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Is commuting a daily behavior? Rhythmic evidence as of France, 2019

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Abstract

Home to Work (H2W) commuting travel, together with urbanization and transport networks, have experienced much development since the end of the 19th century in both workers' lives and transport networks' traffic. The attraction of metropolises and the ease of transport have even triggered long distance commuting, sometimes in conjunction with overnighting practices that stretch the commuting tours (or cycles) beyond the day level. Based on the French nationwide household travel survey of 2019, this article gives a comprehensive description of commuting practices across origin-destination distance and along time as lived by individual workers at the month level. Commuting rhythms are characterized in terms of commuting cycle length in days and monthly frequency. Four typical patterns are exhibited, namely bi-daily, full daily, mono-daily and overnighting. Their respective shares are measured in the statistical populations (i) of workers, (ii) of days of life or just at work, (iii) of distances travelled on modal networks. Elementary discrete-choice models of H2W rhythm choice are designed and estimated: the results show the influence of travel impedance in time and distance at the level of one-way trips for short range H2W and at the level of monthly budgets for long range H2W. Lastly, the shares of commuting trips in modal traffic on road and rail networks are measured, evidencing a significant contribution of long distance commuting to the GHG emissions of transport.

Keywords

Long distance commuting; Commuting tours; Monthly frequency; Travel impedance; Individual behaviors;

Highlights

- Commuting rhythms characterized by cycle length in days and monthly frequency
- Four patterns of rhythms: bi- or full-daily (short range), vs. mono- or multi-day (long range)
- Long distance patterns hold minor shares of workers but large shares of travelled distances
- Travel impedance at trip level influences the rhythms of short range commuting
- Travel impedance at the month level influences the rhythms of long-range commuting

1/ Introduction

Home-to-work origin-destination pairs, flows and distances became a topic of statistical analysis at the end of the 19th century, when an item about job location was included in population censuses (Commenges & Fen-Chong, 2017). Bunle (1934) emphasized the co-

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development of urbanization, of urban transport networks and of inter-communal commuting in the Grand Paris: as of 1931, 56% of its inhabitants were workers, among whom 17% out of their home district (Bunle, 1932). Further on, starting in the USA and spreading to other developed countries, the progressive diffusion of private cars and motorway networks has boosted the growth of cities, increasing both the average commuting distances and the network traffic flows and congestion. Commuting traffic, causing morning and evening traffic peaks on weekdays, has been used as the primary indicator of mobility needs in planning urban transportation networks (Chatzis, 2023). Accordingly, commuting as a travel purpose has been a key topic of household travel surveys since their first US instances in the 1940s and 1950s (Black, 1990). In France, where the car mode began its mass diffusion from the 1960s onwards, inter-communal commuting surpassed its intra-communal counterpart around 1980: among inter-communal commuting trips the average distance was of 5 km in 1982 (Terrier, 1986). Since then, the average commuting distance among all workers in France has risen up to 14 km in 2019 (INSEE, 2023).

Urban economic theory has enjoyed a renewal since the 1960s by focusing on household commuting distances and costs, together with job location and housing prices, to explain household location decisions and the spatial development of cities (Kain, 1962, Alonso, 1964, Fujita, 1989 etc). It also addresses the employment areas accessible to the workers (Lonsdale, 1966), and their combination to household locations yielding specific functional urban areas (Goldstein & Mayer, 1964; Fox & Krishna Kumar, 1965). Continuous improvements to transportation networks have allowed individuals to travel longer distances on comparable time budgets (Zahavi & Ryan, 1978). This raised the issues of wasteful or excess commuting (Hamilton & Röell, 1982; Small & Song, 1992): 'excessive' commuting being measured as the difference between an observed average commuting distance and a theoretical minimum specified as "all workers in a city choosing to live in existing housing closest to their workplace" (Kananoglou et al., 2015, p.14).

Long distance commuting has thus become a topic of specific interest, not only for its traffic consequences (Broto, 2022) but also for the potential negative effects on well-being, health and, besides benefits, on professional careers and social and family lives (Abendroth et al., 2022). Montazer et al. (2020) studied psychological issues of mental health and psychological distress associated with long-distance commuting in the USA.

The European research project "JobMob" on job mobility and family lives specifically addressed long distance commuting in six European countries by means of panel surveys first in 2006 and second in 2009-2010: "long distance commuters" being defined as those making a return trip of more than 2 hours every working day, and "overnighters" as those spending at least 60 nights a year away from home on professional purposes (Collet & Bonnet, 2010). As of 2007, the shares of daily long distance commuters were found of 5% both in France and Germany, along with 5% of overnighters in France and 7% in Germany. Country-specific JobMob results can be found in Bergstrom (2010) for Sweden and Wachter & Holz-Rau (2022) for Germany; international comparisons between two or more European countries are available in Hofmeister et al. (2010) and Romero-Balsas (2022).

Typical profiles of long-distance commuters have been found consistently in different studies including JobMob (Baldazzi & Romano, 2006; Collet & Bonnet, 2010; Jeong et al., 2013; Ravalet et al., 2017; Wachter & Holz-Rau, 2022): strong shares of male workers, middle-

aged, highly-educated, with managerial positions and higher income-levels. Economic issues of long-distance commuting have been studied in the form of the impacts, in Germany, on individual careers (Viry et al. 2014) and job performance (Abendroth et al., 2022).

In this article, we look into the physical features of the whole commuting mobility in France at both the micro level of individual workers and the macro level of modal traffic and the related carbon emissions. We consider temporal features of commuting rhythms (cycle frequency and length in days) along with spatial features of distance and transportation mode. The following research questions are addressed: (RQ1) Which commuting rhythms, in terms of cycle length and monthly frequency, do exist among the French population of working individuals? (RQ2) What are the typical patterns of commuting rhythms, with which respective shares? (RQ3) How do the commuting rhythms depend on individual features? (RQ4) How do they relate to travel impedance in terms of not only H2W distance but also H2W travel time and the related monthly budgets?

We shall devise specific definitions for commuting rhythms relative to days in terms of both the length in days of each commuting cycle and the monthly frequency of such cycles. Using these definitions, we shall look for specific patterns of commuting rhythms in France and relate them first to demographic and socioeconomic features of the individual workers and then to travel impedance in distance and time at the trip level. We will consider travel impedance also at the day and month levels to study its effects on commuting rhythms by devising and estimating discrete choice models.

We address the specific case of commuting mobility in France as of 2018-2019 on the basis of the nation-wide household travel survey (HTS) called "EMP 2018-2019". The emphasis on commuting rhythms goes beyond the definitions in the JobMob panels and the derived studies of long distance commuting in France that were mainly targeted to social issues: work-life balance and conjugal quality (Viry et al., 2010), parenthood issues (Ruger & Viry, 2017; Romero-Balsas, 2022), gender inequalities in the determination of professional careers (Collet & Bonnet, 2010), economic issues and the potential impact of the 2008 financial crisis on daily long-distance commuting and overnighting (Ravalet et al., 2017). The emphasis on rhythms is also distinctive from previous studies of long distance commuting in France that assumed a daily basis on addressing modal usage (Orfeuill & Soleyret, 2002), residential location patterns (Zaninetti, 1999; Ravalet et al., 2014), urban forms (Aguilera & Mignot, 2004; Aguilera & Voisin, 2014) or urban systems (Conti, 2017, 2019).

The article is organized in 7 sections as follows. Section 2 provides the methodology. Section 3 characterizes the commuting rhythms in the French HTS survey sample and points to four typical patterns. These are related in Section 4 to the demographic and socioeconomic features of the individual workers: gender, age group and profession type. Section 5 deals with travel impedance in relation to commuting rhythms. Section 6 derives macroscopic consequences about the average commuting distance either per worker or per working day, and on the commuting-related traffic footprint and its GHG consequences. Section 7 brings a discussion and Section 8 concludes.

2/ Methodology

2.1/ Definitions, issues and notation

2.1.1 Days, places and commuting cycles

Human life is organized in days and the succession of them. One day is the basic unit of time for human life, both for biorhythms (sleep, meals...) and for social life (work, study, leisure activities...). The home, as the place and shelter of private life, accommodates the individual every day or so, at night and during large parts of daytime.

Focusing on people exerting professional activity, the practice of work typically extends over days in a recurrent way: a “workday” designates the time stretch of working along the day, often of about 8 hours, commonly split in two parts respectively before and after lunchtime for daytime workers.

The practice of going from home to work, and then back to home, possibly including side activities (having lunch, shopping, accompanying children) is called home-to-work commuting. For most workers it is a daily routine, meaning two things: first, that it occurs within the day, second, that it is reiterated over many days – more than half of the days in the year for regular workers. Of course, proximity between the places of home and work enables for within-day commuting, easing the overall mobility and logistics of the individual and his or her household.

A “commuting cycle” designates the individual sequence of activities, starting from home to work travel and up to back home (figure 1). An individual that returns to home within the workday, typically to have lunch there, will make two commuting cycles during the day: such “bi-daily commuting” is distinct from full-day commuting that involves one commuting cycle per worked day only.

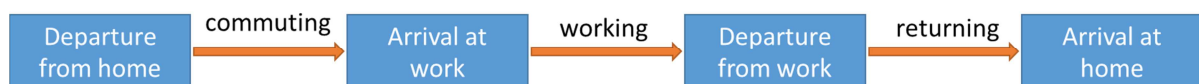


Fig. 1: Structure of a commuting cycle.

2.1.2 Multi-day issues, Commuting frequency and rhythms

“Overnighters” are workers residing far from their usual workplace who organize their working activity on a multi-day level. Their commuting cycle extends on several days of life, each with its own sequence of activities, among which sleeping in a place other than the main residence – whence the “overnighting”. At the day level some “local commuting” is likely to occur between that place of rest and the work place. As our study is focused on commuting between the main residence place and the usual work place, only the multi-day commuting cycle is considered for such individuals.

The time length of a commuting cycle is measured in day units, ranging from one half, one, two etc. It is denoted as λ . While the frequency of within-day commuting is meaningful at the day level, multi-day cycles call for larger timescales: the number of commuting cycles along an average month of say 30 calendar days is considered here as the “monthly frequency”, denoted as φ .

Then, the “commuting rhythm” is the twofold phenomenon involving both the length and the frequency of commuting cycles along time: it is characterized by the (λ, φ) pair (figure 2).

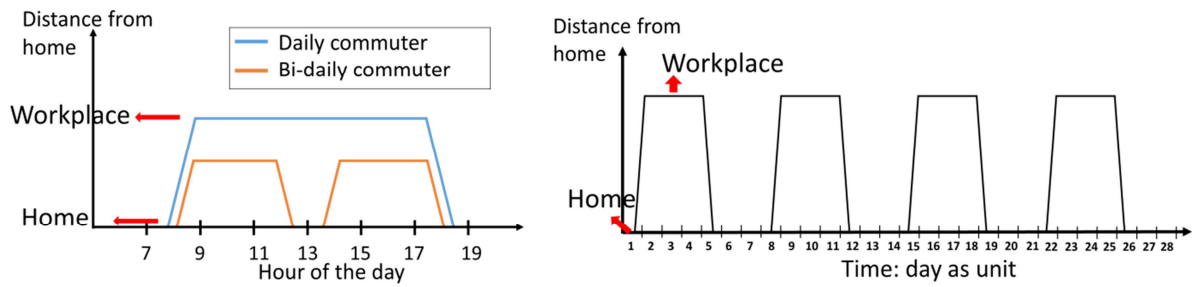


Fig. 2: Representation of commuting rhythms: (A) Plain daily & bi-daily, (B) Supra-daily.

