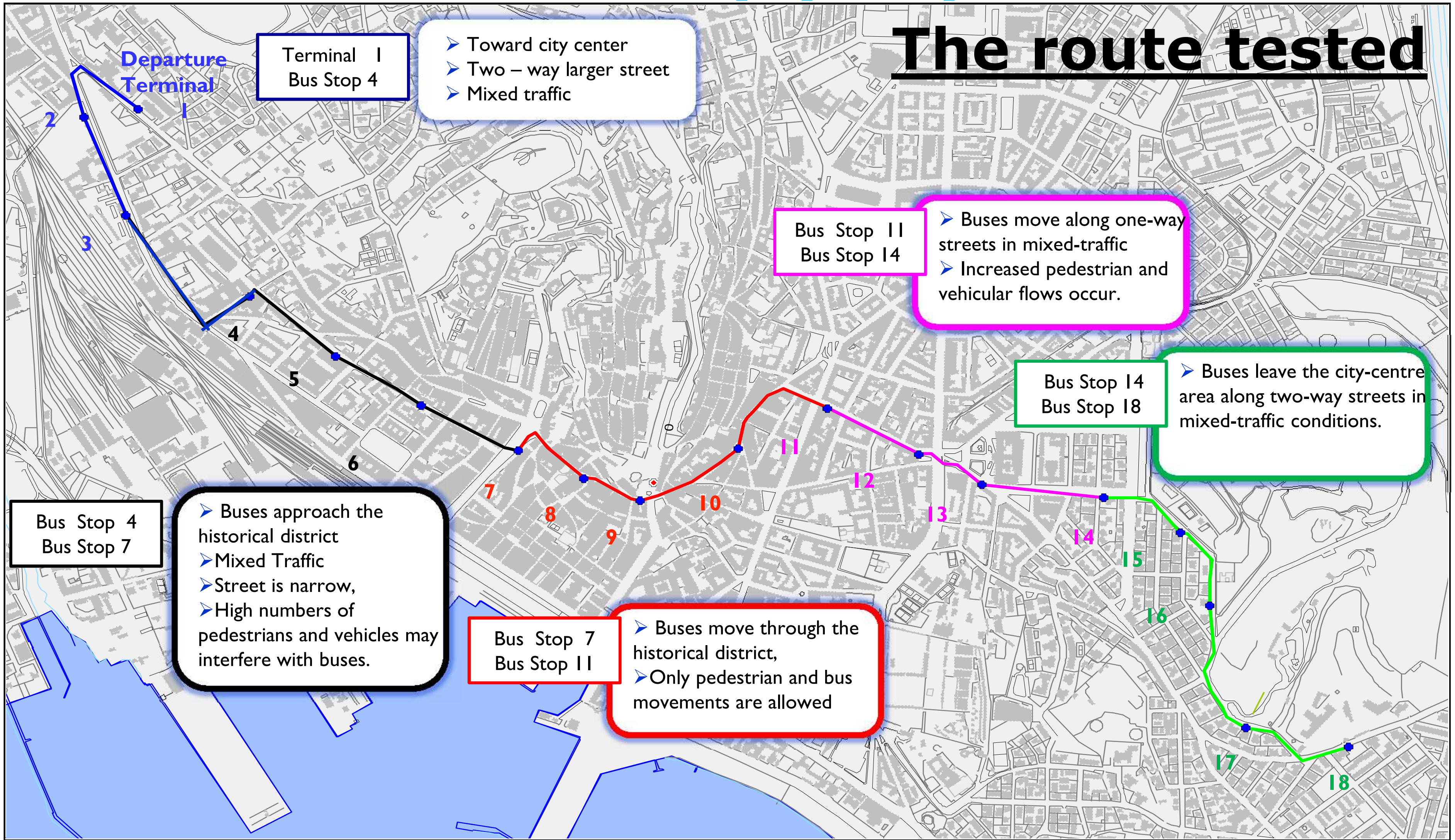

## CTM Spa Bus operator

- 264 Vehicle AVL- equipped, since 2007
- 30 Routes (9 high frequency routes)
- 35 M Passengers carried over the year

## AVL Data

- July 2014, Weekdays, Excel© as tools to develop the method
- About 100,000 transits processed

