# STAGGERED WORK HOURS AT THE UNIVERSITY

## AN ECONOMIC APPRAISAL USING SMART-CARD DATA

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# CONTEXT

Congestion has various economic drawbacks

- increases the generalized cost of travel
- adverse effect on all kinds of activities preceding or following the trip
  - delays at destination, safety margin, productivity loss, …

Congestion relief is thus a key priority in numerous cities across the world

- building new infrastructures: very costly and long-term efficiency remains controversial (Downs, 1962; Vickrey, 1969; Duranton and Turner, 2011).
- congestion pricing: difficult to implement (costly + acceptability)
- increasing interest for alternative Travel Demand Management (TDM) measures

# STAGGERED WORK HOURS (SWH)

Principle: spreading travel demand by acting directly on users' preferences (through preferred arrival times)

- implies coordination between local firms/institutions
- otherwise virtually no implementation cost

Large body of literature on this topic…

- initiated by seminal paper of Henderson (1981)
- 3 effects to consider
  - congestion
  - production
  - scheduling / "desynchronization"

…but empirical studies remain scarce to this day

# OBJECTIVES & METHODOLOGY

Main research objective: carry out a first economic assessment of a SWH policy on a real case study

- provide a first insight into the potential benefits of SWH measures
- case study: implementation of staggered class hours at the University of Rennes

Restricting the scope

- only congestion effects are considered
  - consistency with primary objective of the measure → relieve subway congestion
- production effects: likely to be very limited (if not null)
- « desynchronization » effects: might be significant, but difficult to appraise (no data available for our area)

Methodology

- use of smart-card data + simulation to generate the counterfactual
- secondary objective: evaluate how “big data” can contribute to the evaluation of public policies in the transportation field

# OUTLINE OF THE PRESENTATION

1. Introduction
2. Case study
3. Economic appraisal of the Rennes SWH scheme
4. Conclusion

# CASE STUDY - THE RENNES SUBWAY

Rennes: one of the smallest cities in the world with a subway system

- Line a : length of 9.4 km (VAL system)
- Patronage:  135 000 users/day (2012)
- Commercial speed: 35km/h  /  Minimum headway: 100s
- Average travel time: 6 minutes

Hypercongestion spell during the Morning Peak Hour (MPH)

- High vehicle load
- In some cases one cannot board the first incoming vehicle
  - phenomenon especially salient at Gares station
- Saturation of the unique egress stair at Villejean Université station

One identified cause: influx of Rennes 2 students to attend classes at 8.15 am

# IMPLEMENTATION OF THE STAGGERED CLASS HOURS SCHEME

2009 / 2010: data analysis to describe the hyperpeak phenomenon affecting the subway between 7.40 am and 8.00 am

2011 : consultation organized by the « Time Bureau » of Rennes Métropole to define several scenarios

2012 : the Rennes 2 University approves a 1 year experiment :

- at **8.15 am** (licence 3 and master) : about **6 000 students**
- at **8.30 am** (licence 1 and 2): about **8 000 students**

New term of 2012 : start of the experiment

# METHODOLOGY – OVERVIEW (1)

Scope

- subway trips only
  - consistent with the primary objective of the measure
  - impact on road congestion: likely to be limited (if existing at all)
  - impact on bus congestion: possibly yes $\Rightarrow$ total benefits are likely slightly underestimated
- morning period only

Comparative analysis of the generalized cost of travel for subway users

1. current situation
2. counterfactual situation (if staggered class hours had not been enforced)

- + quantitative analysis of several quality of service dimensions (vehicle occupancy, waiting times, …)

# METHODOLOGY – OVERVIEW (2)

Computations based on the combination of smart-card data and simulation

- simple before-and-after comparison not feasible due to continuous increase in public transit demand
- similarly, an econometric analysis seems not in order
  - phenomena are limited in magnitude and very located in time
  - econometric models cannot account for the physics of the system (including network effects and vehicle capacity effects)
- current travel demand is estimated using smart-card data
- vehicle loads are computed using simulation
- counterfactual is determined using automatic detection of students & class hours and by simulating new departure times

