



## Towards Intra-Vehicular Sensor Data Fusion

Paulo H. L. Rettore, Bruno P. Santos, André B. Campolina, Leandro A. Villas, and Antonio A. F. Loureiro

## Schedule

- Introduction
- Background
- Vehicular Data
- Case Study
- Conclusion

- The world's population has increased
- Over 50% live in huge cities
- Issues related to transportation and traffic begin to grow:
  - Safety and quick mobility
  - Injuries and accidents causes:
    - Expensive cost medical
    - Decrease productivity



Brazil



China





USA

India

- Possible solutions?
  - Governments strategies
    - Rotating vehicles
    - Traffic restriction on selected regions

Monday	Last # 1 and 2
Tuesday	Last # 3 and 4
Wednes day	Last # 5 and 6
Thursda y	Last # 7 and 8
Friday	Last # 9 and 0

Not scalable

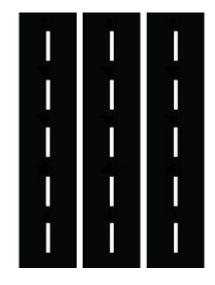
#### • Possible solutions?

- Governments strategies
  - Rotating vehicles
  - Traffic restriction on selected regions
- Additional capacity



#### • Possible solutions?

- Governments strategies
  - Rotating vehicles
  - Traffic restriction on selected regions
- Additional capacity



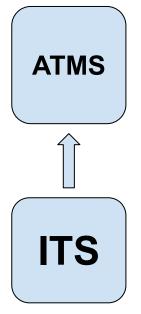
#### **Cost prohibitive**

#### • Possible solutions?

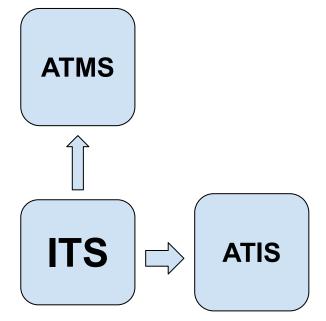
- Governments strategies
  - Rotating vehicles
  - Traffic restriction on selected regions
- Additional capacity
- Intelligent Transportation System (ITS)
  - Can be a feasible way
  - But ITS dependent of data and communication
- We are interested in data for ITS.
  - Especially in car data



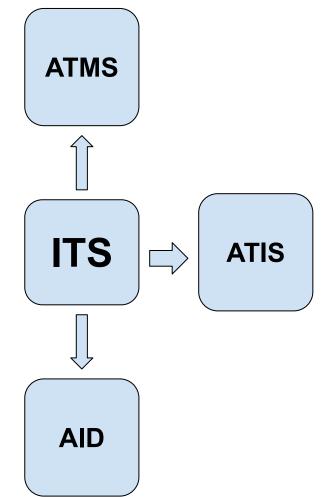
- Advanced Transportation/Traffic Management Systems
  - To control and manage traffic devices (signals, monitoring and safety devices etc...)

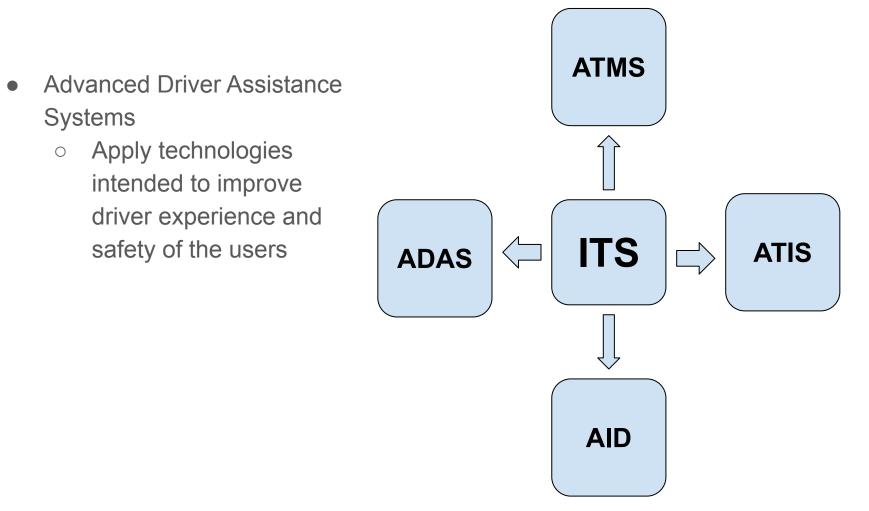


- Advanced Traveler Information Systems
  - To collect data and process it to improve understanding of traffic conditions