2.1.3 Day type issues

Employment contracts typically specify the total number of hours to work during the week, their daily timespan, the number of days worked by week and their days-in-the-week. Mondays to Fridays are the typical “working days” for the majority of workers, possibly also Saturdays and Sundays for all-time duties (e.g. hospitals) or retailing.

Per week the typical frequency of working days is 5. For all commuters we are interested in such frequency of working and the related days in the week. For multi-day commuters we are also interested in the number of days worked and in the respective functions of the days composing the cycle: travel and work, or just work, or just travel: and also in the direction of travel, from home to work or the converse.

2.1.4 Worked days and other days of life

For all workers, on a par with commuting frequency at the month level, we consider the number of days worked in the month and at the usual workplace, denoted μ . In the case of multi-day commuting we expect μ to be close to the product of cycle frequency and cycle length, that is, $\mu \approx \lambda \cdot \varphi$. Thus the two rhythmic components are linked by an upper bound on their product at the month level.

Commuting cycles are related to the individual presence in the places of either home or work. A day of within-day commuting involves the person being alternately in both places during the day, most people at home around the night and at work during day time – or the converse for night-workers. Such a day is a worked day, as opposed to non-worked days. The two kinds of days together make the days lived by the individual: they determine the presence in the places and the mobility pattern at the day level, including commuting or not.

2.1.5 Planning issues and the relativity of home-to-work distance

The attribution of people presence and commuting trips to places and days has implications for the planning of urban areas (as life basins and work basins) and of transport infrastructure and services. Long-distance commuting made on a within-day basis on every weekday from Monday to Friday would imply not only much travel time to the individual but also large travelled distance on transport networks, road or rail. The number of long-distance commuters is already of interest to some network operators, such as the French railway company SNCF. Multi-day commuting will at least halve the commuting-related traffic footprint per worked day since each day accommodates either home-to-work travel in one direction only or no

travel (except for “local” commute).

It follows that the “absolute” home-to-work distance, denoted as ℓ_i for individual i and measured either as crow-fly distance or as a length of traveling along a transport network, cannot be used straightforwardly as an indicator of individual traffic footprint on a daily basis over weekdays. By month, the travelled distance travelled for commuting by the individual amounts to $2\ell_i\varphi_i$. Its attribution to weekdays, in number of 22 per standard month, yields an average daily travelled distance of $\ell'_i = \ell_i\varphi_i/11$. It may be seen as a “pseudo-distance” per business day travelled on home-to-work purpose. The monthly frequency φ_i is thus as much important as the base H2W distance ℓ_i in this construct. Bi-daily commuting reiterated every weekday yields $\varphi_i = 44$ per month. In multi-day commuting at say 3 or 4 cycles per month, the traffic loading effect of a longer ℓ_i may be compensated for by lower φ_i .

2.2/ Empirical material

In France, the places of home and usual work are monitored for each active resident in the General Census of the Population – a comprehensive one fully updated every fifth year. The French National Institute for Statistics and Economic Studies (INSEE) makes available the “MobPro” database of the numbers of people according to the communes of home and work, making origin-destination pairs between zones of heterogeneous population with mean of 1,900 inhabitants per commune. OD numbers are also disaggregated by profession type and travel mode of commuting. Yet, the indications of commuting frequency and cycle length are only available in the National Household Travel Survey (HTS).

2.2.1 The 2019 French National HTS

The most recent French National HTS dates back from 2018-2019 – just before the COVID-19 pandemics. 13,825 households were sampled from the Population Census according to household size, age group and professional status of a reference person, as well as residential location. The survey contains the usual indications about household composition, home type and location, demographic and socio-economic features of the reference person, completed by attributes about mobility tools (ownership of cars and two-wheels, driving licenses, transit subscriptions). One person per household, selected according to the Kish method, described his or her mobility in two respects: first, the one-day mobility of a day randomly selected in the week before the interview in order to feature out “daily mobility”, second, the monitoring of long-range trips, i.e. those beyond 80 km, over the three month period up to the interview. The answers to both kinds of questionnaires were collected in two specific datasets.

2.2.2 The “Daily mobility” dataset and short-range commuting

By construct, the Daily mobility dataset includes only trip-making in a limited range around the home place. For each surveyed individual making trips on their surveyed days (13,370), the following standard set of attributes are indicated: the number of trips made on the selected day, and for each of them the places of origin and destination, the activity purposes at both places, the times of departure and arrival, the travel modes utilized, including parking conditions... We used the “Home” and “Work at fixed place” activity purposes to identify the commuting cycles.

As the workplace was only indicated for work-purported trips, we could only identify it for the 3,098 individuals going to their usual workplace on the selected day, leaving aside the 2,703 that did not go to their usual workplaces on that day. Yet the number of days worked per week at the usual workplace is indicated at the individual level.

2.2.3 The “Long-distance” dataset and long-range commuting

Long-distance mobility is described at the level of tours anchored at the home place. Each tour done by the individual during the three month period up to the interview day is described in a detailed way – up to memory effects, in terms of the sequence of trips, their destination places and activity purposes, and each trip is further described regarding the modal means utilized along it. As for tour timing, the days of the trips and their times of departure and arrival are indicated.

Thus “work tours” of long-range could be identified easily. Yet, in the dataset, per individual only one of them is indicated precisely, together with the number of occurrences over the three month period. From these stems the identification of commuting cycles and their monthly frequencies.

2.2.4 Synthesis

The two datasets of Daily mobility and Long-distance mobility enabled us to measure the phenomenon of home-to-work commuting among French residents as of 2018-2019 in a fairly comprehensive way, up to sampling rate of about 1:5000. As the same individuals were sampled and surveyed about daily mobility and long distance travelling, the sample rate is identical for both places. The 3 month period of long distance monitoring enables for full detection of usual workplaces far away from home and the associated rhythms, while the one-day survey of daily mobility indicates the fixed workplace for only 3,098 individuals out of 5,801 – about 53%. On gathering short- and long-distance commuters, we shall compensate for the 53% detection rate by reweighting short-range by a factor of 1.9, yielding a “pseudo-sample”.

For short-range commuting the frequency indicator was obtained both from the within-day occurrences and the weekly frequency of workplace frequentation, times an average number of such weeks (of business) per calendar month. As for long-range commuting, it was described at the cycle level and the monthly frequency was derived from a three month period.

While the line of demarcation between short and long range is set up to 80 km of crow-fly distance, which corresponds to about 100 km of network length, it turned out that 14 out of the 128 “long-distance” commuters exhibit home-to-work crow-fly distance below 80 km. As their average distance is of 71 km, we inferred that the surveyors had some tolerance margin around the demarcation line, presumably so for the sake of relevance.

3/ Commuting rhythms relative to days

3.1/ Commuting cycles and their length in days

3.1.1 Short-range commuting: half-days vs. full-days

Among the short-range commuters, 13% make two (sometimes even 3) commuting cycles in their working day: the typical length of such cycle is a half-day (regarding working duration) and the associated rhythm would be a bi-daily one. The other 87%, indeed a vast majority, make a full working day in one cycle only: such commuting behavior is a plain daily one.

3.1.2 Long-range commuting: monodays vs. multi-days

The duration of the long-range commuting cycles, measured in days, varies from a single day to several days, thus labeled as "mono-days" or "multi-days". The two behaviors have balanced sample sizes of 61 "mono-dayers" vs. 68 overnigheters. The latter may be further divided depending on whether the cycle takes place within a plain calendar week. Such is the case for 63 individuals i.e. 9 out of 10. Yet the 4.6 average day length of overnigheters' cycles comes from a quite even distribution between lengths of 2 to 6 days (Fig. 3).

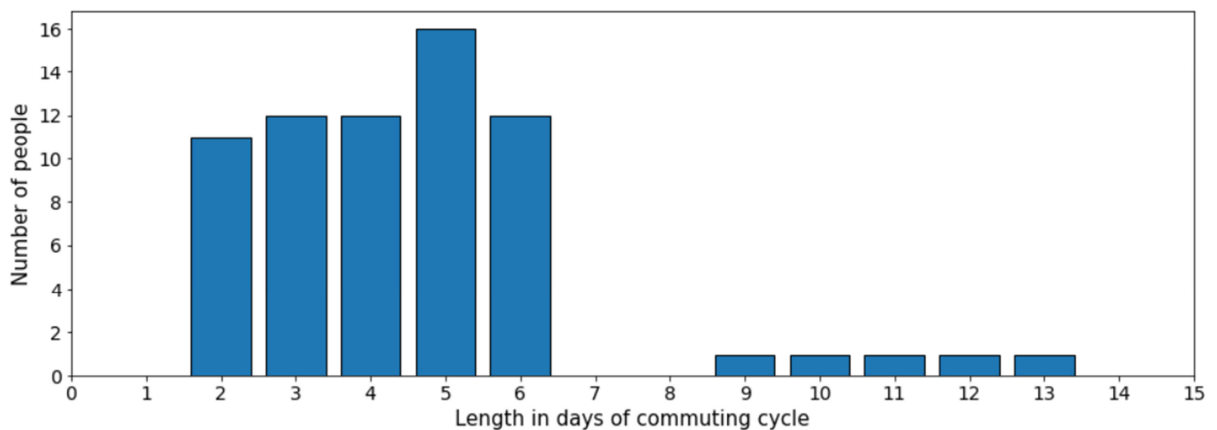


Fig. 3: Commuting cycle length in days of 68 supra-daily workers.

3.1.3 The overall distribution of commuting cycle lengths

Putting together the short-range and long-range sub-populations of workers, the lengths in days of commuting cycles exhibit three typical patterns: (i) half-day, (ii) plain day and mono-day, (iii) multiday. Their respective shares are of 13%, 86% and 1%. Within the main category of full days, short-range commuting prevails over long-range (85% vs. 1%).

3.2/ The monthly frequencies of commuting cycles

3.2.1 Short-range commuting: half-dayers vs. full-dayers

Among the short-range commuters, the number of days worked per week has an average value of 4.7 and a statistical mode at 5. We can then consider those commuters as truly daily ones. Half-day commuters are bi-daily commuters with an average number of days worked per week of 5.1, versus 4.9 for the full-day ones. Multiplying by the respective number of cycles per day and by a week-to-month factor of 22/5, the monthly frequencies amount to 45.2 cycles for bi-daily and 21.7 for plain daily.

3.2.2 Long-range commuting: monodayers vs. overnigheters

As for long-range commuters, the monthly frequencies of their commuting cycles come from their number of occurrences in the 3-month period in the HTS. Around the mean frequency of 6.2 cycles per month, there is strong heterogeneity both intra-class and inter-class between monodayers and overnigheters. Among monodayers, the monthly frequencies have mean of 9.6 and standard deviation of 7.4. Among overnigheters, frequencies have mean of 3.2 and standard deviation of 2.6. Thus the respective coefficients of variation amount to about 80%. The monodayers' average is thrice that of overnigheters.