# DETAILED METHODOLOGY

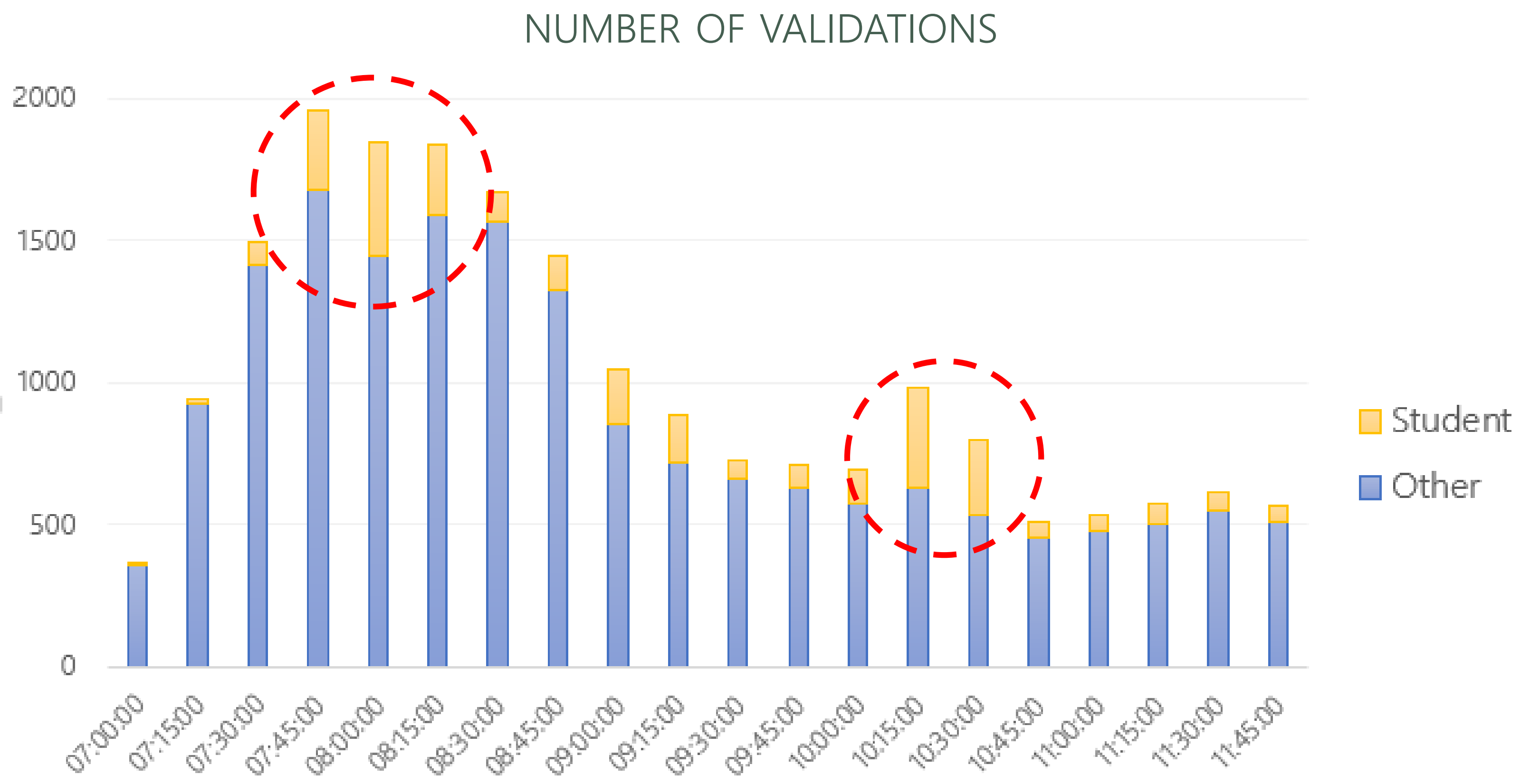
Estimation of the generalized cost (GC) in the current situation

1. analysis of subway trips
   - prediction of destinations
   - correcting for non-validations
2. computation of load profiles
   - matching between demand (trip table) and supply (schedule, vehicle capacity)
3. Computation of the GC

Estimation of the GC in the counterfactual situation

1. detection of Rennes 2 students
   - cross-analysis of passes and daily travel behaviors
2. simulation of the new departure times (assuming that staggered class hours have not been enforced)
3. reiteration of the 3 above steps

# CURRENT SITUATION:
# USE OF THE SUBWAY IN THE MORNING PERIOD




*Day of analysis:*
*Tuesday 2015/03/03*

# TRIP DESTINATION PREDICTION

1st pass: (simple) predictive algorithm

- destination = closest subway station to the next point of validation
  - station where the pass was validated is excluded
- if distance >= 500m → no assignment

2nd pass: random assignment based on "observed" trip destinations

- treatment of all remaining trips
  - includes transit passes and tickets
  - 25% of all trips, but only 4% for student trips (for reference day)
- random assignment based on conditional probabilities observed for trips treated in the 1st pass

# COMPUTATION OF LOAD PROFILES

Input data → **supply**

- Timetable
  - assumes fixed headway of 1 min 40 s (100s)
    - based on field observations for the MPH
    - = minimum possible headway (technically speaking)
- Vehicle capacity: 160 persons
  - based on nominal values: slightly conservative figure