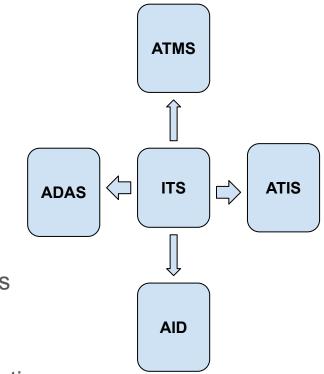
- Automatic Incident Detection
  - To automatically detect incidents as soon as possible to increase safety and reduce users perception of traffic disruption

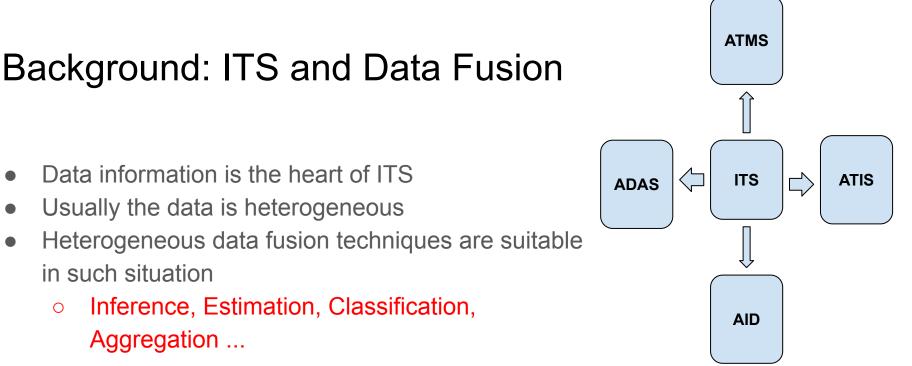




#### Background: ITS and Data

- ITS are powered by data as much as possible
- Traditional traffic sensors are ineffective for ITS requirements
- Fortunately, There are available other data sources
  - Cameras, GPS, Smartphones, vehicles
  - Probe vehicles, Social Media ...
- These sensors provides timely and precise information about traffic status

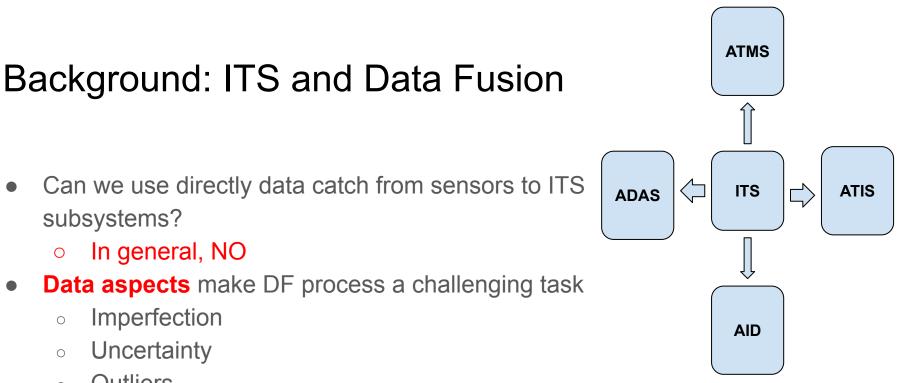




#### Can we use directly data catch from sensors to ITS subsystems? In general, NO Ο

#### **Data aspects** make DF process a challenging task

- Imperfection 0
- Uncertainty 0
- Outliers 0
- Ambiguity 0
- Ο . . .



#### Vehicular Data

- The sensors on a car, communicate with the Engine Control Unit (ECU)
- The data they output is accessible using the On-Board-Diagnostics (**OBD**) interface
- The information is collected from different sensors spread across different parts of the vehicle's body in different measuring units
- It can be considered Heterogeneous



