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Technological Evolution in the Swiss Bus Fleet from 1940 to 2022: An Inventory and Database for Research Applications

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Abstract: (1) Background: A strategic approach to managing and evolving the bus fleet is essential for optimizing public transportation, improving service efficiency, meeting future demands, and incorporating environmentally friendly technologies. However, country-specific data on fleet composition and evolution are often lacking despite their importance in evaluating technological impacts on the environment, passenger comfort, and driver working conditions. This report describes the creation of the inventory of the Swiss bus fleet and analyzes technological developments in bus vehicles from 1940 to 2022. (2) Methods: We collected the data through a comprehensive mapping study and validated it with Swiss bus companies and experts from the Federal Office of Transport. Vehicle approval forms were used to extract technical data. Buses were sorted by brand and model. For each bus model, 58 technical characteristics were documented in a database. A latent class analysis (LCA) was conducted to classify the buses according to their technological characteristics. (3) Results: The inventory comprises 891 bus models, classified into four groups representing different generations. The predominance of thermal buses and the emergence of hybrid and electric buses since 2010 were noticed. (4) Conclusions: This inventory tracks bus technology evolution and highlights potential implications for driver occupational exposure and environmental impact assessment.

Keywords: latent class analysis; mapping study; bus features; technological evolution

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1. Introduction

Public bus transportation is essential for promoting sustainable urban development, reducing traffic congestion, and providing accessible and affordable mobility options for all community members. A strategic approach to the composition and evolution of the bus fleet is crucial for optimizing public transportation, enhancing service efficiency, and meeting future demand while integrating environmentally friendly technologies. These technologies should also benefit human health and well-being from public and occupational health perspectives. Occupational health studies have shown that bus drivers are exposed to many hazards associated with ill health [1–3]. For example, exposure to particulate matter (PM) is associated with cancer in bus drivers [1,2,4], whole-body vibration is linked to musculoskeletal disorders [1–3,5], and noise to hearing loss and tinnitus [1–3,6,7]. Intriguingly, no study assessed the impact of technological improvement in bus vehicle conception on occupational exposure, although some studies considered the effect of energy consumption and pollutant emissions. Compared to traditional diesel buses, hybrid bus technology, which combines an internal combustion engine with an electric motor, has been shown to reduce overall environmental impact, making them an essential contributor to sustainable and environmentally friendly urban transport systems [8,9]. However, they have higher emissions than fully electric buses [10]. The production of electric buses has a more significant impact on the environment than hybrid and diesel buses [8]. Still, electric buses produce zero tailpipe emissions such as nitrogen oxides (NO_x) or carbon dioxide (CO_2) [11]. However, their overall environmental impact depends on the source of electricity used for charging; even in regions where electricity is primarily from green sources, the emission reduction could reach 90%, and in areas where electricity production is based mainly on fossil fuels, electric buses still have a lower environmental impact than conventional diesel buses [12]. The operation of electric buses is also considered less costly for the bus companies and, therefore, more sustainable [11,13]. The various studies mentioned above focused on engine types. Yet, other new technologies accompanying the evolution of motorization are not commented on. Furthermore, the impact of these new technologies on safety, vehicle comfort for passengers, or bus drivers' health remains unknown and deserves investigation.

Throughout the history of public road transport, numerous changes have been made to enhance driver and passenger safety and comfort. Those changes include the design of vehicles, which has evolved considerably since the first buses, which appeared in the 19th century. However, information on how national bus fleets evolved during the last decades is rarely available to occupational and environmental health researchers. Having such information would enable assessments of the impact of the technological evolution of buses, not only on the environment but also on the working conditions of bus drivers. Such information would also fill the gap in exposure data needed for epidemiological studies, for example, on the ill health of bus drivers [14,15].

This study examined the technological evolution of vehicles used in Switzerland since 1940 by making an exhaustive inventory of the Swiss bus fleet. Th information is presented as an open-source database for scientific applications.

2. Materials and Methods

2.1. Data Acquisition

We conducted a mapping study [16] to collect data on bus models and the technical features of buses in service between 1980 and 2022 in Switzerland. It corresponds to buses constructed between the 1940s and 2022, as some models were used for 40 to 50 years. We scrutinized the websites of the bus companies and associations of transport, bus lovers, and collectors, as well as the museums of transport that are located in Switzerland. We also audited some bus companies with the help of the Swiss Public Transport Union (UTP). The bus characteristics were chosen based on expert advice (UTP, bus drivers). It included all parameters that could influence bus drivers' exposure to physical and chemical hazards (e.g., noise, vibration) and ergonomic constraints. We also considered features that could make driving or using vehicles easier, such as heated windscreens, reversing cameras, or rain and light sensors. To this, we added data on vehicle emissions (e.g., hydrocarbons, CO), enabling us to study the evolution of air pollution production. All data were tabulated in an Excel file where all the identified bus models were sorted per company (on separate sheets) and per bus brand in chronological order of technological development. Internal coherence and consistency checks were performed to identify potential discrepancies and missing data.

Then, we contacted seventy-four Swiss bus companies and asked them to verify and complete their personalized inventory. We also asked experts from the UTP, associations, and the Federal Office of Transport to check the completeness and correctness of this inventory. Finally, we looked at vehicle homologation forms available online to check the quality of the technical data collected [17]. Then, we summarized the bus characteristics using bus models.

2.2. Data Analysis

Based on a qualitative review of the collected data and experts' knowledge of bus technological innovation, we identified the technological breakthroughs introduced in bus vehicle construction over the last 80 years. These breakthroughs and changes in the fleet composition were summarized as a timeline. This timeline enabled a visual categorization of bus generations or bus typology, which we further confirmed using latent class analysis (LCA). The LCA is a statistical method used to identify subgroups within a population (here, the Swiss bus fleet) based on the individuals' (here, the bus models) responses to a set of observed variables (here, the bus features). In the LCA, the population is assumed to be heterogeneous and can be divided into several distinct unobserved (latent) classes. The LCA is well adapted when there is the assumption that there are unobserved groupings in the data, but the exact number and nature of these groups are unknown [18,19]. The LCA is adapted for categorical data [18,19].

We assume that there is an unknown grouping based on the bus characteristics (categorical) in the Swiss bus fleet. Therefore, we performed an LCA to uncover the hidden structure of our inventory and check whether a typology (classification) based on bus technical characteristics is relevant for use in other analyses. We used the R (v.4.3.2) package poLCA (v.1.6.0.1) [20] to conduct the LCA. We used the maximum likelihood-based estimation. We built each latent class model using different "response~predictor" formulae, with and without the year of construction of the bus as the covariate, and several classes ranging from 2 to 10. We derived six models from the bus typology mentioned above (Figure S1) (set of variables 1 and 2) and directed acyclic graphs (DAGs) [21] (Figure S2) (set of variables 3 to 6) to highlight bus technological characteristics that could influence exposure to noise and whole-body vibration as a criterion of ergonomics. The models are based on the six sets of independent variables shown below.

