École Polytechnique Fédérale de Lausanne
School of Architecture, Civil & Environmental Engineering

Traffic Engineering (CIVIL-349)
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Lab Assignment 2
Fall 2025

Introduction

In this lab, you will analyze the data collected on November 6, 2025, aboard buses 31 and 705. The assistants of the course compiled all the data that you collected in a single Excel file (named 'Lab2_Data.xslx'), in a format that should simplify the analysis.

In this file you will find the results from the Mobilis subscription survey, as well as 3 excel sheets per bus (31DirVenoge, 31DirRenens, 705), named: xx Time, xx Embark, xx Timetable.

- **Time**: Bus station name, arrival time, stop, extra time (at red traffic light or congestion)
- **Embark**: Bus station name, in, out (number of passengers);
- **Timetable**: planned arrival time by the transportation company.

Please, note that the direction and the terminal stop for each bus line are stated.

Part I

Task 1: Cycle time analysis

For each of the 11 buses that you got on-board and collected data, compute the following:

a. The total travel time excluding the time spent at bus stops;

b. The total time spent at bus stops. Compute separately the time spent at terminals, and the time spent at other stops.

c. The average commercial speed (i.e. the ratio $\frac{D}{w+tt}$, where D is the total distance covered, w is the time spent at bus stops and tt is the net travel time) of each bus and for each trip session (Terminus-Terminus and Depart-Terminus).[1]

d. Quantify and visualize the difference between the experienced trip times and the official timetable. Do you see any relationship with the recorded extra time?

e. Based only on the available observations, estimate the most accurate (i.e. with the lowest error) *proposed timetable* for each bus line (rounded to minute precision, e.g. $17:05:54$ will be $17:06$)

[1] To do this, you will need to find the information of the distance between the departing station and the terminus (use for example Google maps/walking option). Note that you should measure the effective bus path. (Ex: BUS 31, Pâqueret-Venoge Sud, 2.5 Km).

for the measured period between. Is this also the most convenient for the passengers? Explain why.

Provide detailed explanations for what you do at each step and comment on the results that you get.

Task 2: Boarding and alighting

a. Estimate how many passengers were on bus 31 at the Pâqueret stop when the students start the data collection. Do this for each bus of this line, separately in each direction.

b. Make 11 different graphs (grouped by bus line) showing the estimated number of passengers aboard the bus for each bus stop. Can you see a recurring pattern in the demand of passengers? Can you see some differences over the two-hour data collection period? Any significant peak period? Can you comment on your observations and explain these results?

c. Use a multiple linear regression model to estimate simultaneously the impact of the number of boarding and alighting passengers on dwell time. To do so, ignore the bus terminals, ignore the entries where a positive extra time was indicated, and ignore the entries with a dwell time equal to zero. Then copy-paste the data needed for the regression in another sheet and do the regression there, by allowing the constant to be different from zero. Comment on the results and compare the effect of boarding and alighting passengers. Can you think of other factors that are likely to influence the dwell time?

Task 3: Cycle time variability

In this task we want to estimate the variability of the cycle time. However, for each bus line, we only have data for 3 or 4 full bus courses (the ones that you took to collect the data). Therefore, we propose to estimate the variability using the following approximation:

Assumption:

The travel time to go from one bus stop to the next and the dwell time at the bus stop, both follow a distribution that is independent of the time of day and times of all other events (such as the time elapsed since the arrival of the previous bus, the time needed to travel from previous bus stops, etc.)

Based on the above assumption and in order to have more available data, you can produce some virtual realizations of the cycle time of a bus as follows:

Travel time per segment (sec)	Route 1	Route 2	Route 3
Bus Stop 1 - Bus Stop 2	78	70	82
Bus Stop 2 - Bus Stop 3	45	43	50
Bus Stop 3 - Bus Stop 4	112	120	115
Bus Stop 4 - Bus Stop 5	65	43	N.A.
Bus Stop 5 - Bus Stop 6	45	50	N.A.