## Vehicular Data

Lilometers er litreIntake air temperatureAmbient air temperatureCatalyst temperatureRelative temperatureAccelerator pedal positionuel flow ateCO2Ethanol fuel %Engine oil temperatureFuel injection temperatureO2 sensor monitoroltageDistance traveledFuel remainingFuel rail pressureHybrid battery pack remaining lifeEvap. system vapor pressureIngine RPMEngine coolant temperatureFuel typeMalfunction indicator lampExhaust gas sensorMass Air Flow SensorIditudeGPS locationCollision sensor for headlightsActive park assistWater in fuel sensorRear cameraGarometric ressureAccelerationCost per mile/kmFront objectNight pedestrian warning IR sensorTire pressure sensorMicrophonePressureDrowsinessShockRain-Sensing Motion sensorMotion sensor						
Litometers er litreIntake air temperatureAmbient air temperatureCatalyst temperatureRelative temperatureAccelerator pedal positionuel flow ateCO2Ethanol fuel %Engine oil temperatureFuel injection temperatureO2 sensor monitorVoltageDistance traveledFuel remainingFuel remainingFuel rail pressureHybrid battery pack remaining lifeEvap. system vapor pressureVoltageEngine coolant temperatureFuel typeMalfunction indicator lamp brake actuatorExhaust gas sensorMass Air Flow SensordlitudeGPS locationCollision sensor for headlightsActive park assistSteering angle sensorRear camera Airbag sensorGrometric ressureAccelerationCost per mile/kmFront object laser radarNight pedestrian warning IR sensorTire pressure sensor			S	ensors		
er litretemperaturetemperaturetemperaturethrottle positionpedal positionuel flow ateCO2Ethanol fuel %Engine oil temperatureFuel injectionO2 sensor monitoroltageDistance traveledFuel remainingFuel rail pressureHybrid battery pack remaining lifeEvap. system vapor pressureongine RPMEngine coolant temperatureFuel typeMalfunction indicator lampExhaust gasMass Air Flow SensordtitudeGPS locationCollision sensorAutomatic brake actuatorSteering angle sensorRear cameraGPS speedGyroscopeluminosity sensor for headlightsActive park assistWater in fuel sensorAirbag sensorarometric ressureAccelerationCost per mile/kmFront object laser radarNight pedestrian warning IR sensorTire pressure sensorMicrophonePressureDrowsinessShockRain-SensingMotion sensor	Engine load	Vehicle speed	Torque sensor	Fuel pressure	Oxygen sensors	Fuel Tank Level
uel flow ateCO2Ethanol fuel %Engine oil temperatureFuel injection timingO2 sensor monitorVoltageDistance traveledFuel remainingFuel rail pressureHybrid battery pack remaining lifeEvap. system vapor pressureIngine RPMEngine coolant temperatureFuel typeMalfunction indicator lampExhaust gas recirculation errorMass Air Flow SensorIditudeGPS locationCollision sensorAutomatic brake actuatorSteering angle sensorRear cameraGPS speedGyroscopeluminosity sensor for headlightsActive park assistWater in fuel assistAirbag sensorGrowhonePressureCost per mile/kmFront object laser radarNight pedestrian warning IR sensorTire pressure sensorMotion sensorPressureDrowsinessShockRain-SensingMotion sensor	Kilometers	Intake air	Ambient air	Catalyst	Relative	Accelerator
ateCO2Ethanol rulel %temperaturetimingmonitorVoltageDistance traveledFuel remainingFuel railHybrid batteryEvap. systemVoltageDistance traveledFuel remainingFuel railHybrid batteryEvap. systemIngine RPMEngine coolant temperatureFuel typeMalfunctionExhaust gasMass AirIditudeGPS locationCollision sensorAutomaticSteering angle brake actuatorRear cameraGPS speedGyroscopeluminosity sensor for headlightsActive park assistWater in fuel sensorAirbag sensorGerstireAccelerationCost per mile/kmFront objectNight pedestrian warning IR sensorTire pressure sensorMicrophonePressureDrowsinessShockRain-SensingMotion sensor	per litre	temperature	temperature	temperature	throttle position	pedal position
atetemperaturetimingmonitorVoltageDistance traveledFuel remainingFuel railHybrid battery pressureEvap. system vapor pressureAngine RPMEngine coolant temperatureFuel typeMalfunctionExhaust gasMass Air Flow SensorAltitudeGPS locationCollision sensorAutomatic brake actuatorSteering angle sensorRear cameraGPS speedGyroscopeluminosity sensor for headlightsActive park assistWater in fuel sensorAirbag sensorAccelerationCost per mile/kmFront objectNight pedestrian warning IR sensorTire pressure sensorMicrophonePressureDrowsinessShockRain-SensingMotion sensor	Fuel flow	CO1	Ethen al firel (	Engine oil	Fuel injection	O2 sensor
