LYON'S TCL: A MODEL FOR EFFECTIVE PUBLIC TRANSIT SYSTEMS

an investigation of public transit implementation

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Lyon's TCL: A Model for Effective Public Transit Systems

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Abstract

Public transit can provide significant value to communities by promoting accessible and efficient transportation, increasing commerce, and encouraging physical fitness. The goal of this project was to analyze the successes and challenges of the *Transports en Commun Lyonnais* (TCL), Lyon's public transit system. We analyzed the TCL's mobility, accessibility, and usability while also considering social, political, economic, and environmental influences. To accomplish this, our team performed archival research to develop background knowledge on urban transportation, gathered quantitative data on Lyon's system via data scraping, conducted semi-structured interviews to synthesize expert opinions, and collected ethnographic data while using the TCL. The data from these sources was combined in a mixed analysis to understand the TCL's organization, user experience, and benefits to its riders. We found some room for improvement in the TCL, such as the lack of a ticketing app for iOS or the lack of integration with regional train lines. However, the TCL demonstrated many characteristics found in other well-developed transit systems, showcasing usability and user-focused design, providing excellent mobility and accessibility, and offering significant reductions in carbon emissions. As such, the TCL provides significant value to its riders and Lyon as a whole, making it a satisfactory model for other similarly sized cities looking to implement or improve their public transit.

Acknowledgments

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Executive Summary

Our goals for this project were to first understand the current expert consensus on what makes a public transit system "good," and then determine if Lyon fits these standards. We studied the history and the current operational development of the Lyon transit system. With these goals in mind, we established three research questions that would guide our preliminary research, and later, our fieldwork in Lyon: How is Lyon's transit system organized? What makes a transit system "good", and does Lyon's system meet these criteria? How do transit systems, in general, benefit their communities, specifically regarding the *Transports en Commun Lyonnais* (TCL)'s support of the Lyon greater metropolitan community?

After completing our initial research before we arrived in Lyon, we developed our thesis statement: By studying how cities incorporate good public transit systems and applying the knowledge to the case of Lyon, it becomes clear that the benefits of Lyon's public transit system offer valuable lessons for understanding the positive effects of transit systems and their design. Additionally, recognizing the challenges within Lyon's system highlights areas for potential improvement for the system altogether.

Our survey of existing literature supports the thinking that public transit systems offer many benefits to communities, including mobility, economic growth, public health, and environmental sustainability. Effective transit design balances cost efficiency, long-term planning, and user-oriented design through usability. Usability of transit is characterized by Levinger and McGehee (2008) as ease of use (How easy is the system to use?), effectiveness (How effective/efficient is the system at providing mobility?), comfort (Do users feel safe? Is it

free of odd smells?), and aesthetics (Is it visually appealing?). Lyon's TCL system exemplifies these design practices.

The development of Lyon's organized transit began in the 1800s with the introduction of privately owned horse-drawn buses. Transportation in the city was privatized until electric trams were integrated into the city and became a benchmark for the future of transit in Lyon. At this time, converting to or constructing new electric lines was expensive and made it possible for all transportation companies in Lyon to be unified under one privately owned authority. All assets of the authority were subsequently purchased by the government-funded company, SYTRAL, and the unified authority was named the TCL, as it is known today. The TCL is also currently expanding and updating its services, including automating metro lines, optimizing bus lines, constructing tramways, and moving to cleaner sources of energy.

To accomplish our objectives, we used four main research methods. Archival research was effective in establishing a strong foundation of background knowledge about public transit. Data scraping of the TCL website provided us with a significant amount of quantitative data on simulated journeys using public transit in Lyon. Semi-structured interviews with local transit officials and urban mobility researchers allowed us to gather and synthesize expert opinions. The ethnographic data collected about the transit system gave us a first-hand account to support data gathered via other means.

During our time in Lyon, we found that the TCL, in most areas, excels as a public transit system. Throughout this project, we found that Lyon's transit system is well-organized administratively, politically, physically, and financially. Keolis operates under the oversight of SYTRAL, which, on behalf of the government, controls funding and project decisions. The political climate in Lyon, particularly under the influence of the Green Party, has positively

shaped the system's development by promoting sustainable and environmentally friendly policies, which has notably increased investment in public transit.

The TCL demonstrates the characteristics of a usable public transportation system as defined previously. In terms of usability, we find that Lyon's transit system is easy to navigate, with multi-modal integration allowing seamless transfers between different transportation modes. The system is accessible to individuals with reduced mobility, and its infrastructure supports a high level of convenience for all users. The system's effectiveness is reflected in its operational reliability and capacity management. Despite occasional delays, the TCL makes significant attempts to ensure that transit vehicles are available and not overcrowded in order to maintain a consistent and efficient service. Comfort is also a priority, with well-maintained amenities, seating areas, and security measures enhancing the user experience. The aesthetics of the stations and vehicles contribute to a pleasant atmosphere, further supporting user satisfaction.