1. Motorization, gearbox, engine position, and power steering.
2. Motorization, gearbox, engine position, and power steering, with the decade of construction as a covariate.
3. Motorization, engine position, soundproofing, suspension, and shock absorber.
4. Motorization, engine position, soundproofing, suspension, and shock absorber, with the decade of construction as a covariate.
5. Motorization, gearbox, engine position, soundproofing, suspension, shock absorber, power steering, dimension, and air conditioning.
6. Motorization, gearbox, engine position, soundproofing, suspension, shock absorber, power steering, dimension, and air conditioning, with the decade of construction as a covariate.

We developed and compared 54 latent class models (six formulae for nine possible classes). For each formula, the best latent class model was selected according to the quality of the latent class models estimated by the Bayesian information criterion (BIC), the Akaike information criterion (AIC), and the consistent Akaike information criterion (CAIC), with lower information criterion indicating the better fit [22,23]. We also reviewed a classification diagnostic, the entropy, which indicates how accurately the model defines classes [24,25]. A cutoff criterion of 0.8 is often used by convention [18]. Then, we derived rules based on previous knowledge and assumptions to help choose the final model. The goal was to have exploitable groups for further studies. We used the following rules to select the final latent class model:

- Thermal vehicles and electric vehicles must be in different groups.
- The oldest and the newest vehicles must be in different groups.
- Bus models belonging to the same model family (e.g., Volvo B 10M, including Volvo B 10 M low floor, Volvo B 10 M 100 kW, Volvo B 10 M 201 kW) must be in the same group.
- Latent classes should contain at least one bus (no empty classes).

3. Results

3.1. Swiss Bus Fleet Inventory and Database

The Swiss bus fleet inventory included 891 bus models constructed between 1940 and 2022 that were in operation between 1980 and 2022. It was impossible to consider the number of vehicles per bus model as there would be too many missing values for the out-of-order bus models. Therefore, the distribution presented below corresponds to the structure of the bus model inventory and not the vehicles in the Swiss bus fleet. Figure 1 summarizes the proportion of motorization type of bus model per size of bus models. It gives an insight into the composition of the bus model inventory. Articulated bus models (17 to 20 m buses with one joint, also known as pivot axis, carrying up to 150 passengers) account for 11.3%

of the bus model inventory, bi-articulated bus models (24 to 30 m buses with two joints capable of carrying up to 200 passengers) for 1%, double-decker bus models (buses with two decks carrying between 70 and 100 passengers) for 1.7%, minibus models (buses less than 8 m long carrying up to 30 passengers) for 20.9%, and standard and midibus models (8 to 15 m buses carrying up to 100 passengers) for 65.1%. The motorization types that are the most common across the diverse sizes of bus models are thermal bus models (100% (N = 15) of double-deckers, 99% (N = 184) of minibuses, 92% (N = 534) of standard and midibuses, and 59% (N = 60) of articulated buses). The least common motorization type is dual-mode buses (dual-mode bus: trolleybus or bus equipped with two independent locomotion systems allowing the alternative use of one or the other) as only four models exist, specifically three articulated and one standard and midibus.

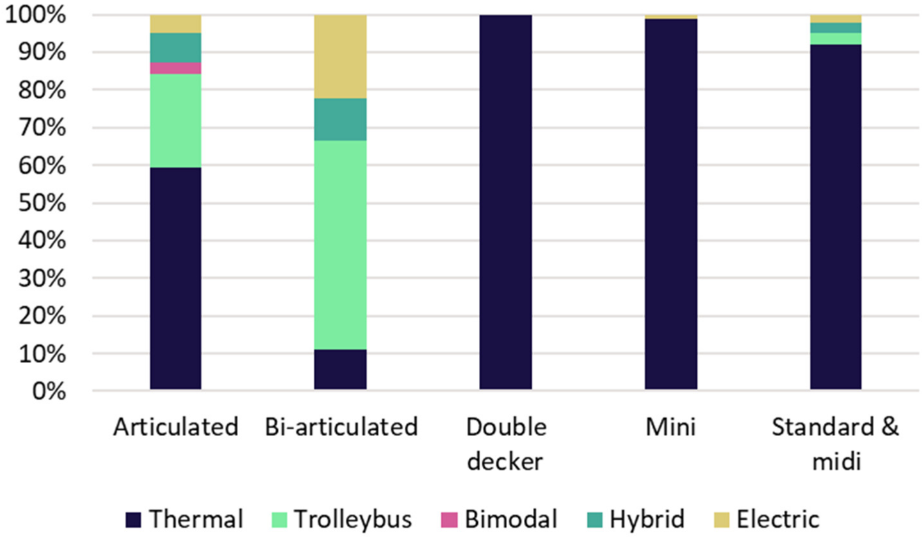

Figure 1. Distribution of the type of bus models according to the size of the bus models. Bimodal: trolleybus or bus equipped with two independent locomotion systems allowing the alternative use of one or the other.

We created an MS Excel database containing the identified 891 bus models of the Swiss fleet and their 58 characteristics. The latter were further divided into additional parameters to be precise with the distribution of specific characteristics such as length (minimum and maximum). Thus, the total number of variables in the database was equal to 73. Among them, we distinguished two types of bus features: fixed features (N = 48), such as engine type or suspension, and company-dependent optional features (N = 10), such as heated windscreens or rain sensors. This database does not contain information on bus companies, region of circulation, or type of route, as most bus models can be used either in regional service or urban service. This database is available at the Unisanté data repository upon request from the authors.

The database comprises 64 brands, the most popular of which are Mercedes-Benz (189 bus models), Volvo (86 bus models), and MAN (86 bus models). These three brands are also the most popular in Switzerland in terms of the number of registered buses. Furthermore, of the 64 brands, only 20 are still active in bus production; this includes Mercedes-Benz, MAN, Volvo, Solaris, Van Hool, and Hess. In addition, seven still active brands stopped bus production, including Citroen, Fiat, and Saurer. The other brands ceased to exist or have been integrated into different brands.

The technical specifications are complete for all vehicles with a type approval certificate, i.e., all thermal, hybrid, and electric buses. Trolleybuses that do not need to be registered do not have a type approval certificate, and their inventory is therefore incomplete for vehicles that do not have a thermal equivalent. We have completed the technical specifications for trolleybuses with a thermal equivalent, e.g., the Volvo B10M (trolleybus and thermal), as they are identical for both bus types except for the engine. Table 1 describes the content of the database, grouping some specific characteristics for more effortless reading (e.g., the ten optional features).