foltagetraveledFuel remainingpressurepack remaining lifevapor pressureangine RPMEngine coolant temperatureFuel typeMalfunctionExhaust gasMass AiraltitudeGPS locationCollision sensorAutomaticSteering angle brake actuatorRear cameraaltitudeGyroscopeluminosity sensor for headlightsActive parkWater in fuel sensorAirbag sensorarometric ressureAccelerationCost per mile/kmFront objectNight pedestrian warning IR sensorTire pressure sensorAccordPressureDrowsinessShockRain-SensingMotion sensor	rate	CO2 E	Ethanor fuel %	temperature	timing	monitor
IndicatorIndicatorPressurePack remaining fileVapor pressureIngine RPMEngine coolant temperatureFuel typeMalfunction indicator lampExhaust gasMass Air Flow SensorIditudeGPS locationCollision sensorAutomatic brake actuatorSteering angle sensorRear cameraGPS speedGyroscopeIuminosity sensor for headlightsActive park assistWater in fuel sensorAirbag sensorGPS speedAccelerationCost per mile/kmFront object laser radarNight pedestrian warning IR sensorTire pressure sensorAccolorPressureDrowsinessShockRain-SensingMotion sensor	Valtana	Distance	Fuel remaining	Fuel rail	Hybrid battery	Evap. system
Ingine RPM temperatureFuel typeindicator lamp indicator lamprecirculation errorFlow SensorItitudeGPS locationCollision sensorAutomatic brake actuatorSteering angle sensorRear cameraGPS speedGyroscopeluminosity sensor for headlightsActive park assistWater in fuel sensorAirbag sensorGerometric ressureAccelerationCost per mile/kmFront object laser radarNight pedestrian warning IR sensorTire pressure sensorMotion sensorPressureDrowsinessShockRain-SensingMotion sensor	traveled	traveled		pressure	pack remaining life	vapor pressure
ditiudeGPS locationCollision sensorAutomatic brake actuatorSteering angle sensorRear cameradtitudeGPS locationCollision sensorAutomatic brake actuatorSteering angle sensorRear cameraGPS speedGyroscopeluminosity sensor for headlightsActive park assistWater in fuel sensorAirbag sensorGereariesAccelerationCost per mile/kmFront object laser radarNight pedestrian warning IR sensorTire pressure sensorMicrophonePressureDrowsinessShockRain-SensingMotion sensor	Engine DDM	Engine coolant	Tra al dana	Malfunction	Exhaust gas	Mass Air
IntrudeGPS locationCollision sensorbrake actuatorsensorRear camerabrake actuatorsensorsensorRear camerabrake actuatorsensorMater in fuelAirbag sensorbrake actuatorsensorsensorAirbag sensorbrake actuatorsensorSensorAirbag sensorbrake actuatorsensorSensorAirbag sensorbrake actuatorsensorsensorSensorbrake actuato	tempera	temperature	Fuel type	indicator lamp	recirculation error	Flow Sensor
BPS speedGyroscopeluminosity sensor for headlightsActive park assistWater in fuel sensorAirbag sensorarometric ressureAccelerationCost per mile/kmFront object laser radarNight pedestrian warning IR sensorTire pressure sensorAccelerationPressureDrowsinessShockRain-SensingMotion sensor	Altituda	CDS location	Collision sensor	Automatic	Steering angle	Poor comore
Arbag sensorArbag sensorarometric ressureAccelerationCost per mile/kmFront object laser radarNight pedestrian warning IR sensorTire pressure sensorAccelerationPressureDrowsinessShockRain-SensingMotion sensor	Alumde GPS location	013 location		brake actuator	sensor	Kear camera
arometric ressureAccelerationCost per mile/kmFront object laser radarNight pedestrian warning IR sensorTire pressure sensorAccelerationCost per mile/kmFront object laser radarNight pedestrian warning IR sensorTire pressure sensor	CDS speed	Gurragaana	luminosity sensor	Active park	Water in fuel	Airbag sensor
Accelerationmile/kmlaser radarwarning IR sensorsensorficrophonePressureDrowsinessShockRain-SensingMotion sensor	GPS speed Gyroscope	Gyroscope	for headlights	assist	sensor	
ressuremile/kmlaser radarwarning IR sensorsensor/licrophonePressureDrowsinessShockRain-SensingMotion sensor	Barometric	Barometric	Cost per	Front object	Night pedestrian	Tire pressure
<sup>1</sup> Motion sensor	Pressure	Acceletation	mile/km	laser radar	warning IR sensor	sensor
ensor sensor sensor sensor Windshield Wipers	Microphone	Pressure	Drowsiness	Shock	Rain-Sensing	Motion cancer
	sensor	sensor sensor	sensor	sensor	Windshield Wipers	would sensor