Table 1: Table of measurements (example)

- Choose only one bus route among the 3 available (specify both the line and direction)
- Create a table of the recorded travel times having the format of Table 1 (the data in the table is just an example).
- Create new, virtual realizations by randomly selecting for each segment one 'observed time' among those listed in the previous table. The excel function `choose(randbetween(1,3),num1,num2,num3)` can be useful for this task.
- Sum all the times to obtain a new realization of the cycle time (excluding extra time).
- Repeat this process to obtain 200 realizations.
- Compute the average cycle time and its standard deviation. Choose an appropriate diagram to visualize the results of your simulation (e.g. histogram with cycle time on x-axis, rounded to minutes, and percentage % of realizations experiencing each value of cycle time on y-axis).
- What is the 95th percentile of this distribution? Compare it to the actual bus schedule and comment on the difference. Are there any other factors that might influence the choice of the cycle time?

Part II

Task 1: Bus Revenue

The objective of this task is to estimate cost / revenue values of the bus trip for the two bus lines considered. In order to estimate these values you need to first estimate the average passenger travel distance / time for each line and the company's average revenue from the sold tickets.

a. Calculate the average number of passengers (boarding & alighting) per cycle, $P^{[i]}$, for each bus line $i \in \{31^2, 705\}$, i.e. how many passengers, on average, take a bus of line i over the period of one cycle (Terminus to Terminus), for the studied period.

[2] For bus 31, please take the eight measurements from eight groups to obtain the average cycle time

b. Estimate the average trip duration per passenger, $T^{[i]}$, for each bus line i. In order to do this, you can first find the number of passengers $p_j^{[i]}$ who are on the bus of line i for each road segment j of the route (road between two consecutive bus stops), and then multiply it by the travel time $t_j^{[i]}$ corresponding to this segment. Then by dividing the total Passenger Hours Travelled (i.e. the sum of these products for all the segments j of the route of the line) by the total number of passengers of line i per cycle, $P^{[i]}$, you have the average trip duration per passenger. This is translated to the following formula:

$$T^{[i]} = \frac{\sum_j p_j^{[i]} t_j^{[i]}}{P^{[i]}} \tag{1}$$

Then you should find the average over all of the buses of the same line i, for which you have measurements.

c. Assume that the distribution of the Mobilis subscription types (e.g. half-fare card, AG, no subscription, Mobilis zones 11/12 etc.) of the passengers for both bus lines under consideration follows the distribution that was estimated from the questionnaire that you filled in your class. By using the answers to this questionnaire, which can be found in the excel file 'Lab2_Data.xslx', first calculate the percentage of passengers of each displayed category of mobility status, meaning passengers with: (i) no reduction, (ii) half-fare cards, (iii) Mobilis pass including zones 11/12 only and (iv) general subscription (AG). Which of these categories are not mutually exclusive and result in different fare for a full cycle trip if they are combined? List all the different possible combinations of the mobility subscriptions displayed in the excel file, that passengers may have, for trips with the two bus lines considered. Estimate the average number of passengers per cycle who belong to each one of the listed cases (or combinations of cases), for every bus line i.

d. Consider that for any trip (any Origin-Destination pair) in bus lines 31 (zones 11-12) and 705 (zones 12-33), the price of the ticket is 3.70 CHF at full price and 2.40 CHF with a half-fare card. Assume that the estimated average trip cost for owners of 'Mobilis' monthly pass (zones 11/12) and also for owners of AG (all zones) is 1.70 CHF/trip. The cost of adding zones to an existing Mobilis pass is 3.00 CHF/zone (full) and 2.40 CHF/zone (half). Calculate the cost of taking each of the two buses from terminus to terminus (one-way), for each possible combination of mobility subscriptions (as defined in question (c)). Based on the passenger measurements for each bus line and assuming that the distribution of mobility subscriptions among all passengers follows the distribution of your class, estimate the av-

erage revenue $G^{[i]}$ for each bus line i for one complete cycle during the period studied[3].