Looking further into the distributions of frequencies, the group of monodayers splits in three sub-groups of roughly equivalent sizes (Fig.4A): between a first sub-group of rare cycles around 3 times per month and a last sub-group around 21 days per month, meaning long range commuting on every working day or so, there is an intermediary sub-group widespread from 5 to 19. Among the overnigheters (Fig. 4B), only the two-day length enables for more than one cycle per week: yet their individual frequencies are widespread around a monthly frequency of 6 only. The cycles of 3+ days exhibit an average monthly frequency of 3.

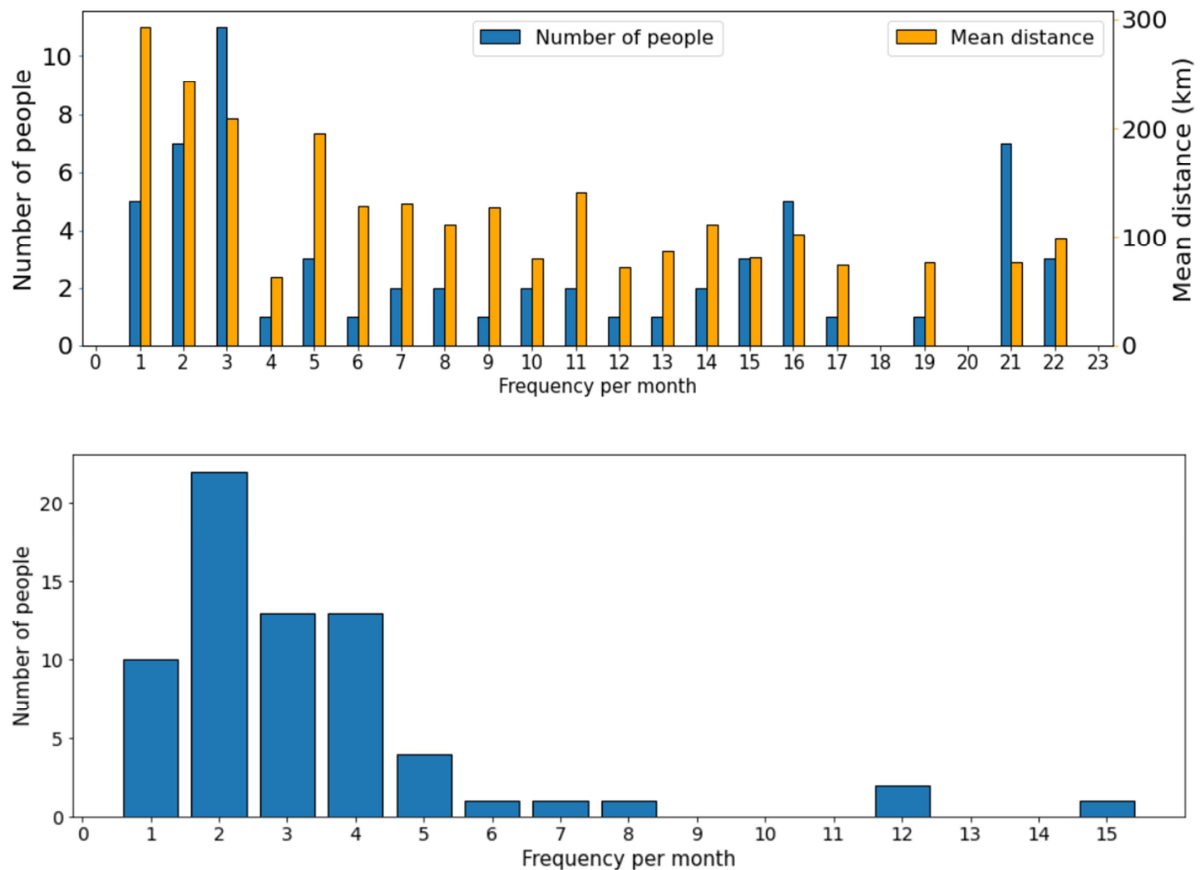


Fig. 4: The monthly frequencies of commuting cycles of (A) monodayers, (B) overnigheters.

3.2.3 Cycle length and monthly frequency give rise to 4 commuting rhythms

Among the commuters with cycle length of 1 day, the short-range ones have high cycle frequency of almost 21 times per month on average, which is more than twice the average frequency among the long-range monodayers. This motivates the distinction of four basic commuting rhythms, the first two of bi-daily and plain daily among short-range commuters,

the other two of monodaying versus overnighting among long-range commuters. The correspondence between rhythms and distance ranges is consistent but not fully exact, as some monodayers have almost full working frequency (the third sub-group).

3.3/ The monthly number of days involved in commuting

The product of cycle length and frequency, denoted as $\varphi * \lambda$, serves as a metric for the number of days related to commuting per month. This metric reflects the working aspect of commuting rather than the travel itself, and as such, it is considered an indicator of the number of days worked per month.

3.3.1 Short-range commuting: all basic working days

The short-range commuters have all of their working days related to commuting. The average monthly numbers of worked days stand at 22.6 and 21.7 days for half-dayers and full-dayers, respectively. Thus the bi-daily commuters spend one more day of work per month than the plain daily workers. This observation is consistent with the duration spent at work on each employed day. On average, bi-daily commuters spend 7.82 hours per day at their workplace, somewhat more than the average 7.58 hours of plain daily commuters.

3.3.2 On average, long-range commuters spend 10 days per month at basic workplaces

Monodayers, with cycle length of 1 day, have monthly number of commuting-involved days identical to their monthly frequency, hence with average value of 9.6 days per month. As for overnighters, the statistical distribution of variable $\varphi * \lambda$ has an average value of 12.8 that falls down to 9.6 on excluding the 5 individuals with extra-long cycles. We may then take 9.6, or say 10, as an average value for monodayers as well as overnighters, making about one half of a typical work load in days per month.

4/ Socio-demographics and Commuting rhythms

Among any human population, there are significant variations in mobility practices depending on demographic and social conditions: the gender influences the respective duties of women and men as parents of children, the age determines the involvement not only in families but also in studies and even more in professional activity that is the basic status of 90+% people aged from about 20 to 60+. Among working people, the types of profession come with different requirements of workplace fixed or mobile, of work hours stringent or flexible, of meetings out of their own workplaces. Furthermore, both the profession type and the age (as a factor of experience) determine the level of wages, hence the incomes of the worker and his or her solvency in travel and housing decisions. Here we look into the relation between socio-demographical conditions in terms of gender, age and profession type, and commuting rhythms. By commuting practice, are there typical socio-demographic conditions making specific profiles? Conversely, by segment in the working population, what are the commuting practices?

Before addressing in turn each of the two questions, the working population in France as of 2019 is featured out in Table 1, based on the national HTS with suitable reweighting. Its pseudo-sample of 5,932 individuals is balanced regarding gender: 51% of Men and 49% of Women. The three intermediate age groups have age span of 10 years each: their respective

shares increase from 22 to 31% with age and surpass the 15% of youngsters below 30 and the 8% aged 60+. Intermediary and Employees make one fourth each, Executives and Workpersons one fifth each, while Others represent 7% only.

Tab. 1: Composition of workers sample in the 2019 French HTS (short-range reweighted).

AGE	MEN BY PROFESSION TYPE						WOMEN BY PROFESSION TYPE					
	Exec	Inter	Empl	WorkP	Other	All	Exec	Inter	Empl	WorkP	Other	All
15-30	59	88	76	158	39	420	45	113	205	59	26	448
30-40	158	187	92	240	37	714	111	212	194	56	13	586
40-50	173	199	100	222	61	755	135	246	244	69	40	734
50-60	170	208	112	307	95	892	151	263	381	109	31	935
60+	80	28	30	39	46	223	43	43	101	17	29	233
TOTAL	639	709	410	966	275	2999	486	877	1123	309	138	2933

Legend: The extensive denominations of the profession types are Executives (code Exec), Intermediary profession (code Inter), Employees (code Empl), Workpersons (code WorkP) and Others.

4.1/ Socio-demographic profiles according to commuting rhythms

As the plain Daily commuting rhythm accounts for 85% of the sample, its composition along gender, age group and profession types is very close to that of the full sample.

The Bi-daily practice among short-range commuters involves Men (52%) somewhat more than Women (48%) on average: this applies to all profession types save for Employees, where Women dominate by far (3 out of 4). Age group from 50 to 60 is more represented for both genders, contrarily to the 30-40 one. Among the profession types, the share of Others is doubled – yet it remains the smallest group.

Coming to long-range commuters, among Mondayers the share of Men rises to 60%. The age group below 30 is halved compared to the full sample, while that above 60 is doubled. Among the profession types, the share of Executives is more than doubled, making them the dominant type at 43%; conversely the shares of Employees and Workpersons are halved.

Among Overnighters, the share of Women reaches 55%. By age group, the shares are relatively close to the full sample, possibly with slightly more 40-50 and slightly less 50-60. As for profession, Executives reach 46% - twice and half their global share –, Workpersons almost maintain their share, while Intermediary professions and Employees are much less represented.

4.2/ Commuting rhythms depending on socio-demographic conditions

The respective shares of the socio-demographic categories within the subpopulations by commuting rhythms come from the combination of two factors: first, the mere share of each category in the full population, second, the “modal share” of that rhythm among each socio-demographic category. To focus on the latter issue, by segment it suffices to compose its modal split between the four rhythms and compare it to the modal split in the full population (Table 2). Yet small segment sizes may lead to unreliable outcomes, especially so as the two long-range rhythms have very small modal shares.

The plain Daily rhythm, with overwhelming overall share of 85%, has somewhat higher share among those aged less than 50 and somewhat lower among those beyond 50. The share is

slightly lower for Men (84%) than for Women (86%). By profession it is lower among Executives (84%) and even more so among Others (68%), but slightly higher among Employees (87%) and still more among Workpersons (88%).

The bi-daily rhythm, of 13% share overall, is used similarly by Men (13%) and Women (12%). The effects of age are confirmed: the share is higher above 50 and lower below, especially in the 30-40 group (9%). By profession type, the share is lower among Executives (Men and Women alike) at around 10%, lower, too, among Workmen (10%), but higher among Workwomen (15%) and Others.

The small 1.0% share of Monoday commuting in the full sample gives rise to many variations across the segments. Yet it is equivalent for Men and Women. The effect of age is confirmed: from 1% only below 30, up to 2% beyond 60. By profession type, the share rises from less than 1% for Employees, Workpersons, and Women in Intermediary professions, to 1.8% for Men in intermediary professions, and up to 2.3% for Executives (Men and Women alike). The combination of Age and Profession leads to a 3% share among Executives aged 40+.

Coming to Overnighting, some segments exhibit notable deviations from the average share of 1.1%. The men's share is 1.6% and women's is 0.7%. Age has an increasing effect: from 1.0% below 30 to 1.3% in the 30-50 age group. Profession types have the largest effects: the rhythm share goes from 1% among Employees and Workpersons, up to 3% among Executives.

Tab. 2: Shares of commuting rhythms: Daily + Bi-daily + Monoday + Overnighting, by segment.