Input data → **demand**

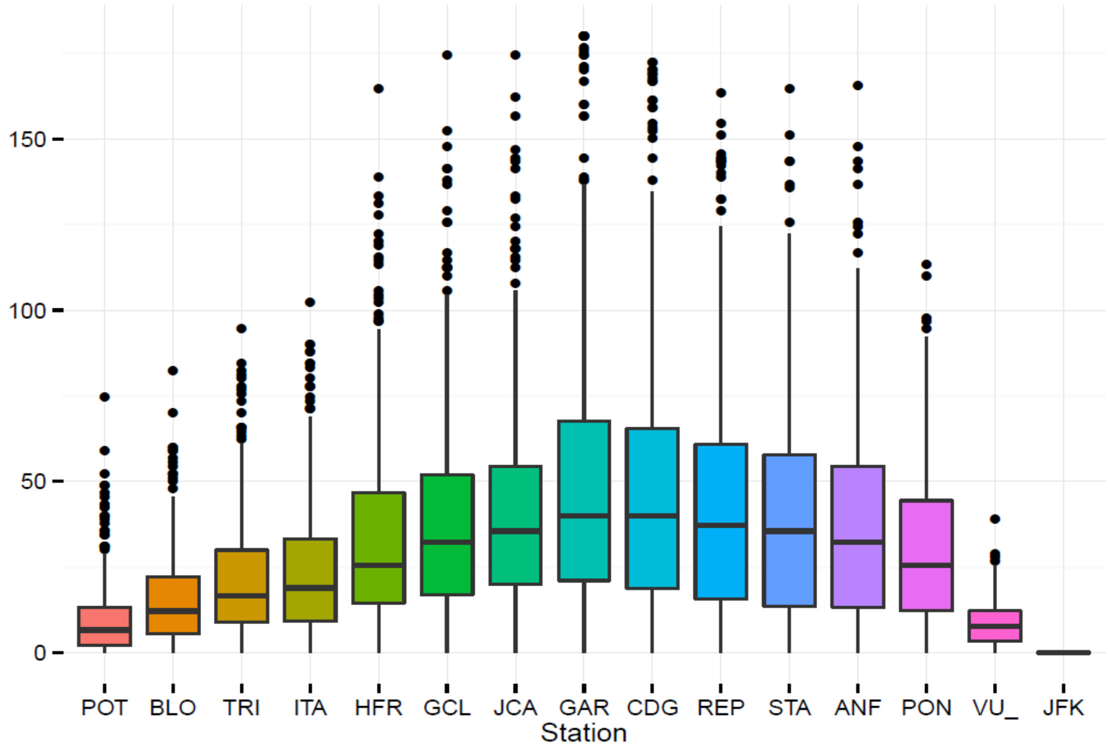
- Subway trip table
- Non-validation rate (including fraud): 10%
  - figure based on field surveys

Standard FIFO assignment procedure

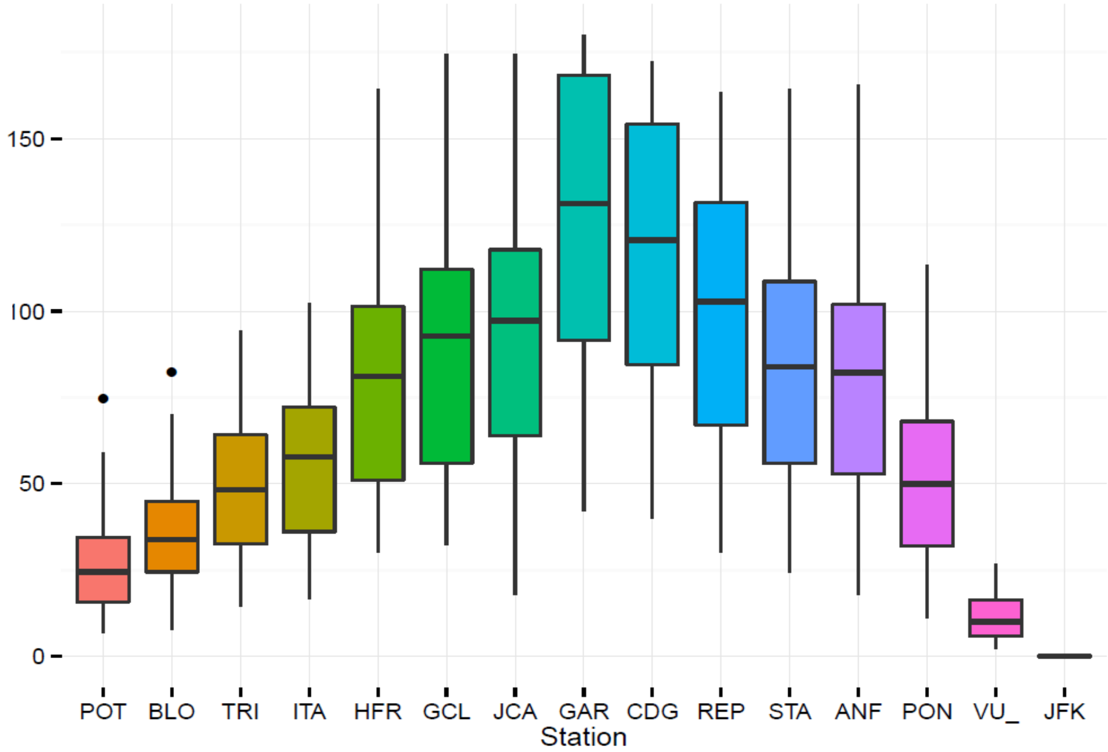
# SUBWAY LOAD LEVELS

DISTRIBUTION OF VEHICLE LOADS
DEPENDING ON THE SUBWAY STATION

*Day period*




*Morning peak period*



# COMPUTATION OF THE GENERALIZED COST

$$GC = \alpha_W T_{W,1} + \sum_{Links\ l} \alpha_V (1 + k\ N_l) T_{V,l} + \beta (t^* - t_A)^+ + \gamma (t_A - t^*)^+ + \alpha_W T_{W,2}$$