Table 1. Database content and completeness. [1] Features present in all homologation certificates; [2] Features present in some homologation certificates.

Characteristics	Type of Variable	Possible Values, Range of Values	Number of Missing Values N (%)
Model certificates	Nominal	3TA317, 285,001, etc.	57 (6.4)
Brand [1]	Nominal	Mercedes-Benz, Volvo, MAN, Hess, Solaris, Van Hool, etc.	0
Model [1]	Nominal	Citaro, B 10 M, Lion's City M, Swisstrolley, Urbino, A330, etc.	0
Dimension [1]	Nominal	Mini, double-decker, articulated, bi-articulated, standard and midi	0
Type	Nominal	Thermal, trolleybus, hybrid, electric, bimodal	0
Manufacturer [1]	Nominal	Evobus GmbH, Volvo Bus Corporations, MAN Truck and bus, etc.	0
Circulation period (year)	Quantitative	1940–2022	1 (0.1)
Activity [1]	Binary	Inactive, Active	1 (0.1)
Length, width, height (meter) [2]	Quantitative	3.3–25.0, 1.7–2.6, 1.5–4.6	7 (0.8)
Tare weight (kilogram) [2]	Quantitative	1000–26,000	245 (27.5)
Maximal weight (kilogram) [1]	Quantitative	2220–40,000	7 (0.8)
Passenger capacity	Nominal	Extra small, small, medium, large, extra large	0
Trailer	Binary	Yes, no	0
Number of articulations	Quantitative	0–2	0
Drive [1]	Nominal	Rear-wheel, front-wheel, four-wheel	0
Gearbox [2]	Nominal	Automatic, manual, semi-automatic, robotic, continuous/without	0
Power source [1]	Nominal	Diesel, natural gas, catenary, battery, benzine	0
Power (kW) [1]	Quantitative	30–460	25 (2.8)
Cubic capacity (cm^3) [1]	Quantitative	0–15,928	3 (0.3)
Number of cylinders [1]	Quantitative	0, 4, 5, 6, 8	3 (0.3)
Engine (design, model, position) [2]	Nominal	Straight, V-engineFront, hood, center, rear	37 (4.2)
Euro norm [2]	Ordinal	NA, 0–6	0
Suspension [2]	Nominal	Air, springs, Air and spring	0
Shock absorber [2]	Binary	Yes, no	0
Power steering [2]	Nominal	Hydraulic, electrohydraulic, electric, on-demand (hydraulic), none	0
Retarder [1]	Nominal	Yes, no, on demand	21 (2.4)
ESP [1]	Nominal	Yes, no, on demand	2 (0.2)
Bus options (heated windshield, rain sensors, etc.)	Nominal	Yes, no, on demand	144 (16.2)
Air conditioning	Nominal	Yes, no, on demand	0
Soundproofing [1]	Binary	Yes, no	0
Brake assist [2]	Nominal	Yes, no, on demand	0
Floor height	Nominal	Low, high, high, or low	0
Emissions (NO_x, CO, etc.) [2]	Quantitative	0–17,100	210 (23.6)

To obtain a first idea of the structure of the Swiss bus fleet, we derived a typology (classification) from the data based on the engine type (motorization), gearbox, engine location, and driver assistance. The Supplement Material (Figure S1) summarizes this typology. This typology focuses on standard and midibuses, representing most bus models (60%) in Switzerland. Moreover, the design of most articulated bus models is based on the equivalent standard bus model. Therefore, articulated buses have the same or a very similar driver's cabin and the same technologies as their equivalent standard bus. Overall, 31 bus types were present on Swiss roads; thermal vehicles represent more than half (16) of those types. Today, the most common type of bus model is a thermal bus with an automatic gearbox, a rear-mounted engine, and hydraulic assistance.

3.2. Technological Evolution of the Swiss Bus Fleet

Figure 2 presents the timeline of the technological evolution of buses and trolleybuses from the 1940s to 2022. The history of Swiss buses began during the 19th century with horse-drawn omnibuses. Carpostal, the largest bus company in Switzerland, opened and operated the first bus service (motorized vehicle) in 1906 in the Canton of Berne. The vehicles were small, with a front-mounted fuel oil engine and a manual gearbox. Then, in 1912, the first trolleybus line was in operation in a Western region of Switzerland (Fribourg). The first trolleybuses had an electric motor and an auxiliary thermal engine. Swiss brands manufactured the first buses and trolleybuses. New technological innovation arrived after World War II: semi-automatic and later automatic gearboxes. In addition, fuel diversified from fuel oil to diesel and natural gas. By the early 1950s, new buses were equipped with hydraulic assistance, making it easier to turn the steering wheel. The engine then pulled away from the driver, first to the middle of the vehicle and then to the rear. Articulated models began appearing in the late 1950s, first on trolleybuses and then on thermal buses. The 1970s saw the arrival of foreign brands, including Volvo and Mercedes-Benz, on Swiss soil. These new brands brought a new type of vehicle, double-decker buses, and the decline of Swiss brands. At the end of the 1970s, the first steps were taken to reduce noise levels, and engine compartments were soundproofed.

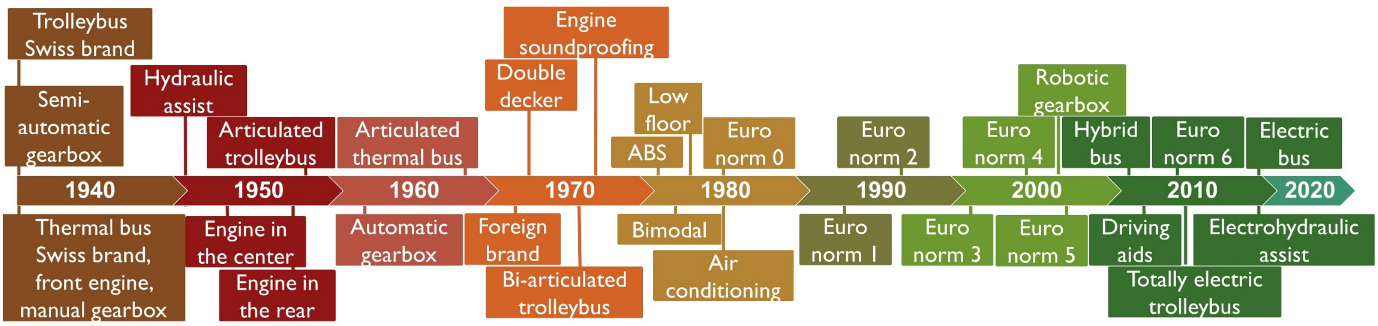

Figure 2. Timeline of the technological evolution of the Swiss bus fleet from the 1940s to the 2020s.