	AGE↓	Executives	Intermediary	Employees	Workpersons	Others	All
Men	15-30	97+3+0.0+0.0	69+28+1.1+1.1	80+17+0.0+2.6	89+8+0.0+2.5	79+21+0.0+0.0	84+15+0.2+1.7
	30-40	88+5+1.9+5	89+8+1.6+1.1	93+7+0.0+0.0	92+7+0.0+1.3	78+22+0.0+0.0	90+8+0.8+1.8
	40-50	84+10+2.9+3	86+12+2.0+0.5	86+11+0.0+3.0	89+9+0.0+2.3	66+33+1.6+0.0	85+12+1.3+1.9
	50-60	82+11+3.5+4	80+17+1.9+0.5	87+12+0.9+0.9	86+13+0.7+0.3	64+33+2.1+1.1	82+16+1.7+1.1
	60+	69+26+1.3+4	68+29+3.6+0.0	93+7+0.0+0.0	77+21+2.6+0.0	61+35+2.2+2.2	72+25+1.8+1.8
	Total	84+10+2.3+3	83+15+1.8+0.7	87+11+0.2+1.5	88+10+0.3+1.3	68+29+1.5+0.7	84+13+1.2+1.6
Women	15-30	98+0+0.0+2.2	91+7+1.8+0.0	86+13+0.5+0.0	83+17+0.0+0.0	96+0+0.0+3.8	89+10+0.7+0.4
	30-40	86+10+1.8+2.7	92+7+1.4+0.0	86+14+0.0+0.0	91+7+1.8+0.0	100+0+0.0+0.0	89+10+1.0+0.5
	40-50	89+8+1.5+1.5	87+12+0.0+0.4	88+9+1.2+1.2	91+9+0.0+0.0	78+20+2.5+0.0	88+11+0.8+0.8
	50-60	83+13+3.3+1.3	84+14+0.0+1.9	83+17+0.3+0.0	79+21+0.0+0.0	68+32+0.0+0.0	82+16+0.6+0.7
	60+	84+9+4.7+2.3	88+9+2.3+0.0	85+15+0.0+0.0	88+12+0.0+0.0	72+21+3.4+3.4	84+13+1.7+0.9
	Total	86+9+2.3+1.9	88+11+0.7+0.7	86+14+0.4+0.3	85+14+0.3+0.0	80+17+1.4+1.4	86+12+0.9+0.7
M&W		85+10+2.3+2.8	85+13+1.2+0.7	86+13+0.4+0.6	88+11+0.3+1.0	72+25+1.5+1.0	85+13+1.0+1.1

5/ Commuting rhythms and travel impedance

The spacing between home and work places impedes travelling between them. While spacing can be measured as a crow-fly distance or a travelled length along a network, travel impedance is a more complex issue involving money costs, travel times and physiological effort, leading to fatigue at the end of the day. The transport modes, as technical means to cross space and overcome distance, have specific impedances. The low speeds of active modes restrict their utilization to short distances and short-range commuting. Motorized modes are in order to commute on long distances, offering comfort during relatively long travel times, achieving high speeds on interurban sections that are likely to make the major parts of the trips' paths: modal speed measures the productivity of travel time as a resource to overcome distance. Car is available everywhere or so to people disposing of one and able to drive theirs. The train is not so widely available, depending on the origin and destination.

Beyond reminding basic facts at the trip level, this section aims at depicting the travel impedance of commuting to the workers in relation to commuting rhythms. Both the travelled distance and the travel time are considered as impedance indicators, from the one-way trip level, to the day level for short-range and also to the month level for long-range ones. Given the mode, the traveled distance is a proxy of money costs since it supports the variable part of them – aside from fixed costs of vehicle ownership and parking or of transit subscriptions. We shall relate travel impedance and commuting rhythms by measuring the impedance according to the rhythms and also by modeling commuting rhythm as a choice depending on the impedance, first for short-range, then for long-range.

5.1/ Short-range commuting

For short-range commuters, travel impedance in distance and time applies to both trips of each commuting cycle. The bi-daily commuting strategy requires twice the travel impedance of one cycle: yet it may enable the person to save money on one's lunch or to use the midday rest time to relax at home or make some household duty.

5.1.1 Impedance indicators at the H2W trip level

Short-range commuters make their H2W trips by means of, first and foremost, private cars and motos (77%), followed by transit modes (14%), walking (7%) and cycling (2%). The modal usage exhibits specific average distances: about 300 m for Walking, about 2 km for cycling, up to 12 km by Car and 15 km by transit. Average times are more concentrated but still quite distinctive: from 14 min by Walking and 17 min by Cycling, to 26 min by Car and up to 54 min by Transit. While motorized modes allow their users to travel over much longer distances than their active counterparts, on average the Car is much more time efficient than Transit. At the individual level, the deviations from the average values are large, with coefficient of variation of 180% for distances and 90% for times: yet, per travel mode, the distance and time variables are highly correlated. Detailed outcomes are provided in Appendix B.

Coming to the daily frequency of commuting cycles, H2W distance is a major determinant: by mode, those commuting twice a day have much lower average distance than those commuting only once. The share of "twice" (that is, bi-daily) decreases from 23% among

walkers and 20% among cyclists, to 14% among motorists and down to 3% among transit users.

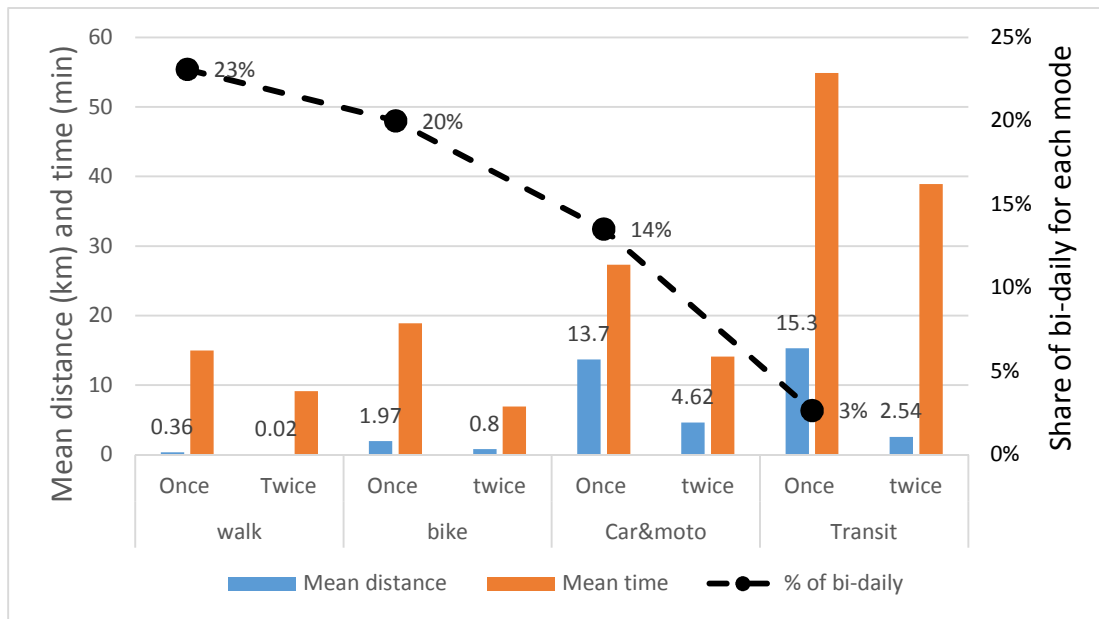


Fig. 5: Features of one-way commuting trips according to travel modes and day frequency.

5.1.2 Daily and monthly budgets

Commuting budgets in travelled distance and travel time were calculated according to the number of one-way H2W trips per worked day. Monthly budgets were derived by multiplying the daily budget by the number of commuted days per month. We analyzed the budgets according to the travel mode and also to one-way H2W distance intervals (on a logarithmic scale): all walked trips belong to the [0-10] km interval, some cycled trips fall in the [10-20] km interval, whereas the upper intervals have only Car and Transit trips. By active mode, based on their short distance advantage, bi-daily commuters have smaller distance budgets than their mono-daily counterparts. Yet only cyclists have smaller time budget. For the H2W distances less than 10km, by mode there is a convergence of distance budgets between mono- and bi-daily commuters. Such is not the case for motorists with H2W distances above 10km, among whom the bi-daily commuters have much larger distance budgets. Time budgets are higher for bi-daily than for mono-daily for both motorized modes, contrarily to cyclists.

A side issue is that of the daily duration at work place. It is quite homogenous around 8 hours per day for all modes and both commuting frequencies. Bi-daily commuters tend to spend 10-20% more time than the mono-daily ones. Between modes, shorter travel times come with shorter time at the workplace. Another counterintuitive outcome is that, within each motorized mode, larger H2W distances also come with longer times at the workplace.

5.1.3 Binary choice model of daily cycle frequency

Considering the number of commuting cycles per working day as an individual decision, we specified a binary logit choice model with one option per number of cycles, $i \in \{1,2\}$. The generalized cost (impedance) per cycle is modeled as the following affine linear function of one-way travel time T and distance D : $g_C = \beta_0 + \beta_T 2T + \beta_D 2D$, wherein β_T is the cost per

unit time (in min), β_D that per unit distance (in km) and β_0 a base cycle cost (e.g. of leaving one's home etc). Then, the utility function of option i writes as $V_i = -i \cdot g_C$.

Five models were estimated: one per modal family (Walking, Bike, Car & moto, Transit) and a multimodal model. The estimation results are given in Table 3. For the Transit model, the estimates of β_0 and β_D have statistical significance, contrarily to that of β_T . The other models yield significant time coefficients β_T , with multimodal and car estimates around 0.03/min, Walk estimate slightly higher but Bike estimate three times higher. Distance coefficients are significant for Car and Multimodal at about 0.03/km and for Transit at about 0.1/km.

Based on a standard unit cost of €0.20 per km on using a car, and putting it in equivalency with β_D , we might infer a car Value-of-Time of $€0.20 \cdot \beta_T / \beta_D \approx €10/\text{hour}$ – a plausible value.

Tab. 3: Estimation of choice models of Daily cycle frequency: # for $p < 1$, * for $p \in [1, 2]$ and ** for $p > 2$.

Coefficient → Modal model ↓	β_0	β_D	β_T	Gain in Log-likelihood	Pseudo R2	Sample size
Walk	0.405*	0.544*	0.0304*	+41	0.28	208
Bike	-0.935*	-0.0566#	0.110**	+24	0.476	75
Car&moto	0.417**	0.0304**	0.0258**	+821	0.500	2361
Transit	1.464**	0.107**	0.00982#	+248	0.804	445
Multimodal	0.395**	0.0264**	0.0296**	+1126	0.524	3098

5.2/ Long-range commuting

For long-range commuters, travelled distance and travel time per one-way H2W trip are to be multiplied by two times the monthly frequency of commuting cycles to yield monthly budgets. For overnighters, travel expenses will also include accommodation fees for out-of-home nights, as well as parking fees if they use cars, both proportionally to the number of out-of-home nights during the month. For overnighters this number is likely to be close to that of days worked at the fixed place during month. We shall thus consider the number of days worked at fixed place per month, hereafter denoted μ for brevity, as a factor of monthly cycle frequency, together with time and distance variables.

5.2.1 Impedance indicators at the H2W trip level

In the sample of long-range commuters, of limited size (129), two thirds use cars while the remaining third takes the train. One-way H2W distances are high: on average of 163 km by car, of 217 km by train. High also are the one-way times: 2h20' by car and 3h by train. The distributions of times and distances exhibit high heterogeneity, with coefficient of variation between 50% and 80% for distances and car times, somewhat lower (33%) on train times. The distance and time are strongly correlated for car trips, somewhat less for train trips. Average car speed is about 70 km/h, versus 90 km/h by train.