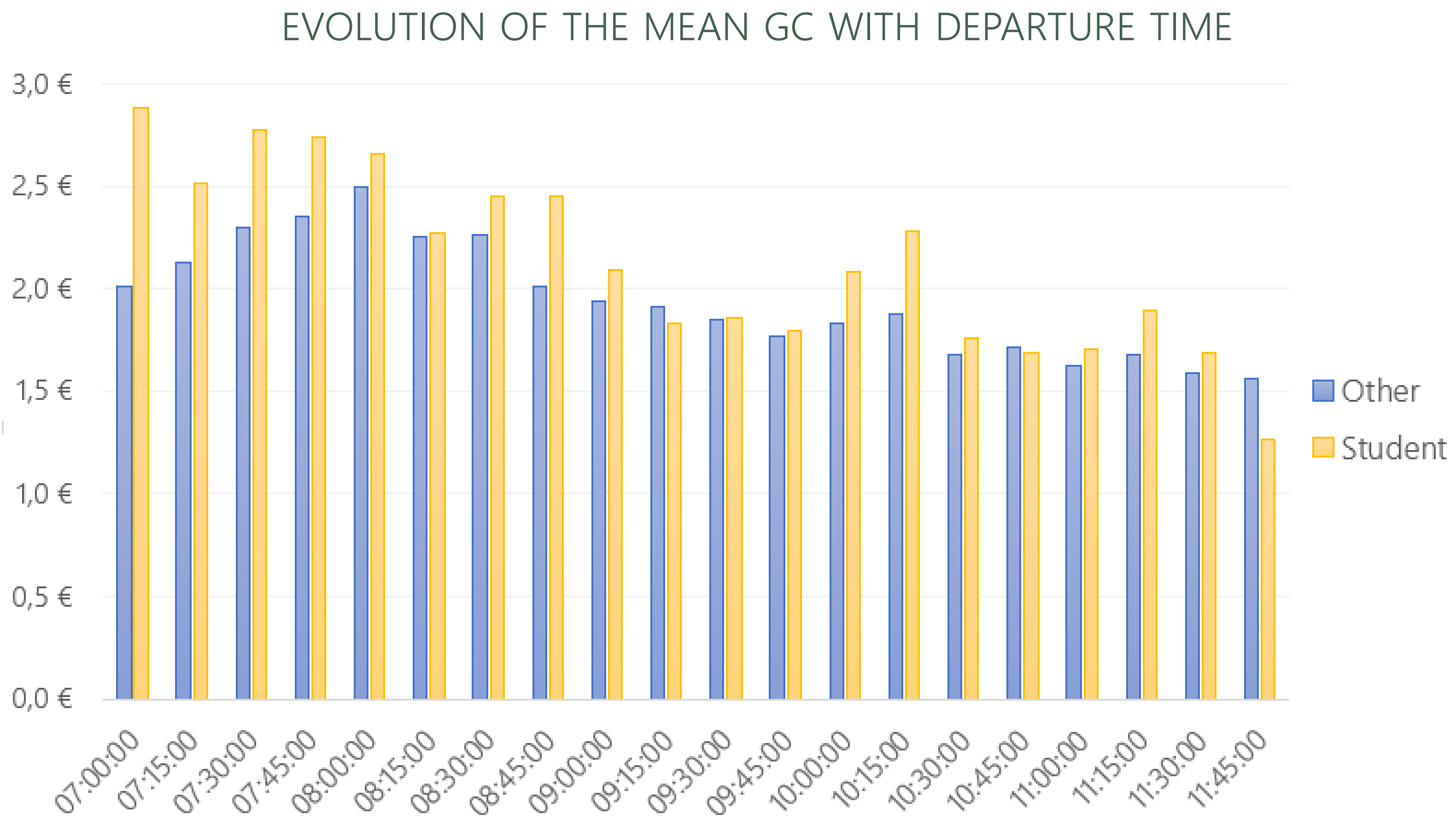
Parameters

- $\alpha_V$ : value of uncongested in-vehicle travel time = 10€/h
- k : penalty parameter for in-vehicle congestion = 0.003375
  - when vehicle is fully loaded: $VTTS_{full}$ = 1,54 * $VTTS_{empty}$
- $\alpha_W$ : value of waiting time = 1.5 * $\alpha_V$ = 15€/h
- $\beta$: unit cost of schedule delay early = 0€ (for now)
- $\gamma$ : unit cost of schedule delay late = 0€ (for now)
- $t^*$: preferred arrival time (for students 8h15 or 8h30)

Variables

- $T_{W,1}$: subway waiting time
- $T_{W,2}$: average exit time at VU station (due to stairway congestion) = ½ * (# of alightings at VU / stairway capacity)
- $T_{V,l}$ : in-vehicle travel time for link *l*
- $N_l$ : vehicle load for link *l*

# MEAN GENERALIZED COST



# SIMULATION OF THE COUNTERFACTUAL SITUATION

Same methodology as before, but with 2 additional steps:

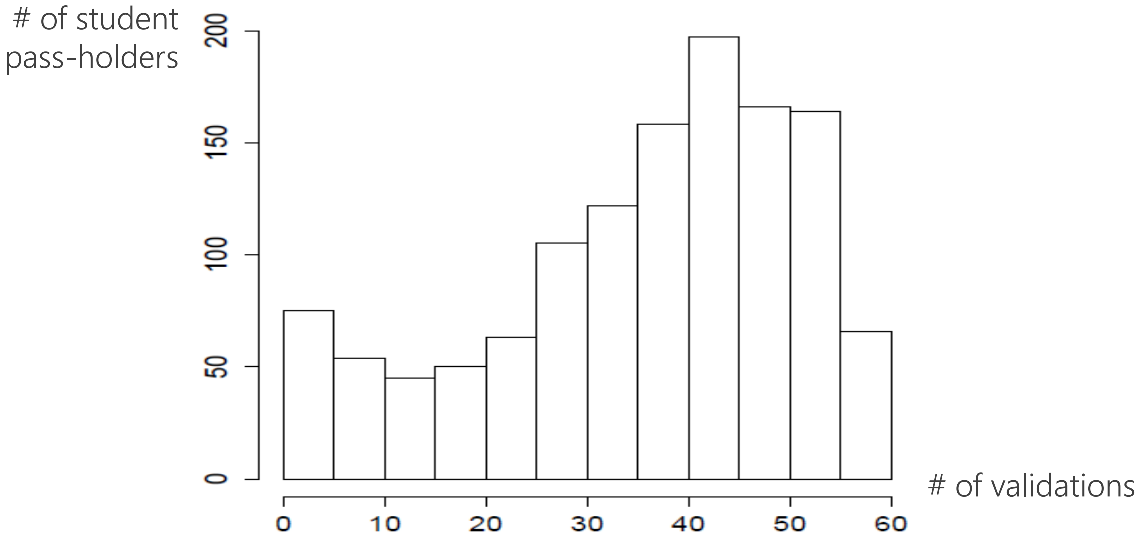
1. Destination prediction for subway validations
2. Detection of students with class at either 8.15am or 8.30am
3. Students with class at 8.30am are shifted back to 8.15am
4. Computation of new load profiles
5. Computation of stairway evacuation times
6. Computation of individual GCs