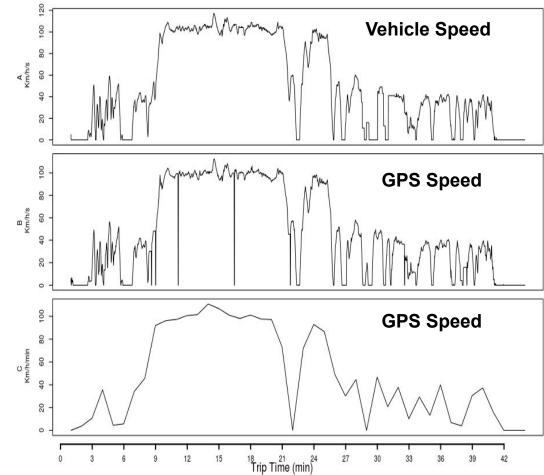
## Vehicular Data

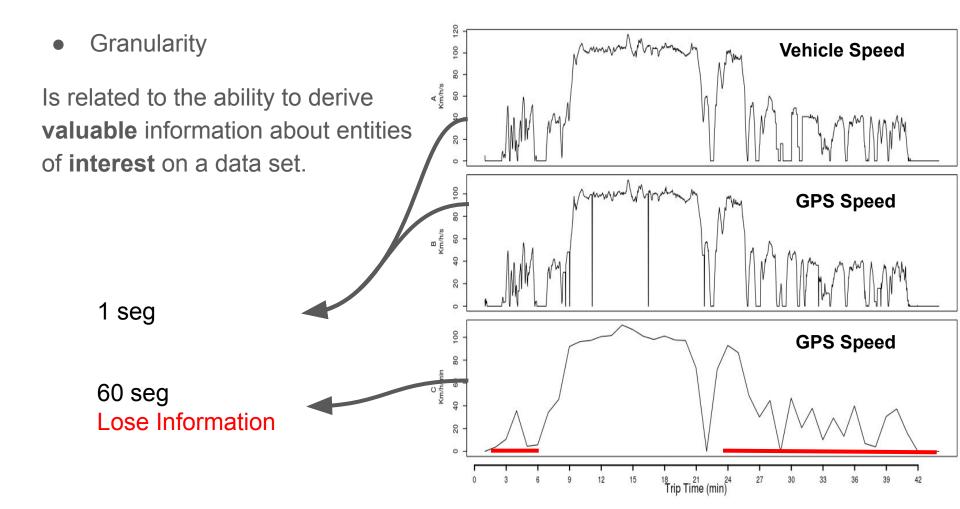
		S	ensors		
Engine load	venicie speed	Torque sensor	Fuel pressure	Oxygen sensors	Fuel Tank Level
Kilometers	Intake air	Ambient air	Catalyst	Relative	Accelerator
per litre	temperature	temperature	temperature	throttle position	pedal position
Fuel flow	CO2	Ethonal fual 0	Engine oil	Fuel injection	O2 sensor
rate CO2	Ethanol fuel %	temperature	timing	monitor	
Voltage	Distance	Fuel remaining	Fuel rail	Hybrid battery	Evap. system
vonage	traveled		pressure	pack remaining life	vapor pressure
Engine RPM Engine coolant	Engine coolant	Fuel type	Malfunction	Exhaust gas	Mass Air
Lingine Krivi	temperature		indicator lamp	recirculation error	Flow Sensor
Altitude	GPS location	Collision sensor	Automatic	Steering angle	Rear camera
Alutude OFS locado	OI 5 Iocation		brake actuator	sensor	
GPS speed Gyroscope	Gwroscope	luminosity sensor	Active park	Water in fuel	Airbag sensor
	Gyroscope	for headlights	assist	sensor	
Barometric	Barometric Acceleration	Cost per	Front object	Night pedestrian	Tire pressure
Pressure	Acceleration	mile/km	laser radar	warning IR sensor	sensor
Microphone	Pressure	Drowsiness	Shock	Rain-Sensing	Motion sensor
sensor	sensor	sensor	sensor	Windshield Wipers	INTOUDII SCHSOI

- **Problems** of **heterogeneous** data fusion
  - A practical and comprehensive data analyses in vehicular sensor data
- We used an **OBD** Bluetooth adapter to collect data from a car
- The logs of these vehicles consist of **55 trips** of **40 km** with an average time of **50 minutes each**

• Granularity

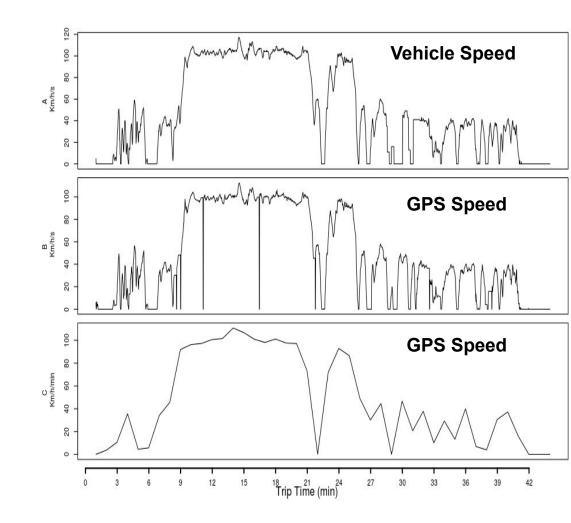
Is related to the ability to derive **valuable** information about entities of **interest** on a data set.