# Case study (2/5)



# Case study (3/5)

## *Regularity Performance*

**Eastbound direction**

| Bus stop | 7.00 7.59 | 8.00 8.59 | 9.00 9.59 | 10.00 10.59 | 11.00 11.59 | 12.00 12.59 | 13.00 13.59 | 14.00 14.59 | 15.00 15.59 | 16.00 16.59 | 17.00 17.59 | 18.00 18.59 | 19.00 19.59 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | nd | nd | nd | nd | nd | nd | D | nd | nd | nd | nd | nd | D |
| 2 | A | A | A | A | A | B | D | nd | nd | A | A | C | E |
| 3 | A | A | A | A | A | B | D | nd | nd | A | A | B | D |
| 4 | A | A | A | A | B | C | D | A | A | A | A | B | D |
| 5 | A | A | A | A | A | C | D | B | A | A | A | B | D |
| 6 | nd | A | nd | nd | nd | B | D | nd | nd | A | A | B | D |
| 7 | A | A | B | A | B | C | D | B | A | A | A | B | D |
| 8 | A | A | B | A | B | C | D | A | A | A | A | B | E |
| 9 | A | A | B | A | B | C | D | B | A | A | A | B | E |
| 10 | A | A | B | A | B | C | D | B | A | A | A | B | D |
| 11 | A | A | C | A | B | C | D | C | A | A | B | C | D |
| 12 | nd | nd | nd | nd | nd | nd | nd | nd | nd | nd | nd | nd | nd |
| 13 | A | B | C | A | B | C | D | C | A | A | B | C | D |
| 14 | A | B | C | B | B | C | D | C | A | A | B | C | nd |
| 15 | A | B | C | B | B | C | D | C | A | A | B | C | nd |
| 16 | A | B | C | A | B | C | D | C | A | B | B | C | D |
| 17 | A | B | C | A | B | C | D | C | A | B | B | C | E |
| 18 | A | B | C | B | B | C | D | C | A | A | B | C | E |

| LoS | Comments |
|---|---|
| A | Service provided like clockwork (Cvh <0.21) |
| B | Vehicles slightly off headway (Cvh<0.30) |
| C | Vehicles often off headway (Cvh<0.39) |
| D | Irregular headway with some bunching (Cvh<0.52) |
| E | Frequent bunching (Cvh<0.75) |
| F | Most vehicles bunched (Cvh>0.75) |

*(Kittelson & ass. et al, 2003a;2003b)*

## *Punctuality Performance (-1 ÷ 3 minutes)*

**Eastbound direction**

| Bus stop | 7.00 7.59 | 8.00 8.59 | 9.00 9.59 | 10.00 10.59 | 11.00 11.59 | 12.00 12.59 | 13.00 13.59 | 14.00 14.59 | 15.00 15.59 | 16.00 16.59 | 17.00 17.59 | 18.00 18.59 | 19.00 19.59 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | A | A | A | A | B | C | C | B | A | A | A | E | E |
| 2 | A | A | B | B | A | B | C | nd | nd | B | B | D | E |
| 3 | C | C | E | E | E | D | D | nd | nd | F | E | E | F |
| 4 | F | E | F | F | F | E | F | D | E | F | F | F | F |
| 5 | F | F | F | F | F | F | F | E | F | F | F | F | F |
| 6 | nd | F | nd | nd | nd | F | F | nd | nd | F | F | F | F |
| 7 | F | F | F | F | F | F | F | F | F | F | F | F | F |
| 8 | F | F | F | F | E | F | F | F | F | F | F | F | F |
| 9 | F | F | F | F | E | F | F | F | F | F | F | F | F |
| 10 | F | F | F | E | D | F | F | F | F | F | F | F | F |
| 11 | F | F | F | F | D | F | F | F | F | F | F | F | F |
| 12 | nd | nd | nd | nd | nd | nd | nd | nd | nd | nd | nd | nd | nd |
| 13 | F | F | E | C | D | E | F | F | E | F | F | F | F |
| 14 | F | nd | E | nd | D | nd | F | nd | E | nd | F | nd | nd |
| 15 | F | nd | E | nd | E | nd | F | nd | D | nd | F | nd | nd |
| 16 | F | E | E | D | D | E | F | F | E | E | F | F | F |
| 17 | F | F | E | D | D | E | F | F | E | F | F | F | F |
| 18 | F | F | E | D | D | E | F | F | F | F | F | F | F |

| LoS | Comments |
|---|---|
| A | 90% ÷ 100% of punctual transits |
| B | 80% ÷ 90% of punctual transits |
| C | 70% ÷ 80% of punctual transits |
| D | 60%÷ 70% of punctual transits |
| E | 50% ÷ 60% of punctual transits |
| F | Less than 50% of punctual transits |