The benefits of Lyon's public transit system extend to commuters, residents, tourists, and the local economy. The system provides significant mobility, facilitating daily commutes and enabling residents to travel for social outings. For tourists, the ease of use and accessibility of the system enhance their experience, encouraging exploration and supporting local businesses. Additionally, English and French are both present on all signage, and the ticketing machines allow users to select from a wide variety of languages. Economically, the transit system facilitates commerce and urban activity with an average of 1.8 million rides per day, making it an essential component of Lyon's infrastructure. This integration of the system is a byproduct of the social and political support that the TCL receives, which have allowed for the costly expansions that have built up a dense network of lines. Due to this density, the 90th percentile distance from residential buildings to the nearest transit station within the city is remarkably low at 252 meters.

Additionally, our statistical analysis showed that public transit usage in Lyon results in substantial CO_2 savings, reinforcing the system's environmental benefits.

Based on our findings, we recommend the creation of a TCL E-Ticket app for iOS, which could expand service to hundreds of thousands of people, and the addition of air conditioning to all cars, which we believe would significantly improve user comfort. Additionally, enhancing integration with regional train lines would enhance the overall ability of the system to provide mobility to its riders. Lastly, the administrative structure of the TCL is scheduled to change in 2025, as Keolis lost its contract to manage the tram and metro lines to RATP, a transit company based in Paris. We are concerned that this change in administration could result in regression of the quality of the system as well as a decrease in political and community support for the system.

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Introduction

According to the American Public Transport Association, “45% of Americans have no access to public transportation” (APTAAdmin, n.d.). Yet, even when Americans do have access to public transit, they often still opt for private transport, despite the higher associated costs, danger, and emissions (Buehler & Hamre, 2015). However, this mentality is slowly shifting: with the investment and technological advancements in the last century, “transit ridership has increased faster than automobile travel since the 1990s.” (Litman, 2024).

Transit benefits the communities it serves in numerous ways. For example, the American Public Transport Association has shown evidence that public transportation can reduce carbon emissions by as much as 90% depending on the system (APTAAdmin, n.d.) as well as “increase public fitness and health.” (Litman, 2024). Therefore, when cities build adequate public transportation, their citizens gain access to efficient travel, see improved public health, reduce carbon emissions, and grow their economy. Simply put, investing in public transportation is crucial in the present day when alternative options are limited or suboptimal.

In response to the need for transportation in dense urban centers, city officials, urban planning groups, and engineers spend a significant amount of time and effort building transit systems that are widely accessible and efficient. The focus of these designs is to create effective systems to transport large groups of people. Public transportation can vary in mode; some are trains that use rails, some are buses that use roads, and some travel through other means such as boats. Some of these transport devices use manmade terrain to conserve physical space, such as subways, tramways, and monorails (Gössling, 2020). To maintain all of these different modes, city planners have to monitor space distribution, economics,

environmental problems, and traffic congestion while adhering to users' social, economic, and personal health (Gössling, 2020). Thus, these groups have continuously adapted their systems to the changing needs of people, the economy, and any external factors that might endanger the longevity of public transit. Today, there are many notable public transit systems worth studying.

A few popular cases of public transit are the systems located in Hong Kong, China; Istanbul, Turkey; and Paris, France. Hong Kong's transport system is widely known for its efficiency, which comes from its fast transport devices and well-connected lines between rapid transit, light rail, and local shuttle services (Mohr et al., 2021). It also ranks highest on the efficiency improvement index since 2021 (Mohr et al., 2021), meaning it had the fastest reduction of general travel time compared to any other city.

This contrasts with Istanbul, which was noted in a subgroup study on the usefulness and convenience of transit after the first peak of COVID-19 for having the highest improvement on the convenience index (Mohr et al., 2021). The convenience index is a summary statistic based on a mixed analysis of transport availability, accessibility, information, time, customer care, comfort, security, and environmental impact (ITF, 2014). The main causes for the increase were likely due to its improved ticketing system (shown in Fig. 1), electronic services, and enhanced ease of use of travel cards and credit card scanners.

Figure 1

Image of the Istanbul Ticketing System

Another notable example of public transportation is the system in Paris. Paris's urban transit planning group primarily desired "to improve traffic safety in Parisian streets and to mitigate noise and environmental pollution." (Mohr et al., 2021, p. 99). This objective was considered while also acknowledging local culture, tourism, and overall physical activity. The system reduced the risk of car accidents by nearly 90% over the last three decades (Mohr et al., 2021), primarily due to enticing people off of private vehicles with a more efficient and safe system that still had access to nearly the entire city. Considering these diverse cases, other municipalities, especially those near these popular cities, can potentially learn and develop better systems. One such city is Lyon, which is this study's focus.