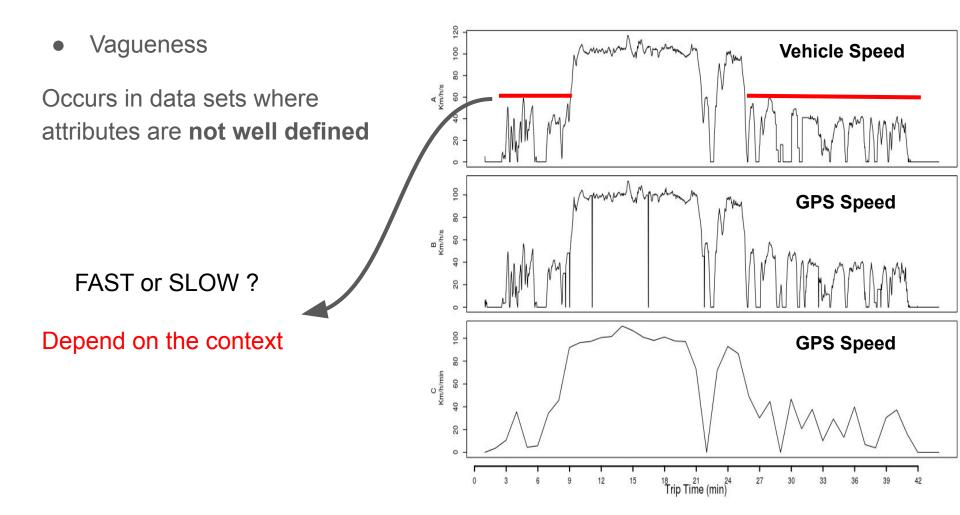




• Vagueness

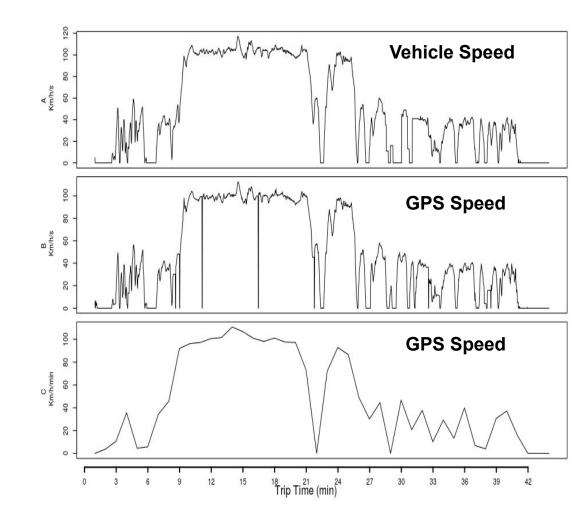
Occurs in data sets where attributes are **not well defined** 





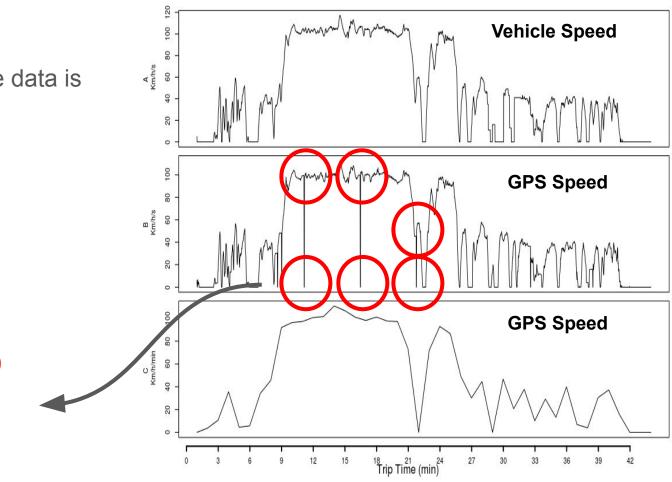
• Outlier

There are points whose data is **incorrect** 



• Outlier

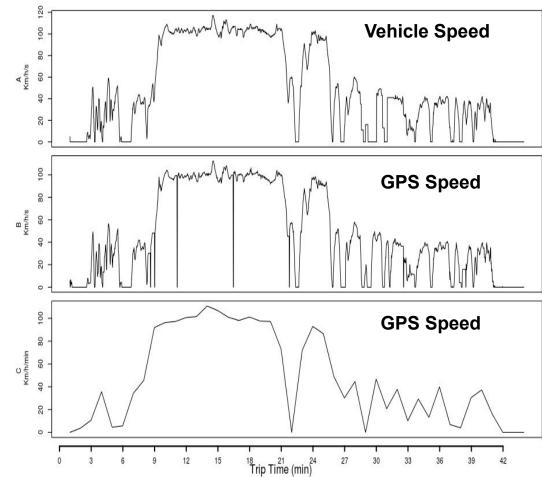
There are points whose data is **incorrect** 