The shares of Monoday and Overnight are balanced in each mode. One-way distance and time are systematically lower for monoday commuters than for overnighters. According to

distance, there are 14 workers with H2W distance in the 40-80 km range, all car-users and monoday commuters. The share of Overnight increases with distance and prevails beyond 160km.

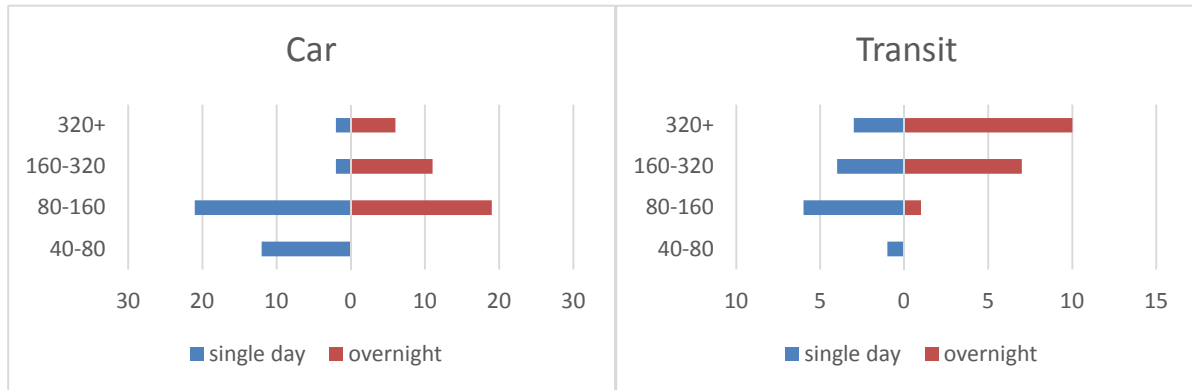


Fig. 6: Monoday vs. Overnighting strategies: trip features and respective shares.

5.2.2 Impedance budgets by day of travel and by month

Considering now the days with traveling in one way or both, the ranking of impedance between Monoday commuters and Overnighters is reversed: for both modes, the daily time and distance spent at traveling is higher for Monodayers than for Overnighters.

At the month level, taking into account the frequency of commuting cycles, the travel impedances are in general higher for Monodayers than for Overnighters – by 60% for car users and by 40% for train ones. Thus, Overnighting appears as a strategy to save travel impedance at both levels of the day with travel and of the month.

5.2.3 Binary choice model of Overnighting or not

The two options of daily frequency are obvious for short-range commuters and it is natural to model their respective utility functions on the basis of a cycle impedance function. As for long-range commuters, the monthly frequencies are more heterogeneous and the frequency of the strategy Monoday / Overnight alternative to the observed one is uncertain. Yet we devised a binary logit model of choice between the two strategies. To strategy Monoday is associated a utility function that is the travel impedance of a round commuting cycle, times the number of days worked at workplace during the month, denoted μ : thus, using the same notation as before, $V_M = -\mu(\beta_T 2T + \beta_D 2D)$.

The utility function of strategy Overnight is the number of cycles φ , times a cycle travel impedance, plus an affine function of μ : $V_O = -\varphi(\beta_T 2T + \beta_D 2D) - \beta_0 - \mu\beta_\mu$. Both φ and μ are observed for Overnighters. For Monoday individuals, μ is observed but not φ : an ad-hoc φ was derived for each of them by taking the average φ of Overnighters using the same travel mode and with μ close to that of the individual (± 2 days/month).

Then, between strategies O and M the difference in utility is of

$$\begin{aligned} V_M - V_O &= -\mu(\beta_T 2T + \beta_D 2D) + \varphi(\beta_T 2T + \beta_D 2D) + \beta_0 + \mu\beta_\mu \\ &= (\varphi - \mu)(\beta_T 2T + \beta_D 2D) + \beta_0 + \mu\beta_\mu \end{aligned}$$

$$p_o = \frac{\exp(V_o)}{\exp(V_M) + \exp(V_o)} = \frac{1}{1 + \exp(V_M - V_o)}$$

Three models were estimated: one per modal family (Car & moto, Transit) and a multimodal model. The estimation results are given in Table 4. All models yield significant estimates of the distance coefficient β_D but none has significant time coefficients β_T . The Car distance coefficient is twice the Transit one.

Tab. 4: Estimation results of overnighting or not: # for $p < 1$, * for $p \in [1, 2]$ and ** for $p > 2$.

Coefficient → Modal model ↓	β_0	β_D	β_T	β_μ	Gain in log likelihood	Pseudo R2	Sample size
Car&moto	1.609**	0.00177**	-0.000458#	0.124*	+19	0.346	77
Transit	0.776*	0.000748**	-0.000193#	0.0623#	+11	0.338	48
Multimodal	1.199**	0.00110**	-0.000201#	0.0908*	+28	0.321	125

5.3 Synthesis

The statistical distribution of workers according to distance bands in log scale exhibits a decreasing influence of distance that is systematic for both sub-populations short- and long-range. The long-range sample, presumably for home-to-work distances above 80km, also includes a dozen workers with commuting distance between 40 and 80 km (Fig. 7A). Their commuting rhythms are at the day level (Monday strategy) but with monthly frequency around 12, distinctive from the 17 of their short range counterparts. The one-way commuting times overlap even more between the two sub-populations (Fig. 7B).

Regarding modal shares, the car prevails for all distance bands and commuting rhythms, save for monodayers beyond 160km and overnighters beyond 320km among whom the train is more used. Yet modal availability is likely more widespread for the car than for the train.

As for monthly budgets in distance and time of travelling, the distance effect between short- and long-range at the trip level transfers to the month level, though attenuated by rhythmic strategies: bi-daily commuters travel 340 km per month on average, daily ones 569 km, versus 2,056 km among mono-day long-range commuters and 1,675 km among overnighters. The rhythmic and modal strategies are effective to contain the monthly time budgets of long-range commuting: bi-daily spend 20.7 hours per month on average, daily ones 21.9 hours which is more than the average 18.2 hours of overnighters, while monodayers have a monthly time budget of 35.7 hours on average, that is, almost twice that of the other categories.

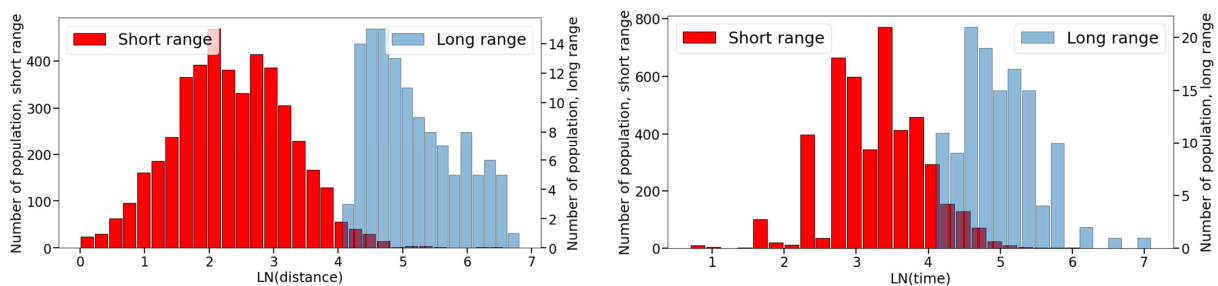


Fig. 7: One-way impedance among short- and long-range: (A) Distances, (B) Times.

6/ From micro behaviors to macro features

So far we have considered H2W commuting at disaggregate, micro level of the individual worker: rhythmic behavior, socio-demographic attributes, and travel impedance on a trip, day or month basis. The individual cases have been characterized jointly, in a statistical way yielding an overall picture of their statistical population.

Here we are interested in macroscopic features of the H2W commuting phenomenon in terms of presence in places and of traffic on transport networks. A well-known instance lies in the peak hours of network traffic on the mornings and evenings of working days – when many people travel on the same purpose work-bound or home-bound at about the same time, yielding large traffic loads and dense conditions.

We shall estimate macro-indicators by using the sample weights to expand the statistical sample into the statistical population of workers. Within each kind of indicator we shall look into the shares of the different commuting rhythms and also of the different ranges – by intervals of distance according to a log-scale. As for the places and times of the macroscopic phenomena, we shall consider modal networks as places and, as times, the days in the week and the hours in the day.

In the following, three issues are addressed in turn: firstly, home-to-work distances as traffic loads distributed on modes, secondly, the resulting traffic footprint of commuting along days and hours within days, thirdly, commuting traffic compared to the rest of traffic and its share in the carbon emissions of transport in France.

6.1/ H2W distances as elementary traffic loads

6.1.1 One-way H2W distances among workers

One-way H2W distances have an average value of 14.7 km but exhibit large heterogeneity (Table 5). Distances up to 80 km represent 98% of workers but the 2% of longer distances induce 28% of traffic load. Active modes have a modal share of 10% of workers but only 0.6% of traffic load. The car mode, used by 75% of workers, accommodates 75% of traffic load. Transit modes, 15% of workers and 25% of traffic load, involve long distance as main contributor.

Tab. 5: Number of workers and average one-way distance (in km) by mode and distance band.

H2W (km)	Walk		Bike		Car&moto		Transit		All modes	
	Nb (M)	Dist	Nb (M)	Dist	Nb (M)	Dist	Nb (M)	Dist	Nb (M)	Dist
0-10	1.85	0.29	0.615	1.51	11.1	3.97	2.48	4.13	16	3.47
10-20			0.055	13.4	4.59	14.6	0.624	13.8	5.27	14.5
20-40					2.92	26.6	0.443	29.6	3.36	27
40-80					0.84	54.8	0.203	57	1.04	55.2
80-160					0.23	115	0.058	114	0.292	115
160-320					0.063	225	0.044	246	0.107	234
320+					0.027	475	0.067	497	0.095	491
All	1.85	0.29	0.067	2.49	19.8	14.6	3.92	24.1	26.2	14.7

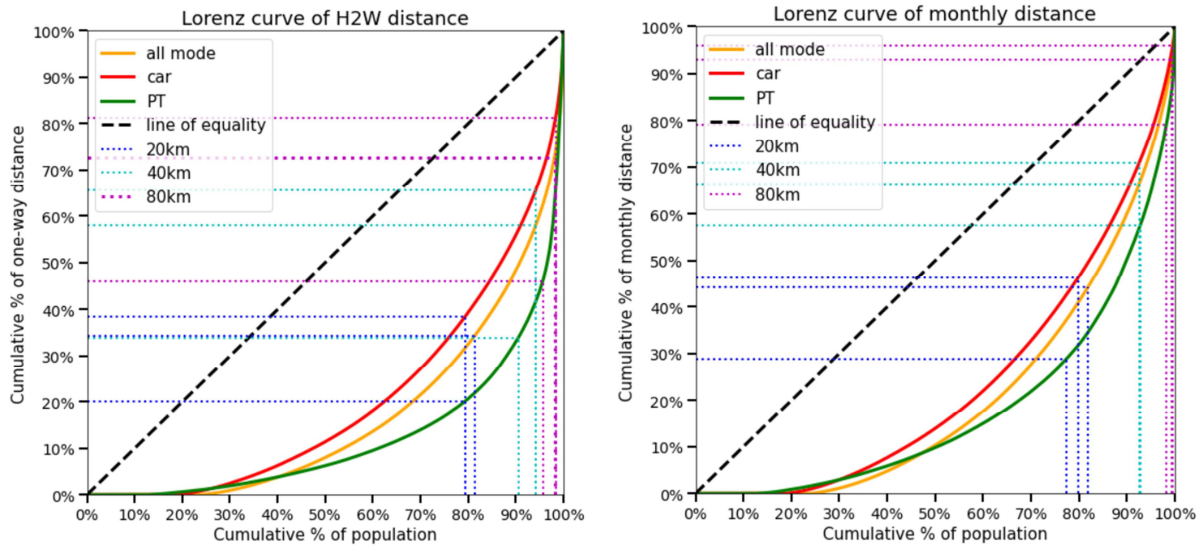


Fig. 8: Lorenz curves of (A) One-way H2W distance, (B) Monthly H2W distance.