# DETECTION OF RENNES 2 STUDENTS

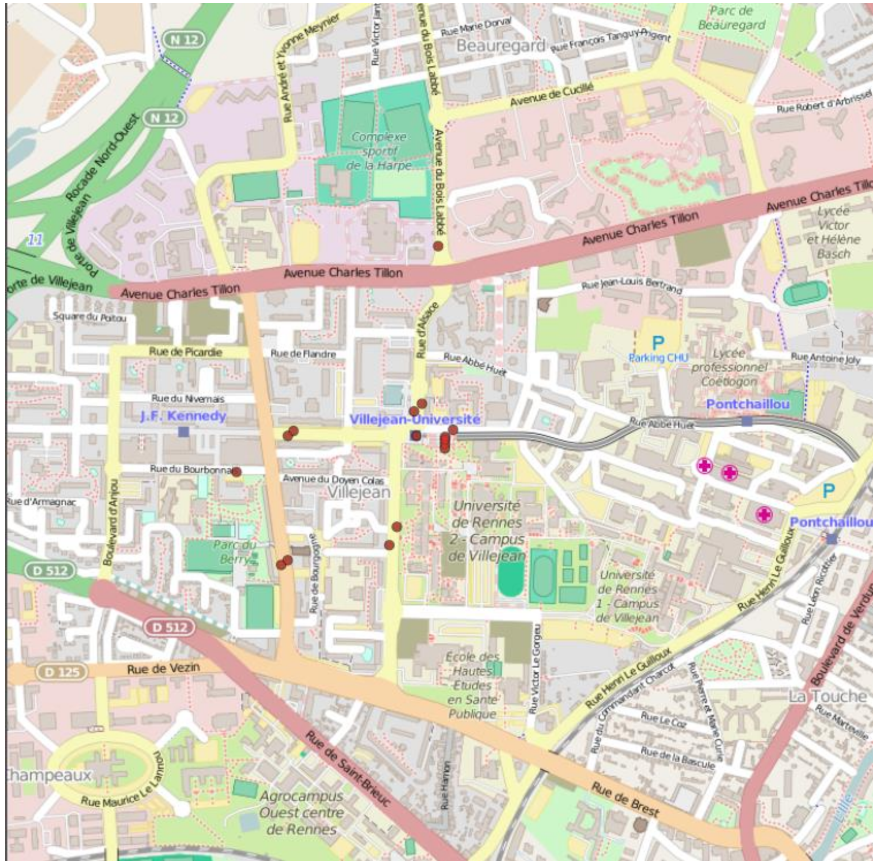
Twofold criterion

1. Holding a « student » pass
2. Regular use of one or several transit stops in the campus vicinity

USE OF TRANSIT STOPS IN THE CAMPUS VICINITY

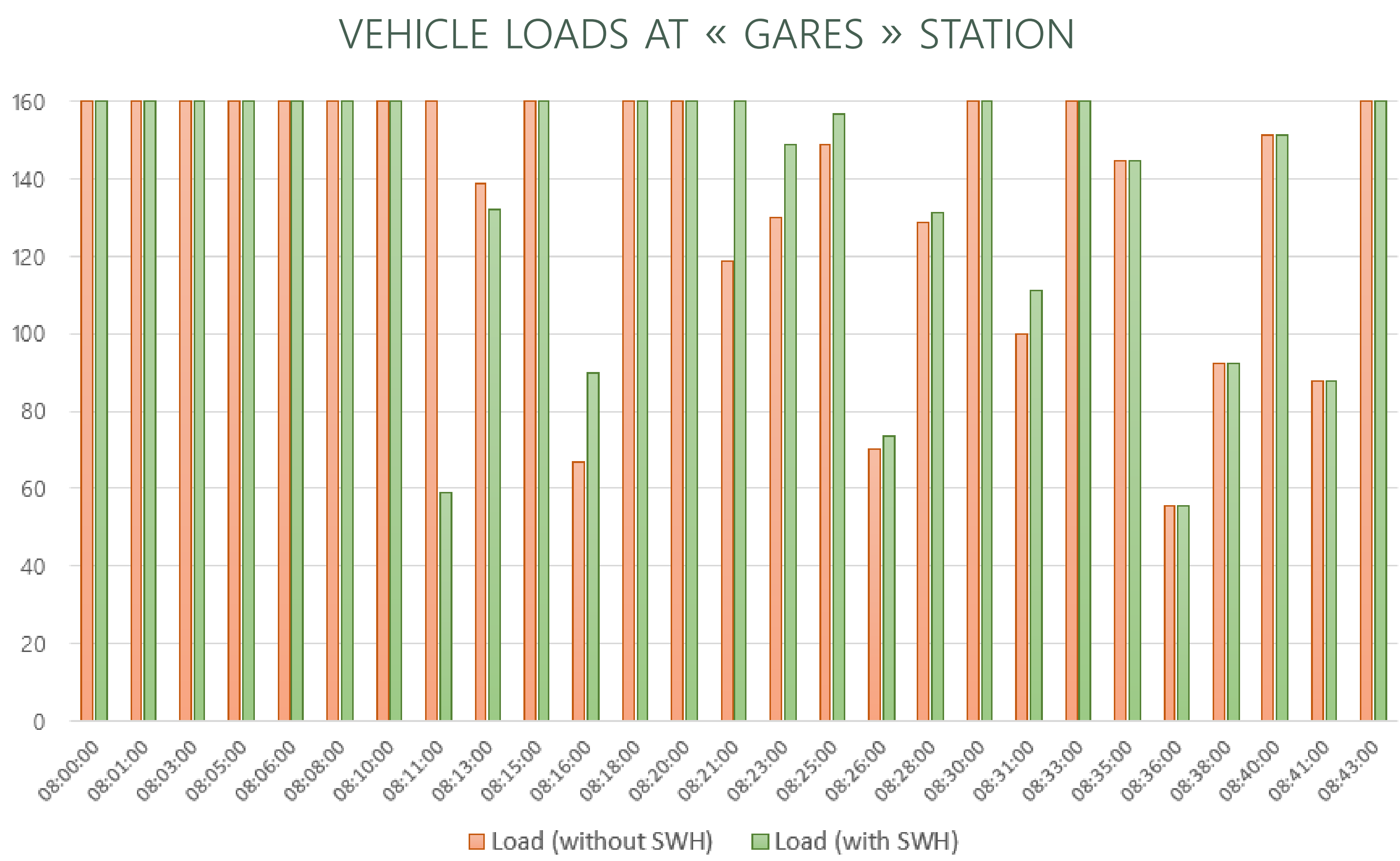



CONSIDERED TRANSIT STOPS