Distorter points with 0 (zero) values

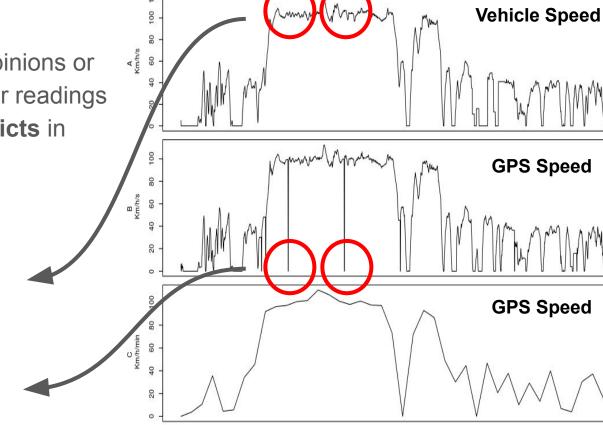
• Conflict

**Divergent** specialists' opinions or punctual **errors** in sensor readings happen and cause **conflicts** in data observations.



• Conflict

**Divergent** specialists' opinions or punctual **errors** in sensor readings happen and cause **conflicts** in data observations.



12

0

15

<sup>18</sup> Trip Time (min)<sup>24</sup>

27

30

33

36

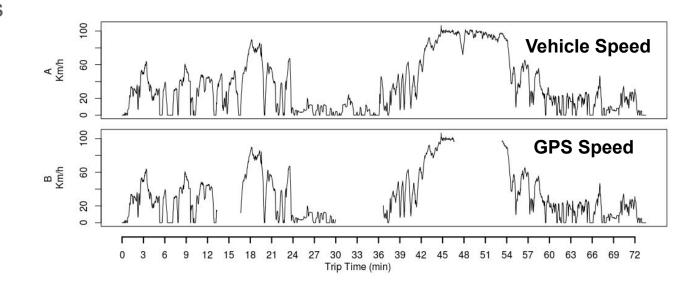
39

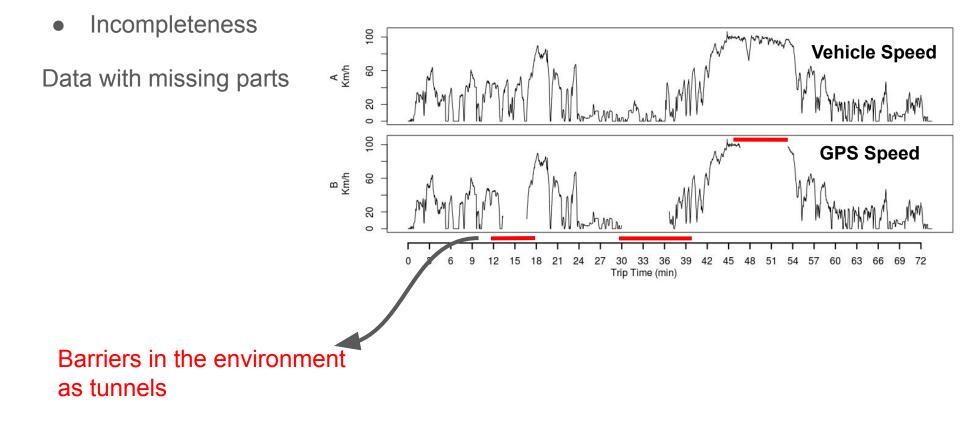
42

Points with 100 km/h

#### Points with 0 km/h

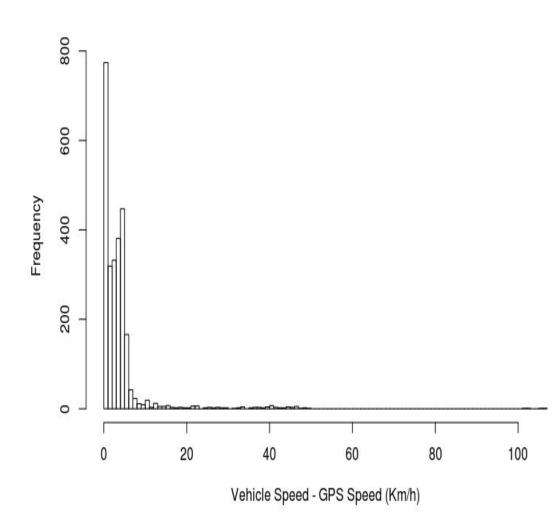
- Incompleteness
- Data with missing parts





• Ambiguity

When occurrences in the data set are assumed to express the same information, however they differ from each other.