The 1980s saw the introduction of dual-mode vehicles, i.e., vehicles with an electric motor, like trolleybuses, and a second diesel engine. This decade saw the introduction of new technologies such as ABSs (anti-lock braking systems to reduce skidding under heavy braking), air conditioning, and the first EURO standards to limit vehicle emissions. EURO standards followed one another through the 1990s, 2000s, and 2010s. The 2000s saw the introduction of a new gearbox: the robotized gearbox (a hybrid transmission system combining manual and automatic gearboxes). The 2010s were a decade rich in technological evolution. The early 2010s saw the arrival of hybrid buses, with an electric motor and an internal combustion engine, usually diesel, although natural gas versions were also available. Since then, hybrid vehicles have evolved and improved.

At the same time, driving aids were being developed for buses. These included Active Distance Control (ADC) and the Electronic Stability Program (ESP) to stabilize the vehicle's trajectory in critical situations, such as skidding or tipping over on a bend. The following years saw the arrival of battery-powered 100% electric trolleybuses. Then, the first electric buses came onto the Swiss market. However, this new technology was not so new, as electric buses already existed in Switzerland in a mountain resort (Zermatt), as early as

1988. However, they were far less powerful than today's vehicles, reaching a maximum of 20 km per hour (up to 100 km per hour for recent vehicles). These buses were created for Zermatt and not marketed on a large scale, so we do not consider them new technology in the late 1980s. These first e-buses are still in circulation. At the same time, in the late 2010s, electrohydraulic assistance was introduced to replace hydraulic assistance on some vehicles. This technology has been improved but not changed for half a century.

In parallel with the new technologies introduced, new models integrated the Swiss bus fleet to replace the older bus models. Figure 3 summarizes the evolution of the number of bus models in service in Switzerland between the 1940s and 2020. In the 1940s, the bus models in service were standard and midi trolleybus and thermal bus models. The last standard and midi trolleybus model was decommissioned in 2021 after over 80 years of operation. Some standard and midi trolleybus models had been in circulation for 40 years for the oldest models and up to 25 years for the most recent models. A maximum of 13 standard and midi trolleybus models were in service in the 1970s. However, standard and midi thermal bus models are still in use, with 258 bus models in service today, indicating a wide variability in the composition of public transport companies' fleets. Their service life can be as long as 20 years for older models and 15 years for current models. It is also interesting to note that dual-mode bus models were in circulation between 1987 and 2021. There have only been four dual-mode bus models (three articulated and one standard and midi). We can see that at the beginning, there were only a small number of hybrid and electric bus models. Still, this number has risen sharply in recent years to 21 hybrid and 20 electric bus models currently on the road, higher than the number of trolleybus and double-decker models. The first minibus model appeared in 1984, and since then, the number of minibus models has risen to 205 currently on the road.

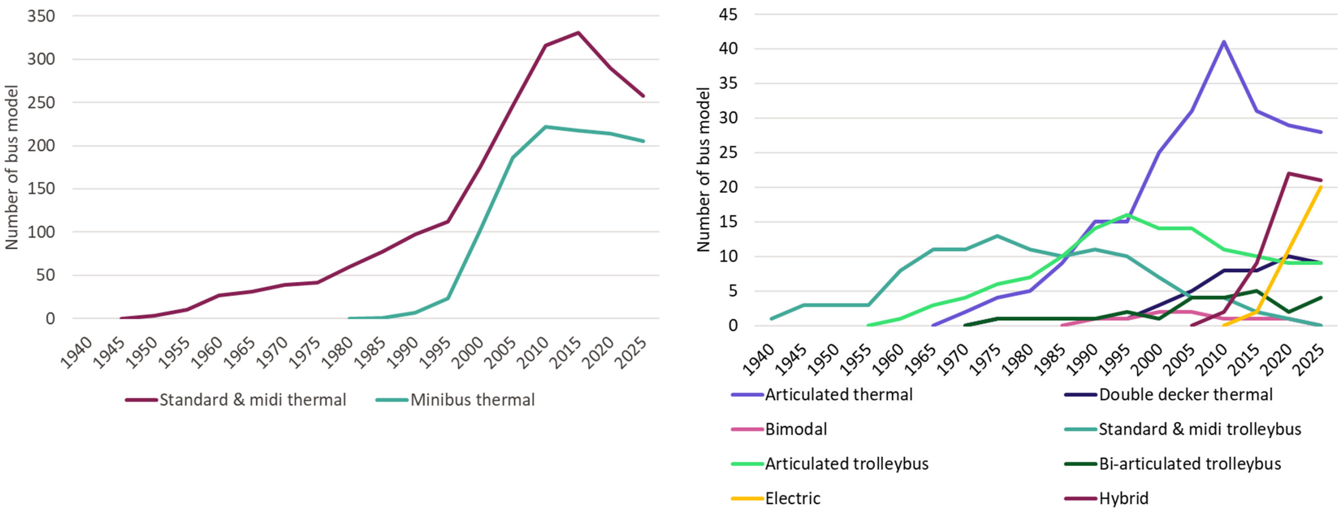

Figure 3. Evolution of the number of bus models (in service for the given period) in the Swiss bus fleet to highlight the integration of technological developments in motorization and bus model size. Left: the two most numerous types of bus models. Right: all the other types of bus models.

3.3. Bus Typology Based on the Latent Class Analysis

The latent class analysis was run on all buses with a complete data set, taking no account of weight, engine design, engine model, options, or emissions. In addition, bus models with power steering set as "on-demand" (19 bus models) were set as two models, one with hydraulic assistance and the other without. The sample corresponds to 873 vehicles (854 unique bus models, corresponding to 96% of the bus fleet). Table 2 presents the bus features of the sample.

Table 2. Characteristics of the bus models from the Swiss bus inventory (1940–2022) which were included in the latent class analysis.