# CONGESTION RELIEF :

# NOT OBVIOUS FOR THE BUSIEST STATION…

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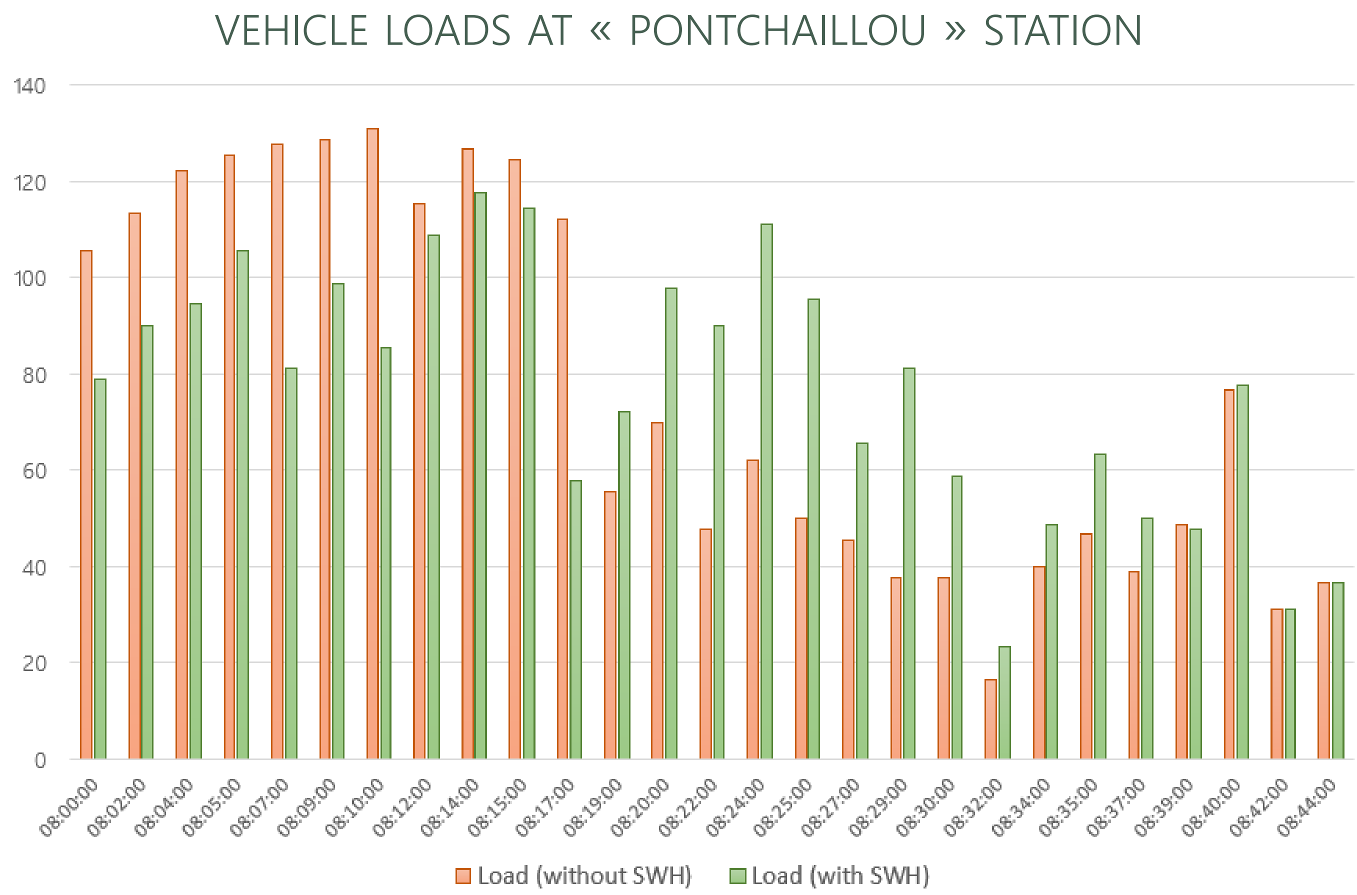
# … BUT MORE OBVIOUS NEAR THE UNIVERSITY

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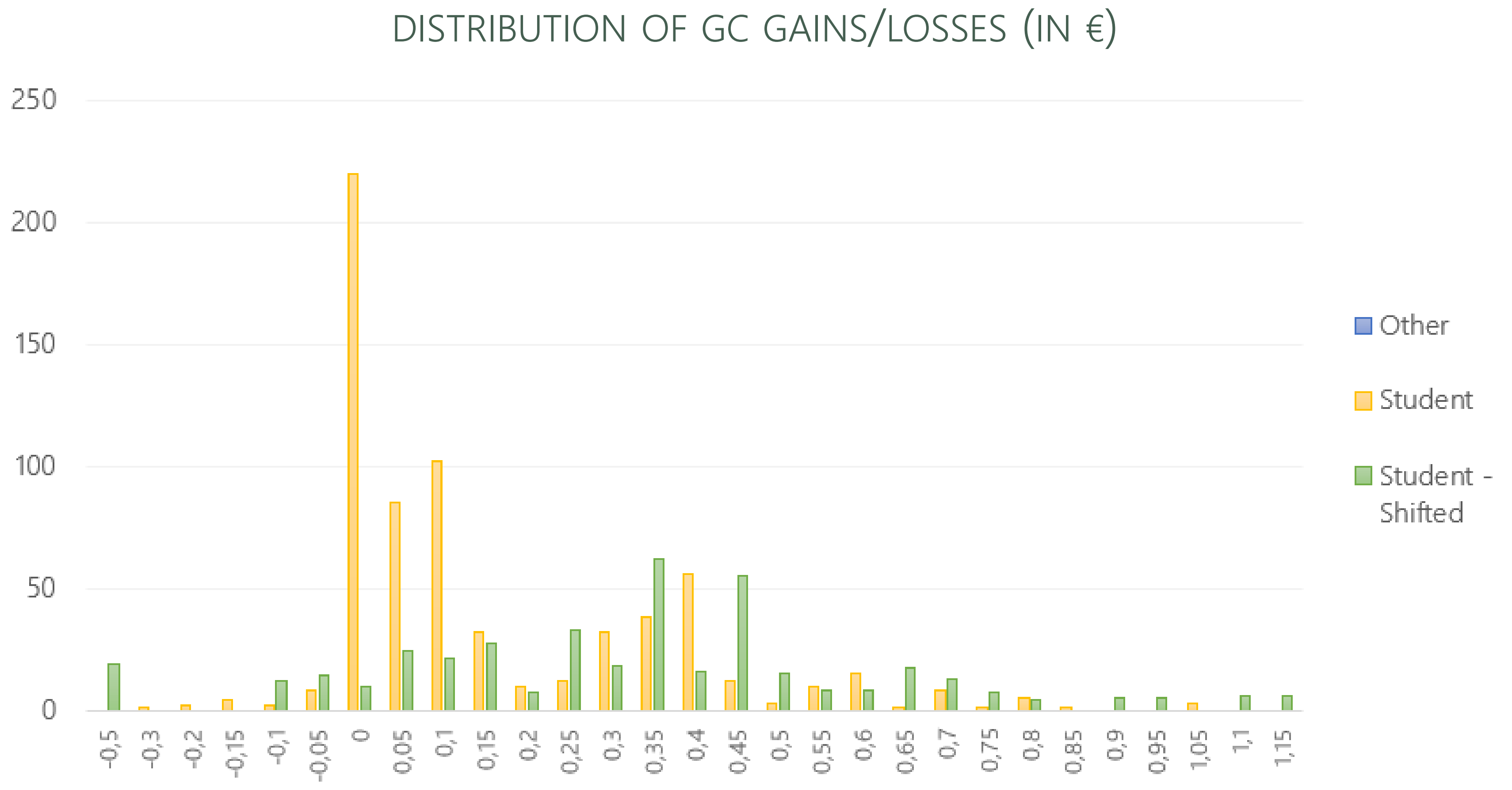
# MAIN WINNERS OF THE SWH POLICY: STUDENTS