Ambiguity

800 When occurrences in the data set Vehicle Speed **GPS Speed** are assumed to express the same 600 information, however they differ from each other. Frequency 400 200 Both sensors collected the same speed 0 vehicle speed shows the current speed 20 60 80 100 40 and GPS speed a different or conflicted value Vehicle Speed - GPS Speed (Km/h)

• Uncertainty

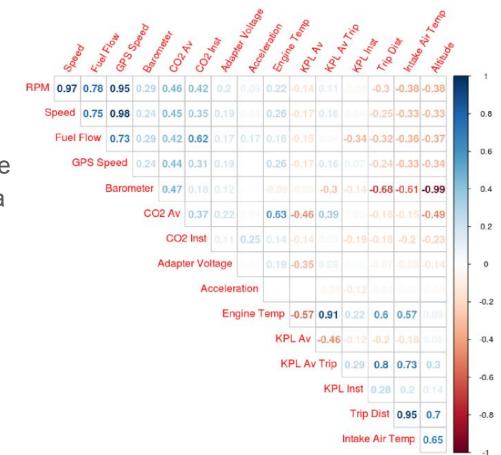
In the case of **sensors**, the uncertainty is **always present**, in other words, it is inherent a property of any sensor

• Disorder

This problems is **not common in our scenarios**, because the process to data collect is **synchronous** 

• Correlation

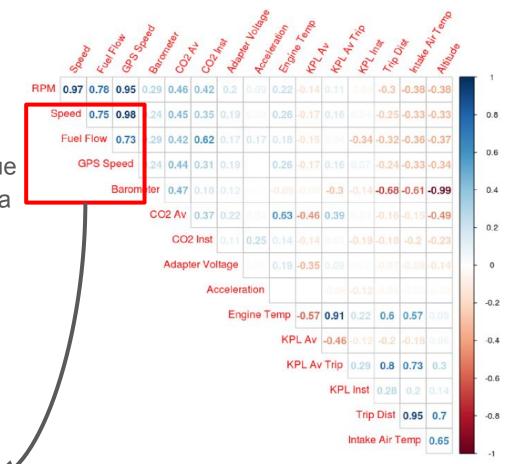
It is problematic since it can either enhance or attenuate some aspects due the data is fed multiple times in the data fusion system, multiplying its importance on the final result.



• Correlation

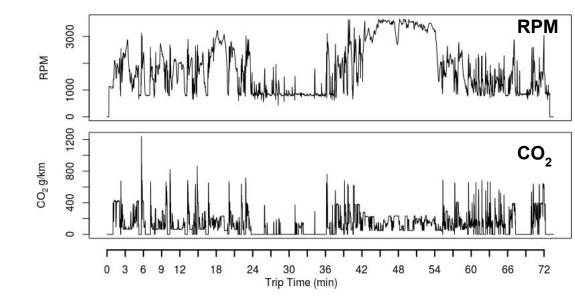
It is problematic since it can either enhance or attenuate some aspects due the data is fed multiple times in the data fusion system, multiplying its importance on the final result.

High correlations. So that, these data can be reduced to only one variable as Speed, for instance



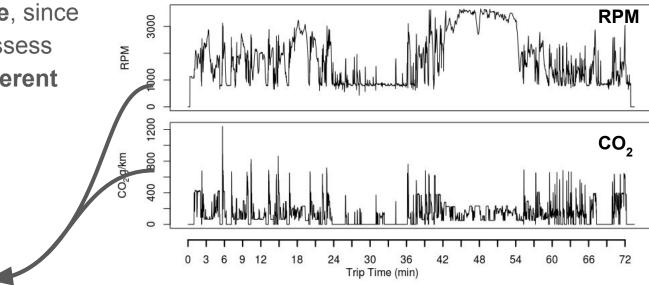
• Disparateness

It is **inherently disparate**, since there are sensors that assess **different aspects** in **different units** and **scales**.



• Disparateness

It is **inherently disparate**, since there are sensors that assess **different aspects** in **different units** and **scales**.



Dissimilarity between two sensors

#### Conclusion

- ITS can be boosted by take in account heterogeneous data collected from several sources as much as possible
- However, in general, the data comes with some issues making difficult heterogeneous data fusion process
- Therefore they must be treated before fusion process
- This work can guide beginner researchers to better understand the data, mainly in vehicular context, and some problems they possibly have to deal.

# Thanks