Bus Features	Number	%
Total	873	100
Motorization		
Dual-mode	3	0.3
Electric	20	2.3
Hybrid	25	2.9
Thermal	812	93.0
Trolley	13	1.5
Engine position		
Hood	184	21.1
Front	43	4.9
Center	86	9.9
Rear	560	64.1
Gearbox		
Automatic	412	47.2
Continuous/without	38	4.4
Robotic	84	9.6
Semi-automatic	21	2.4
Manual	318	36.4
Power steering		
None	47	5.4
Hydraulic	786	90.0
Electrohydraulic	30	3.4
Electric	10	1.1
Soundproofing		
No	197	22.6
Yes	676	77.4
Suspension type		
Air	596	68.3
Air and spring	91	10.4
Spring	186	21.3
Shock absorber		
No	31	3.6
Yes	842	96.4
Dimension		
Articulated	82	9.4
Bi-articulated	7	0.8
Double-decker	15	1.7
Mini	199	22.8
Standard and midi	570	65.3
Air conditioning		
No	231	26.5
Yes	642	73.5
Decade of construction		
1940	3	0.3
1950	18	2.1
1960	23	2.6
1970	25	2.9
1980	72	8.2
1990	171	19.6
2000	300	34.4
2010	239	27.4
2020	22	2.5

The fitness and diagnostic criteria are summarized in Supplementary Table S1. According to the BIC, the best number of classes was between 3 and 7, depending on the model. However, according to the CAIC, the best number of classes was between 5 and 8. According to the AIC, the best number of classes was between 5 and 9, depending on the model. Models 4 and 6 were the only models for which the information criteria (IC) produced the same best number of classes. However, we also verified the model of the second smallest IC. The latent class model fulfilling most of our assumptions and criteria was model 4 with four classes. It meant that the LCA made it possible to separate the bus fleet into four groups based on motorization, engine position, soundproofing, suspension, and shock absorber, with the decade of construction as a covariate.

Furthermore, its entropy was 0.97, above the informal cutoff of 0.8 [18], and the smallest class size was 5.4%. Furthermore, the different classes made conceptual sense. Knowing the composition of the classes (Figure 4), we have assigned each vehicle in the inventory to a corresponding class. Table 3 summarizes the composition and distribution of the four latent classes in the Swiss bus inventory. The latent class 1 is the most common (63%), corresponding to the thermal buses of all dimensions, with a small number of minibuses (0.3%).

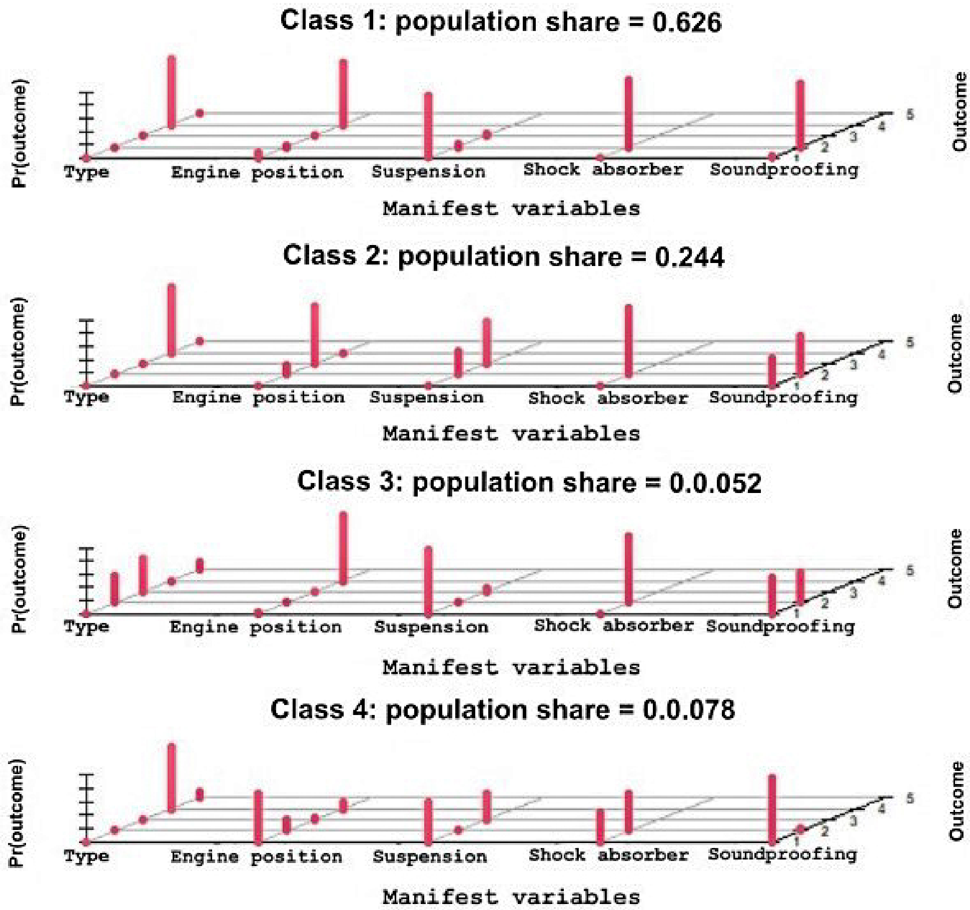

Figure 4. Latent class analysis results. The Pr(outcome) corresponds to the likelihood of being part of a class according to the value (outcome) of the independent variables, which correspond to bus features (manifest variables in the figure). The population share corresponds to the proportion of buses from the sample in a specific class; for example, 62.6% of the buses in the sample are in class 1. All variables were factorized as the latent class works with numerical values (outcome). Type: 1 = Bimodal, 2 = Electric, 3 = Hybrid, 4 = Thermal, and 5 = Trolleybus. Engine position: 1 = Center, 2 = Front, 3 = Hood, and 4 = Rear. Suspension: 1 = Air, 2 = Air and springs, and 3 = Springs. Shock absorber: 1 = No, and 2 = Yes. Soundproofing: 1 = No, and 2 = Yes.

Table 3. Summary of the main characteristics present in each latent class and their distribution in the Swiss bus fleet.

Characteristics	Class 1	Class 2	Class 3	Class 4
Motorization	Thermal	Thermal	Hybrid and electric	Thermal
Engine position	Rear	Hood	Rear	Center
Soundproofing	Yes	Yes, no	No, yes	No
Shock absorber	Yes	Yes	Yes	Yes, no
Suspension	Air	Springs, air and springs	Air	Air, springs
Construction decade	1970–2020	1980–2020	2000–2020	1940–1980
Dimension	Standard and midi, articulated	Mini	Standard and midi, articulated	Standard and midi
Number (%) of corresponding buses in Swiss bus fleet	560 (63)	201 (23)	48 (5)	82 (9)

Conversely, the latent class 3 is the least common (5%), and it corresponds to the electric and hybrid buses but omits minibuses. The latent class 2 comprises minibuses and small midibuses (less than 8.6 m). Finally, the latent class 4 corresponds to the old thermal buses from the 1940s to the 1980s.