On ordering the workers according to increasing H2W distance, the Lorenz curve reveals that long range has a large share of traffic despite a small share of workers (Fig. 8A). The 30% of higher one-way length make almost 80% of cumulated lengths – one more instance of Pareto’s 80-20 principle. The Gini coefficient of 0.67 measures the inequality of H2W distance among workers.

6.1.2 The factorization of one-way distance by frequency

Table 6 exhibits the average monthly frequency of H2W trips in either direction to work or back to home, by distance band and main mode. One-way distance exerts a decreasing influence on the monthly frequency of H2W trips: the decrease is slight among “short-range” commuters but sharper among long-range ones. The resulting distribution of monthly distance travelled for commuting is depicted in Figure 8B.

At the month level, owing to the frequency attenuation associated to one-way trip length, short-range commuting below 20 km constitutes 44% of traffic for 82% of workers, while the 2% of commuters beyond 80 km give rise to 7% of traffic. The Gini index is decreased to 0.59 – still a relatively large value. Intermediary ranges of 20-40 and 40-80 km, respectively 11% and 5% of commuters, induce 22% and 27% of monthly traffic.

Tab. 6: Monthly frequency and commuting distance budget by mode and distance band.

H2W (km)	Walk		Bike		Car&moto		Transit		All modes	
	Freq	Dist	Freq	Dist	Freq	Dist	Freq	Dist	Freq	Dist
0-10	28.2	13.8	27.8	77.6	26.6	201	21.9	177	26.1	171
10-20			22	589	22.7	658	20.6	565	22.5	647
20-40					22.2	1,176	21.3	1,265	22.1	1,188
40-80					19.9	2,129	20.1	2,315	19.9	2,165
80-160					10.3	2,225	12.6	2,653	10.7	2,311
160-320					4.08	1,765	7.53	3,625	5.48	2,522
320+					2.89	2,475	5.82	5,727	4.98	4,793
All	28.2	13.8	27.3	120	24.5	565	21	644	24.3	527

6.1.3 Pseudo-daily distance of H2W

Commuting rhythm is an individual behavior: the adaptation of frequency is a microeconomic decision of the individual commuter to lessen the travel impedance to him- or herself. The resulting effect on traffic loads may be put in equivalence to a reduction of commuting distance on a daily basis. Let us call “pseudo-daily” H2W distance (PDD) the quotient of the monthly travelled distance by 44 occurrences, i.e., the typical number of one-way trips for plain daily commuting on 22 working days in a standard month. Significant attenuation comes out since the average PDD of 11.9 km is 20% less than the average basic H2W distance (appendix B).

6.2/ The traffic footprint of commuting on transport networks

The monthly quantities of commuting traffic by the population of workers, established according to H2W distance range and travel modes, split between days and hours in the day.

6.2.1 Daily traffic and modal assignment

Distinguishing weekdays from Monday to Friday, on the one hand, versus weekend days, on the other hand, the total distance travelled per weekday is about four times that per weekend day – thereby confirming the stronger assignment of work days to weekdays (Table 7).

According to one-way H2W distance, the weekday commuting traffic splits into four parts: 20% of short distances below 10 km, 24% of 10-20 km, 26% of 20-40 km and 30% above 40 km. Indeed, though much less numerous, the longer commuting trips induce much larger traffic quantities. Weekend days exhibit still higher traffic shares of longer H2W distances, including 35% of traffic for trips beyond 40 km.

The modal splits are similar on weekdays and weekend days. Active modes make about 1% only of traffic, due to low share of trips combined to the short lengths of them. The car dominates overall traffic with share of 80% that is four times that of transit modes. Half of transit traffic is due to H2W distances beyond 40 km.

Tab. 7: Total distance (M km) per day on typical day (weekday vs. weekend), by distance range and mode.

Range	Week day					Weekend day				
	active	car	<i>Occup</i>	transit	all	active	car	<i>Occup</i>	transit	all
0-10	2.34	70.2	<i>1.09</i>	12.9	85.4	0.106	14.3	<i>1.22</i>	2.46	16.9
10-20	1.01	89.2	<i>1.05</i>	10.7	101		9.03	<i>1.15</i>	2.73	11.8
20-40		96.1	<i>1.04</i>	15	111		25.4	<i>1.02</i>	4.19	29.6
40-80		51	<i>1.08</i>	14.3	65.2		10.7	<i>1.1</i>	1.72	12.4
80-160		23.8	<i>1.31</i>	6.9	30.7		11.6	<i>1.62</i>	2.95	14.6
160-320		5.82	<i>1.02</i>	8.2	14		0.654	<i>1.0</i>	1.0	1.66
320+		2.36	<i>1.0</i>	19.1	21.5		1.97	<i>1.0</i>	1.1	3.1
All	3.35	338	<i>1.07</i>	87.1	429	0.106	73.7	<i>1.15</i>	16.2	90

6.2.2 Within-day temporal variations on weekdays

Commuting traffic along the hours in a typical weekday exhibits a pattern with three statistical modes: high peak at morning around 7-8 am, large peak at evening around 5-7 pm, moderate midday peak around noon (figure 9). The midday and evening peaks have similar shapes for short range commuters below 20 km, while intermediate ranges 20-40 and 40-80

km have evening peak sharper than midday. Long-range commuters beyond 80 km contribute significant traffic quantities from 5 am to 9 pm, with two peaks of large spread, respectively on morning from 6 to 9 am and on evening from 5 to 8 pm.

Car traffic, representing 80% of p.km, has day time distribution analogous to the overall one. In contrast, the daily variations of transit traffic exhibit two peaks only on morning and evening respectively, of matching shapes, together with almost empty hours from 10 am to 4 pm.

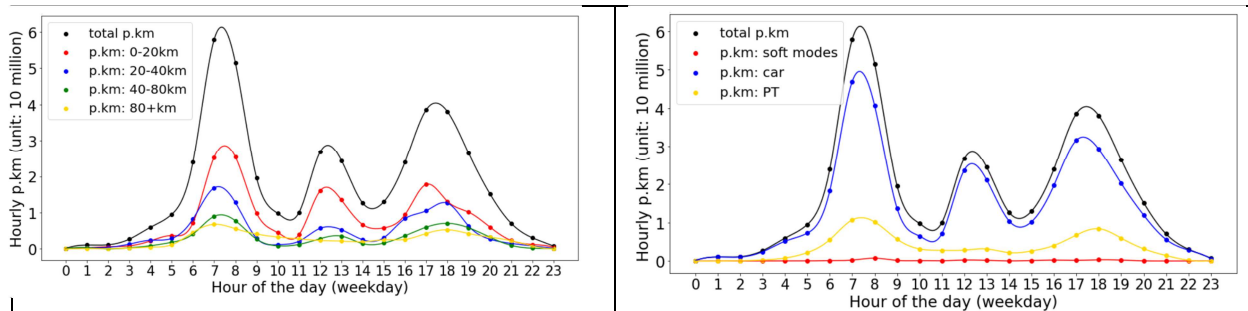


Fig. 9: Weekday commuting traffic according to (A) Distance bands, (B) Travel modes.

6.3/ The share of commuting in transport traffic and carbon emissions

6.3.1 Comparing commuting traffic to other travel purposes on weekdays

On an average weekday, the traffic of other purposes amounts to thrice that of commuting, reducing its share to 24% of a total of 1.8 G p.km (Appendix C). Regarding trip lengths, non-commuting traffic splits into three thirds: 29% for trips above 320 km, 32% between 40 and 320 km, 39% below 40 km: the latter make 526 M p.km, much ahead of the 300 M p.km of commuting traffic on that distance band which includes urban mobility.

In the traffic of trips beyond 40 km, the 130 M p.km of commuting purposes amount to one sixth of the traffic with other purposes (830 M p.km). Keeping to ground transport modes, other purpose traffic has modal split close to that of commuting traffic: 0.8% of Active modes (somewhat less), 17% of transit (idem) and 82% of car (somewhat more). The train has a traffic share of 33% among the trips above 320 km.

As for within-day time variations, the non-commuting traffic has two marked peaks respectively at morning around 10 am and end-afternoon around 6 pm, which is quite sharp. Between 4 and 7 am the increase from night to daytime regime has increasing slope equivalent to the decreasing one in the evening. Long trips over 80 km and short trips below 20 km contribute most of the slopes. All ranges included, on its 7-9 am peak period, commuting traffic is about equivalent to the rest of purposes. At the evening peak of commuting, this purpose involves about one third of the traffic with other purposes (compare Figures 9 & 10).

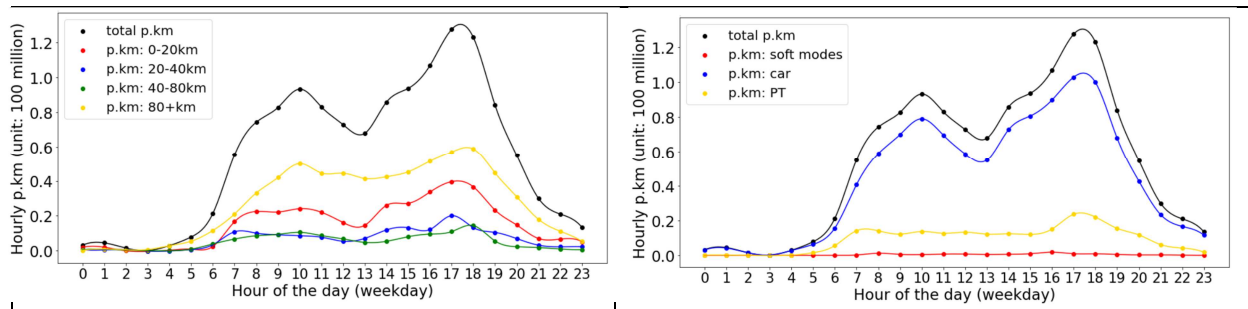


Fig. 10: Weekday non-commuting traffic according to (A) Distance bands, (B) Travel modes.

6.3.2 Commuting versus other purposes on weekend days

On an average weekend day, the overall traffic of about 2.1 G km surpasses the weekday average by 17%. Commuting represents 4% of it only. According to trip length classes, the intermediate range of 40-320 km has a 43% share of traffic, significantly higher than the 31% of trips below 40 km and the 26% of trips above 320 km. The time variations of other purposes exhibit steady increase from 5 am to 11 am, followed first by a decline up to 1 pm, then by a steady increase until 5pm and next by a sharper decrease up to 11 pm, at which point it takes its near-zero night level up to 4 am (figures 11 & 12). Commuting traffic is smaller than that of other purposes by one order of magnitude. As for travel modes, once again private cars carry out the major share of traffic, with time profile fairly identical to the overall one (figure 12). Transit modes exhibit a morning peak period between 10 and 12 am and an evening one around 6 pm.