# NON INTUITIVE EFFECTS

For day of analysis

- waiting costs and exit costs decrease…
- …but crowding costs increase overall
- Result of heavy congestion for this specific day?

| | *Total GC savings* | | *Waiting Time savings* | | *Crowding cost savings* | | *Exit time savings* | |
|---|---|---|---|---|---|---|---|---|
| Departure time | Other | Student | Other | Student | Other | Student | Other | Student |
| 07:00:00 | 0,00 € | 0,00 € | 0,00 € | 0,00 € | 0,00 € | 0,00 € | 0,00 € | 0,00 € |
| 07:15:00 | 0,10 € | 0,00 € | 0,00 € | 0,00 € | 0,06 € | 0,00 € | 0,04 € | 0,00 € |
| 07:30:00 | -0,75 € | 0,03 € | -0,42 € | 0,00 € | -0,35 € | 0,02 € | 0,01 € | 0,01 € |
| 07:45:00 | 94,63 € | 37,96 € | 52,50 € | 25,42 € | 38,59 € | 9,19 € | 3,54 € | 3,35 € |
| 08:00:00 | 139,45 € | 94,99 € | 198,75 € | 87,08 € | -60,67 € | 1,79 € | 1,36 € | 6,12 € |
| 08:15:00 | -93,19 € | 99,81 € | -21,67 € | 101,25 € | -66,65 € | -6,27 € | -4,87 € | 4,83 € |
| 08:30:00 | -6,67 € | 2,06 € | -1,67 € | 1,67 € | -4,66 € | 0,37 € | -0,34 € | 0,02 € |
| 08:45:00 | 1,24 € | 0,33 € | 0,00 € | 0,00 € | 1,16 € | 0,27 € | 0,08 € | 0,06 € |
| **Overall total** | **134,81 €** | **235,18 €** | **227,50 €** | **215,42 €** | **-92,52 €** | **5,37 €** | **-0,17 €** | **14,40 €** |

# VARIABILITY OF RESULTS

Overall economic benefits strongly vary from one day to the other

- analysis for 4 different weeks : 2014/11/[17 to 21], 2015/01/[12 to 16], 2015/03/[2 to 6], 2015/[03/30 to 04/03]
- Key statistics
  - Mean: 132.86€ / SD: 110.79€
  - Min: 1,96€ / Max: 369,99€

Transport effects also strongly vary

- overall crowding effect may be positive or negative
- overall waiting time effect may be very large or close to 0
- exit costs are always positive

There is also variability in which group gains the most

- main winner is always students, either the shifted group or the other depending on "external travel demand"
- other users: are always the least privileged, but may benefit from the measure for some specific days (to be confirmed)

# Conclusion

# CONCLUSION

Empirical analysis confirms and specifies the effects of SWH on congestion…

- allows to smooth vehicle loads for the hyperpeak period
  - decreases risk of not being able to board the 1st incoming vehicle
  - decreases congestion costs (via convexity of the aggregate cost function)
- network effects ⇒ policy effects get more conspicuous as nearing the treated area
- strong day-to-day variability → reflects the variability of travel demand

… but which remain quite limited in magnitude

- mean daily overall benefit is very modest: about 130€/day
- benefits primarily accrue to the treated population group

# CONCLUSION

Paradox: the measure has met great success among the population

- slight underestimation of the number of students ⇒ total benefits could be (slightly) underestimated
- are congestion costs correctly appraised?
  - French national guidelines imply a VTTS * 1,6 when the vehicle is fully loaded: value too weak over the long term?
  - affine formulation of the congestion cost ⇒ aggregate cost function is weakly convex ⇒ low valuation of congestion smoothing

From a methodological point of view: « big data » may be leveraged to carry out cost-benefit analyses

- time depth
  - detection of Rennes 2 students by analysing travel behaviors over long periods of time
  - computation of GC savings may be easily repeated for any given day
- coverage rate
  - computation of load profiles
  - computation of the cost of travel at the user level