4. Discussion

4.1. Latent Class Analysis as a Tool for Understanding Bus Generations and Technological Evolution

Latent class analysis, more often used in marketing or medicine, helps understand the structure of the bus model inventory. The bus model inventory is divided into four groups of latent classes influenced by time (Figure 4 and Table 3). Although the structure of the buses has remained unchanged for decades, numerous technological evolutions have only concerned specific elements or additions with little influence on driving and operating the bus. Three of the four bus classes are predominantly thermal vehicles. Furthermore, the latent classes 1, 3, and 4 can be interpreted as distinct bus generations. For example, latent class 4 corresponds to the oldest thermal buses, latent class 1 involves currently used thermal buses, and latent class 3 corresponds to the new technologies, hybrid and electric buses, often based on an existing thermal model. These new technologies are seen as a solution for limiting emissions from public transport and are an integral part of Switzerland's plan to reduce CO_2 emissions. The latent class 2 corresponds to minibuses with a different design than standard, articulated, or bi-articulated buses. It makes sense that minibus have their latent class. The LCA allows a classification of the buses into four groups based on statistics. Each group is composed of similar buses with similar technologies, which means we can expect that they have similar advantages and disadvantages, as well as similar exposure to physicochemical hazards or ergonomic constraints. The latent class could be used as a variable in analysis to either model data or group data, for example, to compare the energy efficiency or the CO_2 emission. In comparison, the typology (Figure S1) created based on the classification method had 33 groups, making it difficult to use in analysis. The LCA allows the highlight of a practical grouping considering the manufacturing year.

4.2. Study Outputs and Internal Consistency

The composition of the Swiss bus inventory is not the same as the Swiss bus fleet. The Swiss bus fleet corresponds to all the buses used in public transport, meaning that the number of buses per model must be known. No such inventory exists; there are mainly data on the type of vehicle (size, motorization type, and age), and the exact models are unknown. For example, trolleybus models accounted for 2% of the bus models in circulation in 2020, corresponding to 8% of the total number of buses in circulation in Switzerland. This means that public transport companies employing trolleybuses use the same trolleybus models. Indeed, the most popular trolleybuses in Switzerland are Hess trolleybuses, such as the Swisstrolley 5.

On the other hand, minibuses accounted for just 6% of the total number of buses on the road in 2020, but 36% of the models are in the inventory. This means that bus companies use a wide variety of models. The bus inventory does not specify the number of buses per model because there is too much uncertainty, and there would be many missing values. The number of old buses per model is not reliably found. The bus homologation form registers only concern the recent vehicles (1990–2000). Trolleybuses do not have a registration card, so it is impossible to know their exact number. In addition, some models of buses used only for regional service are the same as transport coaches. Minibuses are also problematic because they are frequently used for private transport, such as for retirement homes. Indeed, the number of minibuses per model indicated in the approval forms includes public and private buses.

Furthermore, we did not include autonomous buses in our inventory as they were withdrawn from circulation after testing in Switzerland. Only a few cities tested autonomous minibuses for less than 10 km bus routes and were not satisfied with their tests.

There are few hybrid and electric bus models on Swiss roads compared with diesel bus models. This can be explained by several factors that are present in other countries. On the one hand, the acquisition cost of these vehicles is higher than that of diesel buses [26], as are the costs associated with infrastructure modifications, such as recharging systems for electric buses. Still, the operational and maintenance costs are lower than diesel buses [26,27]. On the other hand, the range of electric buses is often more limited than internal combustion buses, requiring regular recharging throughout the day [27]. Another explanation for the low number of hybrid or electric bus models is that in Switzerland, the average lifespan of a diesel bus is 10 to 15 years, while that of a trolleybus can reach 20 years. In the past, trolleybuses were in service for 40 years, and thermal buses for up to 20 years. It is, therefore, possible to wait a decade or more between the appearance of a new technology, such as hybrid engines, and its democratization within the Swiss bus fleet.

The timeline (Figure 2), showing technological innovations implemented since 1940, is data-driven and specific to Switzerland. We drew it based on the Swiss bus fleet inventory, not the literature. New technologies might have appeared earlier or later in other countries. For example, between the 1910s and 1930s, motor coach companies in Chicago and New York (USA) used articulated and double-decker buses imported from France [28]. In comparison, they were used in Switzerland as early as the 1950s and 1970s, respectively, nearly a generation later. This example shows that the development of a bus fleet depends on the country's bus market's needs and offers.

4.3. Bus Inventory Comparison

We found bus inventories online that were different from ours as they give the number of buses for a brand or fuel type. The vehicle database provided by the American Public Transportation Association (APTA) [29] is extensive. It includes information on manufacturers, bus models, and their characteristics, such as floor height, number of seats, and dimensions. However, it is provided by a bus agency. The database format is convenient for information but might not be convenient for research. There is also the database from the Italian National Registration Organization (ACI) [30] containing the number of buses per brand and per period. However, we did not find a table with bus model information. To our knowledge, this is the first Swiss bus model inventory in the scientific literature. Therefore, comparing this work with the other scientific literature is impossible.

4.4. Study Strengths

LCA is a probabilistic model that identifies unobserved subgroups in categorical data, allowing for more flexible cluster shapes and providing probabilistic membership, which offers more profound insights into the data structure. Other clustering methods, such as K-means and hierarchical clustering, were less adapted for grouping bus models. K-means requires the number of clusters to be predefined. It assumes spherical clusters, which can limit its applicability. Hierarchical clustering is computationally intensive for large datasets and sensitive to noise and outliers [31], which could occur in the bus model inventory. The LCA allows the structure of the bus inventory to be highlighted in four practical groups.

Forty percent of companies, including the largest ones, responded to our requests and shared their current and historical bus inventories. If we missed one or more bus models, the potentially missing models would not be widespread in Switzerland.

4.5. Study Limitations

LCA can be complex, computationally demanding, and requires large sample sizes for stable estimation [18,32]. We used LCA to understand the underlying structure of the Swiss bus inventory as we did not know the class number and expected to have outliers. Using LCA to define the bus classification has some limitations. Proper class assignment cannot be guaranteed as the assignment is based on probabilities [33]. Therefore, misclassification might occur. We reviewed all bus models in each latent class to ensure proper classification and consulted experts, such as bus drivers and UTP members when needed to reduce the likelihood of misclassification. When looking at the data, the final model appears more straightforward and exploitable for future analysis. The other models tended to mix electric and thermal buses and old and new buses, which was the opposite of our criteria and knowledge. If misclassification occurred, it would probably be for bus models in class 1 or 4, constructed in the 1970s (Table 3), as the two classes overlap and can be interpreted as consecutive bus generations.

Although the inventory is based on buses present in Switzerland, since the 1980s, most bus models have been from foreign manufacturers, notably German, Swedish, and Polish, to name but a few. This means that it corresponds to the buses in Europe and that the technological evolution, which may differ by a few years from one country to another, should be similar in Europe. Consequently, the latent classes should be the same for most European bus fleets. However, it is not possible to compare our work to another inventory.