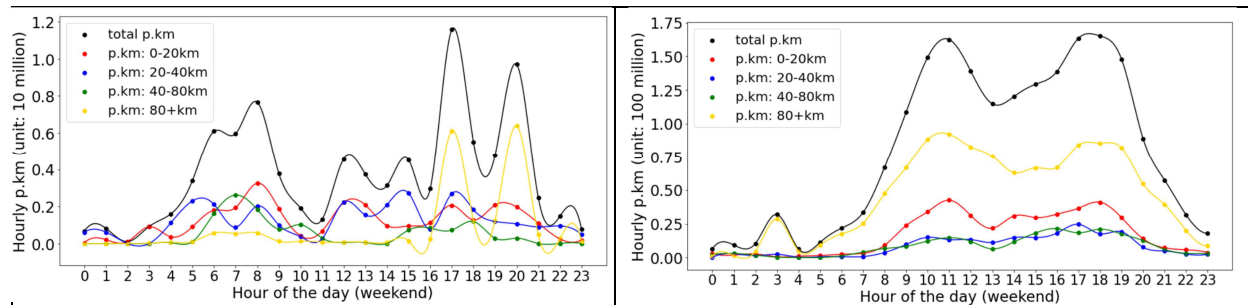


Fig. 11. Weekend day commuting vs. non-commuting traffic according to Distance bands.

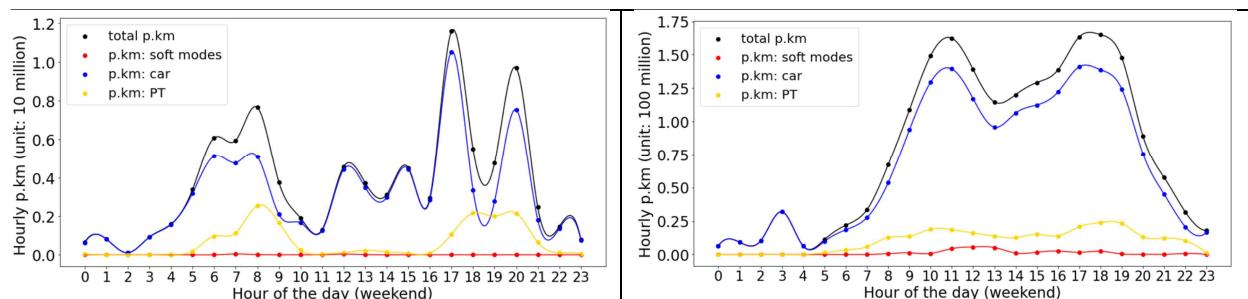


Fig. 12. Weekend day commuting vs. non-commuting traffic according to Travel modes.

6.3.3 On the commuting purpose in car traffic

The traffic shares considered previously are estimated in person.km. Focusing now on the car mode, traffic in veh.km can be estimated from dividing those in p.km by the car occupancy rate measured at the trip level (table 8). It then appears that commuting makes about 30% of all car traffic on weekdays. For trips below 40 km the share of commuting rises to 40%, making it the leading purpose of car traffic in urban areas. On weekend days, commuting trips make 6% of all car traffic, and 11% of that resulting from trips below 40 km.

These shares of commuting in roadway traffic translate straightforwardly into shares of carbon emissions in France. Assuming (i) identical average private car between Commuting and other purposes (of French people as well as foreign people driving in France), (ii) average GHG emission rate of 143 gCO₂e per car.km as of 2019 France, the yearly carbon emissions of 16.5 Mt CO₂e from commuting represent 24% of the 69 Mt CO₂e emitted by the roadway traffic of passenger cars. As the latter constitute 15.7% of the direct carbon emissions of France (Datalab, 2020), in turn the share of car commuting amounts to 3.7% of carbon emissions in France as of 2019.

Tab. 8: Car traffic in M km per day: (A) Commuting, (B) Other purposes.

Trip length (km)	Weekday			Weekend-day			Weekday			Weekend day		
	M p-km	occup	M veh-km	M p-km	occup	M v-km	M p-km	occup	M veh-km	M p-km	occup	M v-km
0-10	70.2	1.09	64.4	14.3	1.22	11.7	167	1.30	128.5	185	1.48	125.0
10-20	89.2	1.05	85.0	9.03	1.15	7.9	154	1.31	117.6	189	1.58	119.6
20-40	96.1	1.04	92.4	25.4	1.02	24.9	149	1.29	115.5	188	1.65	113.9
40-80	51	1.08	47.2	10.7	1.10	9.7	112	1.55	72.3	195	1.78	109.6
80-160	23.8	1.31	18.2	11.6	1.62	7.2	137	1.68	81.5	313	2.01	155.7
160-320	5.82	1.02	5.7	0.654	1.00	0.7	132	1.70	77.6	283	1.71	165.5
320+	2.36	1.00	2.4	1.97	1.00	2.0	265	1.88	141.0	364	2.02	180.2
All	338	1.07	315.2	73.7	1.15	64.0	1116	1.52	733.9	1716	1.77	969.5

7/ Discussion

7.1/ On the methodology and its outcomes

The twofold definition of commuting rhythms, involving both the cycle length in days and the monthly frequency of commuting cycles, gives rise to a comprehensive understanding of the commuting. It enables specifically to unfold the notional “daily behavior” that combines within-day cycle length and routine behavior at the day level. According to the definition, four patterns of commuting do emerge: the first two with daily routine of one or two commuting cycles per day, the other two with heterogeneous days and commuting cycle lengths of either one or several days.

To our knowledge, this study is the first to encompass the spectrum of commuting rhythms by paying due attention to cycle frequency. Previous literature on long-range commuting considered either just a daily frame or overnighing cumulated along a year (e.g. in the JobMob panel surveys).

Our results about the demographic and socioeconomic features of long range commuters are consistent with previous findings about long distance commuters: that they are mainly male (Baldazzi & Romano, 2006; Collet & Bonnet, 2010; Wachter & Holz-Rau, 2022), middle-

aged (Baldazzi & Romano, 2006) and with managerial positions (Jeong et al., 2013).

Here the twofold definition of commuting rhythms is focused on a *usual workplace*: it does not integrate Work from home or in other places. It may well be the reason why the 1% of overnights in our sample is much less than the 5% of overnights observed in France in JobMob panels (Collet & Bonnet, 2010) that consider all places for professional purposes. In the same vein, the 1% share of mono-day long range commuting in our sample is much less than the 5% observed in JobMob using a different criterion of daily travel time beyond 2 hours, instead of one way crow-fly distance above 80 km in our sample. By including the higher end according to time of the trips below 80 km (see figure 7B), we would recover about 180 workers, thereby raising the share of mono-day “long distance” commuting to 4% in the full EMP sample.

The definition of “long distance” is essential to estimate the related traffic and its shares in both roadway traffic and the related carbon emissions. Considering as “long trips” all those above 10 km (resp. 20km), then the “long trips of commuting” would make 15% of car traffic GHG emissions (resp. 10%) leading to a share of 2.3% of French yearly carbon emissions (resp. 1.6%).

Our study is also the first to quantify, on a monthly basis, time and distance budgets in a comprehensive framework including all commuting rhythms and dealing with frequency consistently. Based on the French nationwide HTS, the respective shares of the four rhythmic patterns were measured first in number of workers, second in monthly number of days worked at the usual workplace, third in monthly travel time spent by the individual and fourth in monthly distances travelled at commuting. It was found that the one-way distance exerts a strong influence on the monthly budget, despite attenuation by the reduction in monthly cycle frequency. The commuting rhythms of overnights enable them to bring their monthly travel time budget down to those of truly daily commuters, while long-distance monodayers have double monthly time budget which amounts to the average work time in a week. This makes the **secondary use** of that time, additionally to the primary use for traveling, an obvious topic for future research.

7.2/ Space-focused vs. Usage-focused Commuting distances

Between the main home place and the usual place of work, the one-way home-to-work distance is a geographic feature at the level of the individual worker. Yet it may be taken as a proxy indicator of travelled distance per worked days for short-range commuting only. Long-range commuting requires considering the timeframe more closely and integrating the frequency effect of commuting cycles. We emphasized the attenuation of travelled distance by rhythmic behaviors at the month level, hence at the level of “worked days” as perceived by system planners – urban, transportation...

Frequency attenuation constitutes a temporal spreading of the monthly budget in commuting distance. There is likely also a spatial spreading between urban and interurban roads, since the latter are likely to accommodate the larger shares of long-distance commuting trips. The two kinds of spreading certainly relieve the pressure of commuting traffic on network flows. Yet the large amounts of commuting traffic need be taken into account in planning network capacities: the special focus of network planning studies on peak periods of working days is very relevant in this respect, all the more so if all ranges of commuting distances are

addressed, without any restrictions to the commuting mobility of “resident workers”. The commuting mobility of outside workers need be considered, too, whether bound to jobs in the planned area or just traversing it.

More comprehensive consideration of commuting in planning studies will enable to shed more light on the issue of spatial mismatch between life basins and job basins. Such mismatch is not only a source of much traffic on networks but also an economic burden to those workers experiencing it, due to travel impedance in both time and money and the related individual budgets at the end of the month.

7.3/ On the information source

This study was motivated initially to estimate the traffic effect of home-to-work travel on modal networks. This is why we resorted to the French nationwide HTS. The study is fully based on that data source as empirical material, regarding individual mobility on the two sides of daily mobility and long-distance traveling over a long period. The survey provided not only standard items such as individual description, home and work places, the number and description of the trips, but also original features such as the weekly frequency of worked days and the frequency of long-range commuting tours. While the two kinds of frequencies allowed us to characterize commuting frequency for short-range as well as long-range commuters, some discrepancy was found between them for long-range commuters – the number of worked days per week being systematically higher than the weekly average of the combined commuting cycles. This suggests that long-range commuters make a relatively abundant usage of other work places, probably including their homes.

Another feature of the HTS is its sample rate: about 1:5000, definitely a small one. While sufficient to estimate the modal shares of the rhythmic patterns, the sampling rate was barely enough to apprehend socio-demographic profiles among long-distance commuters and to study the influences of travel impedances. The two choice models introduced in this study are first attempts, yielding some hints that need be taken with care.

Alternative data sources would certainly be useful to understand commuting rhythms better. Massive datasets of mobile traces with individual trajectories over several weeks would provide ampler evidence of long-distance commuting practices, with sampling rate far superior to that in the HTS even with tracing scheme limited to some percents of the population: this would enable for origin-destination matrices between zones of several tens or hundreds thousand people each. Social data provided by employers about their employees to fiscal administrations would also be much more representative to compare workplaces and home places depending on socio-demographic conditions: possibly also to measure worked days and the share of the usual workplace among them.

Ideally, in line with teleworking developments, it would be relevant to integrate questions about commuting rhythms in future General Censuses of population, complementarily to those about the usual workplace and the main travel mode to it (the latter one was introduced about 30 years ago, in 1991 in France following other countries notably the US and the UK).