Lyon is the third-largest city by population and second-largest metropolitan area in France, being home to over half a million residents and a plethora of vibrant and diverse cultures (Visit Lyon - Lyon Tourist Office, n.d.). Transportation options for the city's sizable population are plentiful with accessible walkways throughout the city; an expansive network of public buses, trams, subways, and trolleybus systems and numerous roadways serve Lyon's residents (TCL - Transports Communs Lyonnais | TCL, n.d.). The public transportation system in Lyon, the TCL, has operated under many different identities since its conception in the 1800s and historically represents a benchmark for transit systems across the globe (TCL - Transports Communs Lyonnais | TCL, n.d.). As a sort of "secondary" city in comparison with its neighbor, Paris, Lyon stands out in its quality and pace of continued expansion of its offerings to its community. Given these standout qualities, we believe that Lyon is a suitable benchmark for public transportation developments within smaller cities. The Lyon public transit system will be discussed in detail as a case study, showcasing its ability to adhere to efficiency, satisfaction, and organization operability.

To perform a proper case study, thorough research must be conducted on existing literature to ensure new topics are broached while existing topics are expanded on. Carrying out this research requires approaching the topic with direct questions that can later be analyzed from different perspectives for potential problems or areas of interest: "Issues are not simple [...] but intricately wired to political, social, historical, and especially personal contexts." (Stake 2010, pg. 17).

After an initial discussion of future goals, we established the following research questions:

1. What are the benefits of having a “good” public transit system?
2. What are the characteristics of a “good” public transit system?
3. How is Lyon’s transit system organized administratively, politically, physically, and economically?

In our literature review, we first explore why public transit should exist and why it is a public good. We find scholars agree that public transportation is time and cost-efficient for moving large groups of people, spurs economic activity, improves public health, and reduces carbon emissions of transport as a whole. Additionally, we identify the features of transit design to determine what factors distinguish good systems from bad ones. We discuss how good designs balance cost efficiency, long-term planning, and the needs of its users, such as ease of use, effectiveness, comfort, and aesthetics. Finally, after discussing ideals of urban transit design in presenting scholarly consensus, we will outline many positive attributes that allow the Lyon public transportation system to be a beneficial force in the city.

Thus, by studying how cities incorporate good public transit systems and applying the knowledge to the case of Lyon, it becomes clear that the benefits of Lyon’s public transit system offer valuable lessons for understanding the positive effects of transit systems and their design. Additionally, recognizing the challenges within Lyon’s system highlights areas for potential improvement for the system altogether.

Literature Review

What are the benefits of having a well-established public transit system?

Public Transit as a Necessary Utility

Public transit is a necessary service that exists to provide basic mobility for, by circular definition, the public (Levinger & McGehee, 2008). Mobility, as a service, is the "concept that combines different transport modes to offer consumers the possibility to get from A to B in a flexible, personalized, on-demand and seamless way." (Reyes García et al., 2019). A study published in the Berkeley Planning Journal writes, "many people without regular access to automobiles depend on public transit as their main method of transportation. For these 'transit dependents' the continued availability of public mass transit is vital for access to jobs, schooling, medical care, and other necessities of life" (Garrett & Taylor, 2012).

Many areas previously classified as "suburban" are growing in population, becoming more urbanized, and experiencing increased levels of congestion (Shaheen & Cohen, 2018). These increases in congestion lead to increases in traffic accidents, travel time, and fuel use, while also reducing demand by shifting traffic to other highways or even other methods of transportation (US DOT, 2020). This increased congestion and reduced demand lead to a higher level of reliance on public transit systems and allow people to avoid issues such as commercial clustering, land values, and parking (Litman, 2024). Transit becomes more important as cities grow, serving an increasing population of discretionary riders, and in doing so provides more benefits, such as supporting more efficient land use patterns and reducing traffic issues (Litman, 2024). Other current trends such as rising fuel prices, rising road expansion costs, and increasing health and environmental concerns are contributing factors to the growing demand for alternative modes of transportation (Litman, 2024). Thus, the primary

role of public transit is as an alternative method that provides mobility for those who cannot drive or prefer not to (Litman, 2024; Garrett & Taylor, 2012).