4.6. Examples of Potential Applications

This inventory of bus models is a basis for further studies requiring knowing the technical characteristics of buses and the variety of bus models in circulation from 1940 through 2022. We offer some examples of the use of bus model inventory in different areas.

The inventory could be used to create a bus exposure matrix (BEM) [34]. The BEM is analogous to Job Exposure Matrices (JEMs), which are tools used to assess and categorize exposure levels to various hazards or risk factors that employees might face in their jobs. JEMs provide a structured way to evaluate potential risks based on job functions and historical data [35]. The BEM contains the bus models as an identifying variable (row) and the corresponding occupational exposure, such as noise, whole-body vibration, and electromagnetic fields (column). To create the BEM, we must select representative bus models to measure the chosen occupational exposure. Then, the exposure values would be modeled using bus technical characteristics to extend them to the whole bus fleet. Knowing the bus models a bus driver operates makes it possible to estimate the corresponding occupational exposure and use it in epidemiological studies. The BEM could also be used as an information tool to compare bus models and bus drivers' exposure to physicochemical hazards.

The inventory can also be used to study the evolution of the bus cabin design and to elaborate quantitative or semi-quantitative scores corresponding to ergonomic constraints (e.g., seat height and dashboard accessibility). Such a scoring could inform bus companies' knowledge and ergonomic risk assessments and help decide upon accompanying measures to reduce the risks of musculoskeletal diseases [36–38] and bus drivers' fatigue [39–42].

Another use of the inventory could be the study of the pollution emission in the bus fleet based on the homologation forms. Knowing the precise vehicle by model would be necessary to determine the bus fleet's emissions at a given time. This inventory can also be used to study the effect of introducing hybrid and electric buses on fuel consumption and emissions of CO_2, fine particles, etc., or to study the fuel consumption using actual data or simulation.

5. Conclusions

The bus database tabulates 58 technical features of 891 bus models constructed between 1940 and 2022. This database is available upon request on the Unisanté depository under the name of the project: *Stratégie Energétique et Santé (SENS)*. It constitutes a valuable resource for studying the evolution of bus fleets at the national level and in neighboring countries. The bus inventory and its technical database will enable an assessing of the environmental impact and bus drivers' occupational exposures to physical, chemical, and ergonomic hazards.

It will improve the quality of epidemiological studies assessing the relationship between occupational and environmental exposure and health outcomes in bus drivers and general populations. Moreover, the database also captures the hybridization and electrification of the Swiss bus fleet, reflecting efforts to enhance the sustainability of the public transport system and reduce emissions. In addition, the bus inventory helps understand the integration of new technologies in bus fleets. Therefore, it can inform other studies and research questions, assessing the impact of technological innovation in bus conception on population mobility, air quality, or socioeconomic development.

Supplementary Materials: The following supporting information can be downloaded at https://www.mdpi.com/article/10.3390/su16198537/s1: Figure S1: The typology of the standard and midi bus of the Swiss bus fleet to highlight the variety of bus models existing in Switzerland; Figure S2: DAGs of the possible influence of bus features on noise and vibrations; Table S1: model fit criteria and diagnostic criteria of the latent class analysis.

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References

1. Tse, J.; Flin, R.; Mearns, K. Bus Driver Well-Being Review: 50 Years of Research. *Transp. Res. Part F Traffic Psychol. Behav.* **2006**, *9*, 89–114. [CrossRef]
2. Schneider, E. *OSH in Figures: Occupational Safety and Health in the Transport Sector—An Overview*; European Agency for Safety and Health at Work: Bilbao, Spain, 2011.
3. Kompier, M.A.J.; Di Martino, V. Review of bus drivers'occupational stress and stress prevention. *Stress Med.* **1995**, *11*, 253–262. [CrossRef]