*(Ad hoc scale)*

# Case study (4/5)

| Bus stop | D&SF | ISD | ISD and or D&SF | ok |
|---|---|---|---|---|
| 1 | 0 % | 49 % | 1% | 50% |

| Time period [19.00 - 19.59] | | Down-streaming analysis | | | | Time spent analysis | | |
|---|---|---|---|---|---|---|---|---|
| | Bus stop | E_E | L_L | Other | OK | L_UPV | U_UPV | OK |
| Part 1 | 2 | 1% | 41% | 14% | 44% | 100% | 0% | 0% |
| Part 1 | 3 | 9% | 34% | 27% | 30% | 79% | 1% | 20% |
| Part 1 | 4 | 26% | 27% | 21% | 26% | 59% | 12% | 29% |
| Part 2 | 5 | 39% | 25% | 10% | 26% | 23% | 19% | 58% |
| Part 2 | 6 | 46% | 23% | 6% | 25% | 38% | 11% | 51% |
| Part 2 | 7 | 49% | 22% | 1% | 28% | 5% | 65% | 30% |

| Leg_Code | Speed analysis | | | |
|---|---|---|---|---|
| | D&SF | ISD | UEF | OK |
| *T1A* | 100% | 0% | 0% | 0% |
| *T2A* | 100% | 0% | 0% | 0% |
| *T3A* | 85% | 0% | 6% | 9% |
| *T4A* | 90% | 0% | 1% | 9% |
| *T5A* | 96% | 0% | 2% | 3% |
| *T6A* | 42% | 0% | 25% | 32% |

# Case study (5/5)

| Time period [19.00 - 19.59] | | Down-streaming analysis | | | | Time spent analysis | | | Leg_Code | Speed analysis | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Bus stop | E_E | L_L | Other | OK | L_UPV | U_UPV | OK | | D&SF | ISD | UEF | OK |
| Part 3 | 7 | 49% | 22% | 1% | 28% | 5% | **65%** | 30% | *T7A* | 7% | 0% | **80%** | 13% |
| | 8 | 45% | 21% | 8% | 26% | 5% | **71%** | 24% | *T8A* | 6% | 0% | **82%** | 12% |
| | 9 | 38% | 23% | 15% | 23% | **93%** | 2% | 5% | *T9A* | 6% | 0% | **77%** | 17% |
| | 10 | 30% | 27% | 22% | 21% | 8% | **58%** | 34% | *T10A* | 0% | 0% | **100%** | 0% |
| Part 4 | 11 | 24% | 39% | 10% | 27% | 7% | **54%** | 39% | *T11A* | *nd* | *nd* | *nd* | *nd* |
| | 12 | *nd* | *nd* | *nd* | *nd* | *nd* | *nd* | *nd* | *T12A* | *nd* | *nd* | *nd* | *nd* |
| | 13 | *nd* | *nd* | *nd* | *nd* | 12% | 42% | 47% | *T13A* | *nd* | *nd* | *nd* | *nd* |
| Part 5 | 14 | *nd* | *nd* | *nd* | *nd* | *nd* | *nd* | *nd* | *T14A* | *nd* | *nd* | *nd* | *nd* |
| | 15 | *nd* | *nd* | *nd* | *nd* | *nd* | *nd* | *nd* | *T15A* | *nd* | *nd* | *nd* | *nd* |
| | 16 | *nd* | *nd* | *nd* | *nd* | **53%** | 2% | 46% | *T16A* | **100%** | 0% | 0% | 0% |
| | 17 | 27% | 38% | 8% | 27% | **75%** | 0% | 25% | *T17A* | **99%** | 0% | 0% | 1% |
| | 18 | 31% | 36% | 5% | 28% | | | | | | | | |

- **Recommended strategies:**
  - Schedule adjustment

# Conclusions

## Main contributions

- Generate a mainstream source of AVL archived data;
- Include streams of AVL data in the framework using a single data source and integrating procedures to measure the magnitude of each unreliability source;
- Provide details on bus route unreliability sources at all bus stops and time periods.

## Main implications

- Significant time and energy savings in the study of large data sets
- Usefulness of an accurate AVL in the specific application
- Understandability of CDs for transit managers and improvement of decision-making processes

## Future research

- Application at all route directions
- Tuning of thresholds
- Headway-based analysis of unreliability sources

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# Thank you for your kind attention

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