[3] The cost or revenue of every trip should be calculated by considering that all passengers will pay a ticket corresponding to the maximum number of zones of the line (e.g. from terminus to terminus)

e. By using the result of (b), use the average commercial speed of the bus line (calculated in Part I, task 1c.) to find the average distance travelled per passenger of each line.

f. Calculate the average trip cost per km travelled, $C_{km}^{[i]}$ in CHF/km that is charged to a passenger of every bus line i between 16h00-18h00. This represents how much the average trip costs, per distance unit. Then, calculate the average cost for a passenger per hour of in-vehicle time, $C_{h}^{[i]}$ in CHF/h. Do this calculation for both bus lines.

g. By considering the current scheduled frequencies of the lines (timetable) during the period of study (16h00-18h00) and the average revenue per cycle (from question (d)), what should be the maximum sum of the hourly operating costs per bus that would be acceptable for the company, in order to make a profit that should be at least equal to 10% of the average revenue for each bus line? Assuming that the operational costs per bus would be the same for any bus of any line, provide the acceptable cost that would satisfy the constraint of a minimum 10% profit for both bus lines.

h. Assuming that the operating cost per bus is equal to the value found in (g) and remains constant, while the number of passengers in both lines increases uniformly by 15%, answer the following questions:

- How much higher would the profit of the company be per line compared to what it was before the increase?
- Provide the absolute values of the hourly average profit per line.
- Assuming that all buses have a capacity of 80, do you think that an increase in the frequency of the buses would be necessary in terms of capacity of service?
- If the value of time of the passengers is estimated around 20 CHF/hour, what would the total (aggregated) additional waiting cost at the bus stops be, assuming that passengers arrive at the bus stops with a constant rate over time?
- If one extra bus were to be added to operate in the cycle of every line (this means adding *one* bus for line 31, not two), what fraction of the (increased) revenue would represent the profit for the company per line? How much would the average total waiting cost of the passengers decrease in this case?

For all questions, describe and explain the formulas you use and make comments on the results.

Task 2: Cost-Benefit Analysis

In the second task, we consider that the operational cost for the bus company, including driver's wage, fuel and maintenance, is estimated to be $C = 4.5$ CHF/km. Assume that this cost is estimated by considering the characteristics of the bus service as measured in the field experiment (commercial speed etc.).

a. Find, for each bus line, the average profit per cycle for the company for the studied period of a typical weekday (as the measurements day). Express this profit in CHF/hour.[4]

[4] The profit is found as the result of subtracting the operational cost from the corresponding revenues.

b. Specify the minimum number of passengers $P_{\min}^{[i]}$ for each line i that guarantees no monetary loss for the bus company. Assume the same distribution of ticket types as in Task 1. Comment on the result. Which bus line has the lowest profit for the bus company? Which one has the highest? In your opinion, where may these differences come from?

c. *Theoretical question*: Imagine you were in charge of the management of the mobility of this zone around EPFL. Which strategies or ideas would you propose in order to optimize the profit of the transportation service provider while maintaining an adequate offer to the passengers of lines 705 and 31? Explain briefly your ideas.

Administration

To answer the questions, you may use any software, such as Excel, Python, or Matlab. The format of the dataset is in Excel.

You should work together with your group and produce a well-structured, high-quality report, where you answer all questions of this assignment, describe the methods and formulas used, explain your thoughts, comment on your results and justify your conclusions and suggestions, as you would do in a professional technical report. Provide good quality tables and figures, by adding titles and captions, notations and units for the axes, easy to the eye font size and good analysis.

The presentation of your methods and your results should reflect your understanding of the study and should support your conclusions. Always provide comments for all your results and derive reasonable conclusions.

The report should include a cover page with the title of the assignment, the group name (e.g. Group A, B, etc.), the names of the students and the date of submission. The report should consist of the following structural elements:

- Table of Contents
- Introduction (topic, objectives)

- One chapter per task with answers and comments to all questions
- Conclusions (General remarks, knowledge acquired)
- References (Cite every source utilized, e.g. books, scientific articles, web pages etc.)

The report should be saved under the name:

civil349_groupX_lab2_report.pdf,

where X is the letter representing your group. All the Excel files or code that you used for your calculations should be submitted as well, as one compressed (.zip) file under the name civil349_groupX_lab2.zip. All calculations and figures that you include in the lab report should be present in your files.

This lab assignment counts as 50% of the total lab grade. The Lab (Lab Assignments 1 and 2) in total counts as as 30% of the total grade for the course CIVIL-349. As Lab 2 assignment is composed of two parts, i.e. (i) Data collection and (ii) data analysis and report, the overall grade for Lab 2 will be composed of the following:

- Data collection: 20%
- Report: 80% (Part I: 40% and Part II: 40%)

The due date and time for the Report of Lab 2 is announced on Moodle. Please make sure that you submit your assignment before the deadline. The files should only be submitted once for the entire group.