4. Merlo, D.F.; Stagi, E.; Fontana, V.; Consonni, D.; Gozza, C.; Garrone, E.; Bertazzi, P.A.; Pesatori, A.C. A historical mortality study among bus drivers and bus maintenance workers exposed to urban air pollutants in the city of Genoa, Italy. *Occup. Environ. Med.* **2010**, *67*, 611–619. [CrossRef]
5. Lewis, C.A.; Johnson, P.W. Whole-body vibration exposure in metropolitan bus drivers. *Occup. Med.* **2012**, *62*, 519–524. [CrossRef]
6. Alizadeh, A.; Etemadinezhad, S.; Charati, J.Y.; Mohamadiyan, M. Noise-induced hearing loss in bus and truck drivers in Mazandaran province, 2011. *Int. J. Occup. Saf. Ergon.* **2016**, *22*, 193–198. [CrossRef]
7. Bruno, P.S.; Marcos, Q.R.; Amanda, C.; Paulo, Z.H. Annoyance evaluation and the effect of noise on the health of bus drivers. *Noise Health* **2013**, *15*, 301–306. [CrossRef]
8. Zhao, E.; Walker, P.D.; Surawski, N.C. Emissions life cycle assessment of diesel, hybrid and electric buses. *Proc. Inst. Mech. Eng. Part D J. Automob. Eng.* **2022**, *236*, 1233–1245. [CrossRef]
9. García, A.; Monsalve-Serrano, J.; Sari, R.L.; Tripathi, S. Life cycle CO_2 footprint reduction comparison of hybrid and electric buses for bus transit networks. *Appl. Energy* **2022**, *308*, 118354. [CrossRef]
10. Dulce, F.; Murillo-Hoyos, J.; Caicedo, E. Comparative analysis of the performance, environmental impact, and costs of electric, combustion, and gas buses in an operating context of a mid-sized city of an emerging country. *Transp. Res. Interdiscip. Perspect.* **2024**, *25*, 101113. [CrossRef]
11. Borén, S. Electric buses' sustainability effects, noise, energy use, and costs. *Int. J. Sustain. Transp.* **2020**, *14*, 956–971. [CrossRef]
12. Lubecki, A.; Szczurowski, J.; Zarębska, K. A comparative environmental Life Cycle Assessment study of hydrogen fuel, electricity and diesel fuel for public buses. *Appl. Energy* **2023**, *350*, 121766. [CrossRef]
13. López, C.; Ruíz-Benítez, R.; Vargas-Machuca, C. On the Environmental and Social Sustainability of Technological Innovations in Urban Bus Transport: The EU Case. *Sustainability* **2019**, *11*, 1413. [CrossRef]
14. Remy, V.F.M.; Canu, I.G. The impact of the SARS-CoV-2 pandemic on health and working conditions of Swiss bus drivers. *J. Transp. Health* **2023**, *32*, 101683. [CrossRef]
15. Remy, V.F.M.; Canu, I.G. Healthy Bus Drivers, Sustainable Public Transport: A Three-Time Repeated Cross-Sectional Study in Switzerland. *Int. J. Public Health* **2023**, *68*, 1605925. [CrossRef]
16. Cooper, I.D. What is a "mapping study?". *J. Med. Libr. Assoc. JMLA* **2016**, *104*, 76–78. [CrossRef]
17. Motoriker, S. Motoriker Typenscheine.ch by Motoriker. Typenscheine.ch. 2024. Available online: https://typenscheine.ch/fr (accessed on 1 May 2024).
18. Weller, B.E.; Bowen, N.K.; Faubert, S.J. Latent Class Analysis: A Guide to Best Practice. *J. Black Psychol.* **2020**, *46*, 287–311. [CrossRef]
19. Hagenaars, J.A.; McCutcheon, A.L. *Applied Latent Class Analysis*; Cambridge University Press: Cambridge, UK, 2002.
20. Linzer, D.A.; Lewis, J.B. poLCA: An R Package for Polytomous Variable Latent Class Analysis. *J. Stat. Softw.* **2011**, *42*, 1–29. [CrossRef]
21. Tennant, P.W.G.; Murray, E.J.; Arnold, K.F.; Berrie, L.; Fox, M.P.; Gadd, S.C.; Harrison, W.J.; Keeble, C.; Ranker, L.R.; Textor, J.; et al. Use of directed acyclic graphs (DAGs) to identify confounders in applied health research: Review and recommendations. *Int. J. Epidemiol.* **2020**, *50*, 620–632. [CrossRef]
22. Nylund, K.L.; Asparouhov, T.; Muthén, B.O. Deciding on the Number of Classes in Latent Class Analysis and Growth Mixture Modeling: A Monte Carlo Simulation Study. *Struct. Equ. Model. A Multidiscip. J.* **2007**, *14*, 535–569. [CrossRef]
23. Vermunt, J.K. Latent class analysis of complex sample survey data: Application to dietary data. *J. Am. Stat. Assoc.* **2002**, *97*, 736–737.
24. Wang, M.-C.; Bi, X.; Ye, H.; Yang, W. Performance of the entropy as an index of classification accuracy in latent profile analysis: A Monte Carlo simulation study. *Acta Psychol. Sin.* **2017**, *49*, 1473–1482. [CrossRef]
25. Celeux, G.; Soromenho, G. An entropy criterion for assessing the number of clusters in a mixture model. *J. Classif.* **1996**, *13*, 195–212. [CrossRef]
26. Li, X.; Castellanos, S.; Maassen, A. Emerging trends and innovations for electric bus adoption—A comparative case study of contracting and financing of 22 cities in the Americas, Asia-Pacific, and Europe. *Res. Transp. Econ.* **2018**, *69*, 470–481. [CrossRef]
27. Bakker, S.; Konings, R. The transition to zero-emission buses in public transport—The need for institutional innovation. *Transp. Res. Part D Transp. Environ.* **2018**, *64*, 204–215. [CrossRef]
28. Allen, J.G.; Levinson, H.S.; Newmark, G.L. Urban motor coach companies of the 1920s and their legacy for transit. *J. Public Transp.* **2022**, *24*, 100024. [CrossRef]
29. Dickens, M. *Public Transportation Vehicle Database—American Public Transportation Association*; American Public Transportation Association: Washington, DC, USA, 2024; Available online: https://www.apta.com/research-technical-resources/transit-statistics/vehicle-database/ (accessed on 15 September 2024).
30. Automobile Club d'Italia. ACI Studi e Ricerche—Open Data. 2024. Available online: https://www.aci.it/laci/studi-e-ricerche/dati-e-statistiche/open-data.html (accessed on 15 September 2024).
31. Kaushik, M.; Mathur, B. Comparative Study of K-Means and Hierarchical Clustering Techniques. *Int. J. Softw. Hardw. Res. Eng.* **2014**, *2*, 93–98.
32. Lanza, S.T.; Rhoades, B.L. Latent class analysis: An alternative perspective on subgroup analysis in prevention and treatment. *Prev. Sci.* **2013**, *14*, 157–168. [CrossRef]
33. Muthén, B.; Muthén, L.K. Integrating Person-Centered and Variable-Centered Analyses: Growth Mixture Modeling with Latent Trajectory Classes. *Alcohol. Clin. Exp. Res.* **2000**, *24*, 882–891. [CrossRef]

34. Remy, V.F.M.; Innocent, G.; Vernez, D.; Guseva Canu, I. Bus-Exposure Matrix, a Tool to Assess Bus Drivers' Exposure to Physicochemical Risks. 2024; *submitted*.
35. Guseva Canu, I.; Tell-Lamberton, M. Traçabilité et évaluation rétrospective des expositions. In *Construire en Permanence la Prévention des Cancers Professionnels*; Hery, M., Goutet, P., Eds.; EDP-Scienses: Paris, France, 2015; p. 259.
36. Senthanar, S.; Bigelow, P.L. Factors associated with musculoskeletal pain and discomfort among Canadian truck drivers: A cross-sectional study of worker perspectives. *J. Transp. Health* **2018**, *11*, 244–252. [CrossRef]
37. Yasobant, S.; Chandran, M.; Reddy, E. Are Bus Drivers at an Increased Risk for Developing Musculoskeletal Disorders? An Ergonomic Risk Assessment Study. *J. Ergon.* **2015**, *S3*, 1–5.
38. Hanumegowda, P.K.; Gnanasekaran, S. Prediction of Work-Related Risk Factors among Bus Drivers Using Machine Learning. *Int. J. Environ. Res. Public Health* **2022**, *19*, 15179. [CrossRef] [PubMed]
39. Useche, S.A.; Ortiz, V.G.; Cendales, B.E. Stress-related psychosocial factors at work, fatigue, and risky driving behavior in bus rapid transport (BRT) drivers. *Accid. Anal. Prev.* **2017**, *104*, 106–114. [CrossRef] [PubMed]
40. Makowiec-Dąbrowska, T.; Gadzicka, E.; Siedlecka, J.; Szyjkowska, A.; Viebig, P.; Kozak, P.; Bortkiewicz, A. Climate conditions and work-related fatigue among professional drivers. *Int. J. Biometeorol.* **2019**, *63*, 121–128. [CrossRef] [PubMed]
41. Kim, H.; Jang, T.W.; Kim, H.R.; Lee, S. Evaluation for Fatigue and Accident Risk of Korean Commercial Bus Drivers. *Tohoku J. Exp. Med.* **2018**, *246*, 191–197. [CrossRef]
42. Biggs, H.; Dingsdag, D.; Stenson, N. Fatigue factors affecting metropolitan bus drivers: A qualitative investigation. *Work* **2009**, *32*, 5–10. [CrossRef]