8/ Conclusion

Is commuting between home and the usual workplace a daily behavior? To answer, we introduced a twofold notion of commuting rhythm at the individual level, involving the length in days of commuting cycles together with the monthly frequency of such cycles. Four rhythmic patterns have been identified. On the one hand, there are two truly daily patterns according to both daily routine and within-day cycles: once or twice per worked day. On the other hand, there are two rhythmic patterns without daily routine: monodaying on part of the days only, and overnighing i.e. multi-day cycles reiterated several times per month.

Based on the French nationwide HTS, in France as of 2019 there is an overwhelming majority of truly daily commuters, 98% that split in 14% of bi-daily and 84% of plain daily – also a vast majority. The other two rhythms are rare behaviors, 1% each, both associated to long-range commuting. Between the patterns, the number of days spent per month at the usual workplace decreases from truly daily (about 22 days per month) to overnighing and to monodaying (both about 10 days per month). In each long-range subpopulation there is considerable heterogeneity in the frequency of cycles, around average values per month of 9.6 for monodayers and 3.2 for overnighers. Highly heterogeneous, too, are the cycle lengths of overnighers. On relating the rhythmic behaviors to socio-demographic characteristics, it came out that bi-daily commuting is more practiced by older workers, with lower share among Executives but higher among Workwomen. Long-range monodaying also increases with age and its share depends on profession types, culminating among executives, up to 3% for executives aged 40+. Overnighing also increases with age and depends on profession types, up to 3% among executives.

We also investigated the relation between commuting rhythms and travel impedance in terms of distance and time. Among short-range commuters, bi-daily commuting is associated with lower cycle impedance, enabling for a higher share of active modes; yet, at the day level and by distance interval, the travel impedance of bi-daily is close to that of plain daily. The respective effects of time and distance on the number of cycles per worked day were estimated using a logit choice model. Long-range commuters use the car or the train to reach their usual workplaces. The high average speeds of the modes counteract the distance effect up to a partial extent only: one-way travel times are high, typically between 2 and 3 hours. Overnighing appears as a strategy to save travel impedance at both levels of the day of travelling and the month.

On comparing the four rhythmic behaviors according to monthly budgets of travel impedance, monodaying involves time budgets about double of those of the other patterns. Monthly travelled distances show an attenuation of long-range by the monthly frequency of commuting trips: from 340 km for bi-daily, to 569 km for plain daily, up to 1,675 km for Overnighers and 2,056 km for monodayers.

Additionally to the research directions mentioned in the Discussion, long-distance commuting could be observed more intensively using higher sampling rates and diversified survey instruments, including on-board surveys in interurban trains, en-route surveys on the interurban road network and digital traces on large territories. Overnighing practices require deeper characterization regarding the individual practices of "local mobility" around the workplace and especially the conditions of accommodation.

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APPENDICES

APPENDIX A: Socio-demographics and commuting rhythms

Tab. A1. Distribution of workers sample by age class and profession type

AGE	Executive	Intermediary	Employee	Workperson	Other	total
15-30	1.8%	3.4%	4.7%	3.7%	1.1%	14.6%
30-40	4.5%	6.7%	4.8%	5.0%	0.8%	21.9%
40-50	5.2%	7.5%	5.8%	4.9%	1.7%	25.1%
50-60	5.4%	7.9%	8.3%	7.0%	2.1%	30.8%
>60	2.1%	1.2%	2.2%	0.9%	1.3%	7.7%
Total	19.0%	26.7%	25.8%	21.5%	7.0%	100%

Tab. A2. Composition of workers sample in the 2019 French HTS: bi-daily

AGE	Men, by profession type						Women, by profession type						M&W total
	Ex.	In.	Em.	Wo.	O.	total	Ex.	In.	Em.	Wo.	O.	total	
15-30	2	25	13	13	8	61	0	8	27	10	0	45	106
30-40	8	15	6	17	8	54	11	15	27	4	0	57	111
40-50	17	23	11	19	20	90	11	30	23	6	8	78	168
50-60	19	36	13	40	31	139	19	38	63	23	10	153	292
>60	21	8	2	8	16	55	4	4	15	2	6	31	86
total	66	106	46	97	81	396	46	95	154	44	23	362	758
M&W	112	201	200	141	104	758							

Tab. A3. Composition of workers sample in the 2019 French HTS: full daily

AGE	Men, by profession type						Women, by profession type						M&W Total
	Ex.	In.	Em.	Wo.	O.	total	Ex.	In.	Em.	Wo.	O.	total	
15-30	57	61	61	141	31	351	44	103	177	49	25	398	749
30-40	139	167	86	220	29	641	95	194	167	51	13	520	1161
40-50	146	171	86	198	40	641	120	215	215	63	31	644	1285
50-60	139	167	97	264	61	728	125	220	317	86	21	769	1497
>60	55	19	28	30	28	160	36	38	86	15	21	196	356
total	536	585	357	853	188	2519	420	770	961	264	111	2526	5045
M&W	956	1355	1318	1117	299	5045							

Tab. A4. Composition of workers sample in the 2019 French HTS: long-range mono-daily

AGE	Men, by profession type						Women, by profession type						M&W
	Ex.	In.	Em.	Wo.	O.	all	Ex.	In.	Em.	Wo.	O.	all	
15-30	0	1	0	0	0	1	0	2	1	0	0	3	4
30-40	3	3	0	0	0	6	2	3	0	1	0	6	12
40-50	5	4	0	0	1	10	2	0	3	0	1	6	16
50-60	6	4	1	2	2	15	5	0	1	0	0	6	21
>60	1	1	0	1	1	4	2	1	0	0	1	4	8
total	15	13	1	3	4	36	11	6	5	1	2	25	61
M&W total	26	19	6	4	6	61							

Tab. A5. Composition of workers sample in the 2019 French HTS: overnighting

AGE	Men, by profession type						Women, by profession type						M&W
	Ex.	In.	Em.	Wo.	O.	all	Ex.	In.	Em.	Wo.	O.	all	
15-30	0	1	2	4	0	7	1	0	0	0	1	2	9
30-40	8	2	0	3	0	13	3	0	0	0	0	3	16
40-50	5	1	3	5	0	14	2	1	3	0	0	6	20
50-60	6	1	1	1	1	10	2	5	0	0	0	7	17
>60	3	0	0	0	1	4	1	0	0	0	1	2	6
total	22	5	6	13	2	48	9	6	3	0	2	20	68
M&W total	31	11	9	13	4	68							

APPENDIX B: Travel impedance of commuting

Tab. B1. Time spent (daily) on commuting trips (M p.hour).

Trip Distance	Weekday				Weekend day			
	active	Car	transit	All	active	Car	transit	all
0-10	1.07	4.86	2.0	7.93	0.256	1.03	0.368	1.66
10-20	0.043	2.89	0.800	3.73		0.251	0.202	0.453
20-40		2.55	0.711	3.27		0.625	0.212	0.836
40-80		1.07	0.430	1.51		0.192	0.061	0.253
80-160		0.386	0.132	0.519		0.024	0.063	0.087
160-320		0.083	0.084	0.167		0.008	0.008	0.016
320+		0.029	220	0.250		0.022	0.008	0.031
All	1.11	11.9	4.38	17.4	0.256	2.15	0.922	3.33

Tab. B2. Pseudo-daily one-way commuting distance (in km).

H2W (km)	Walk		Bike		Car&moto		Transit		All modes	
	Nb (M)	Dist	Nb (M)	Dist	Nb (M)	Dist	Nb (M)	Dist	Nb (M)	Dist
0-10	1.85	0.313	0.615	1.76	11.1	4.57	2.48	4.02	16	3.89
10-20			0.055	13.4	4.59	14.9	0.624	12.8	5.27	14.6
20-40					2.92	26.7	0.443	28.7	3.36	26.9
40-80					0.838	48.3	0.203	52.6	1.04	49.2
80-160					0.233	50.5	0.058	60.2	0.292	52.5
160-320					0.063	40.1	0.044	82.3	0.107	57.3
320+					0.027	56.2	0.067	130	0.095	108
All	1.85	0.313	0.671	2.722	19.8	12.8	3.92	14.6	26.2	11.9

APPENDIX C: Non-commuting trips and traffic.

Tab. C1. Trip length (km) of non-commuting trips.

Trip Distance	Week day				weekend			
	active	car	transit	all	active	car	transit	all
0-10	0.16	2.46	2.44	1.64	0.22	2.80	2.53	1.90
10-20	13.2	14.0	14.3	14.0	16.3	14.2	14.7	14.2
20-40	23.8	27.1	27.8	27.1	26.9	27.8	26.4	27.7
40-80	61.5	55.3	54.8	55.3	47.8	54.0	54.6	53.9
80-160	87.6	112	109	111	151	116	101	116
160-320	298	224	240	227	230	224	239	226
320+	589	492	533	505	322	496	520	502
All	0.26	12.5	21.4	9.55	0.80	18.2	35.6	14.5

Tab. C2. Daily traffic (M p.km) of non-commuting trips.

Trip Distance	Week day					Weekend day				
	active	car	Occup	transit	all	active	car	occup	transit	all
0-10	6.9	167	1.30	21.4	195	8.01	185	1.48	15	208
10-20	1.24	154	1.31	15.2	170	4.71	189	1.58	7.76	201
20-40	0.304	149	1.29	12.3	161	1.03	188	1.65	15.7	204
40-80	0.126	112	1.55	11.2	123	3.33	195	1.78	10.3	209
80-160	0.382	137	1.68	17	154	1.46	313	2.01	9.7	325
160-320	0.683	132	1.7	24.2	157	8.87	283	1.71	51.9	343
320+	1.5	265	1.88	133	400	2.65	364	2.02	171	537
All	11.1	1,110	1.52	235	1,360	30.1	1,720	1.77	281	2,030

Tab. C3. Time spent daily on non-commuting trips (p.hour).

Trip Distance	Weekday				Weekend day			
	active	Car	transit	All	active	Car	transit	all
0-10	10.9	15.3	5.09	31.2	12.3	15.4	3.63	31.3
10-20	0.047	5.38	1.12	6.55	0.153	6.66	0.587	7.4
20-40	0.020	4.33	0.591	4.94	0.059	5.13	1.08	6.27
40-80	0.012	2.77	0.324	3.11	0.034	4.23	0.294	4.56
80-160	0.006	2.9	0.390	3.29	0.019	6.33	0.192	6.55
160-320	0.001	2.31	0.434	2.74	0.039	5.28	0.724	6.05
320+	0.003	3.95	1.42	5.37	0.687	5.27	2.04	7.31
All	11	36.9	9.37	57.2	12.6M	48.3	8.55	69.5

Tab. C4. Number of non-commuting trips per day on average (M).

Trip Distance	Weekday				Weekend day			
	active	car	transit	All	active	car	transit	all
0-10	42.5	68	8.77	119	37.1	66	5.94	109
10-20	0.093	11	1.07	12.1	0.289	13.3	0.527	14.1
20-40	0.128	5.48	0.441	5.94	0.038	6.73	0.592	7.36
40-80	0.002	2.02	0.204	2.23	0.069	3.62	0.188	3.87
80-160	0.004	1.22	0.155	1.38	0.01	2.68	0.096	2.79
160-320	0.002	0.586	0.101	0.688	0.038	1.26	0.216	1.52
320+	42.54	0.537	0.250	0.790	0.008	0.733	0.328	1.07
All	42.6	88.9	11	142	37.6	94.3	7.89	140