Public Transit Spurs Economic Activity

In providing efficient mobility, public transit spurs economic activity. By offering a convenient and affordable service, the public transit system as a whole unlocks opportunities for people who are disadvantaged by low income, social status, or physical disability (Sultana et al., 2021; Litman, 2005; Giuliano, 2005). Additionally, according to the American Public Transportation Association (APTA), for every billion dollars invested annually into public transportation, the annual GDP would grow by more than $1.7 billion and around 30,000 jobs would be created (Weisbrod & Reno, 2009). Similarly, an analysis of the city of Chicago's transit plan estimated an annual return on investment of at least 21%, boosting to over 60% with the adoption of transit-oriented development, which will be explored further in the next section (Litman, 2024).

In addition, it can also be helpful to consider parties outside of the realm of transit. For example, a high-quality transit system could not only generate a decent return on investment but also benefits local businesses. A local restaurant might benefit from the increased pool of available employees and reduced absenteeism from vehicle failures. Increased bus service is negatively correlated with employee turnover rates, letting businesses save by reducing the cost of training new employees (Faulk & Hicks, 2016).

Not only are businesses benefiting economically from public transportation, but individuals are as well. A 2007 report showed that households that own a single vehicle and use accessible public transportation typically spend around 50% as much on transportation as

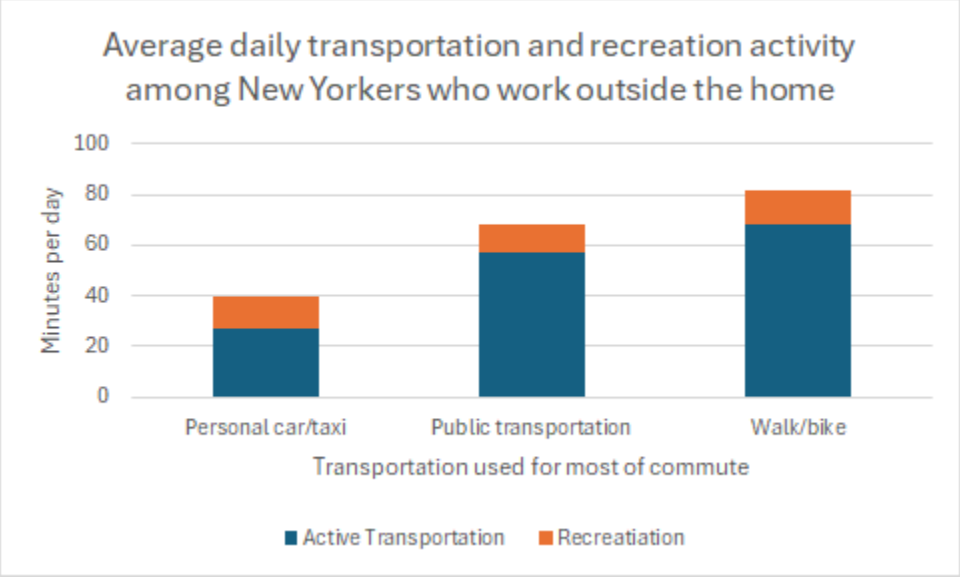
households that own two vehicles and do not use public transportation (Bailey & Highway, 2007). Levinger & McGehee (2008) also note that passengers who switch from commuting via car to commuting via public transit can save over $7,000 ($10,211 adjusted for inflation) in transportation costs annually. On a similar note, transit services can also increase economic productivity by improving access to education and employment (Porter, et al. 2015), as people who previously would not have access to these things now have a reliable method of transportation to take to and from their place of employment or education.

Public Transit/Transit-Oriented Development Improves Public Health

High-quality public transit not only promotes economic development, it also has a significant effect on public health. High-quality public transit fosters *transit-oriented development* (TOD), which can be defined as "the creation of compact, walkable, pedestrian-oriented, mixed-use communities centered around high-quality train systems" (Transit Oriented Development Institute, para. 1). TOD leads to neighborhoods where, on average, residents "own about half as many vehicles, generate half as many vehicle trips, and rely on non-auto travel much more than in automobile-dependent communities" (Litman, 2024, p. 15). High-quality public transit and TOD affect the way people travel. As a method of non-automobile travel, public transportation is complemented by active methods of transportation like walking and cycling (Litman, 2024). When combined with TOD, this complement often leads to improved public fitness, improved physical and mental health, and improved basic access to medical care (Barton, et al. 2009; Hanson & Jones, 2015; Lee & Buchner, 2008; Litman, 2016). As seen in Fig. 2, people who commute by public transit, cycling, or walking typically achieve double the amount of exercise as those who commute via car and are therefore much more likely to achieve the public health target of thirty minutes

of physical activity per day (New York City Department of Health and Mental Hygiene, 2011).

Figure 2



Bar Graph of Average Daily Transportation and Recreation Activity Among New Yorkers

Ref. (New York City Department of Health and Mental Hygiene, 2011).

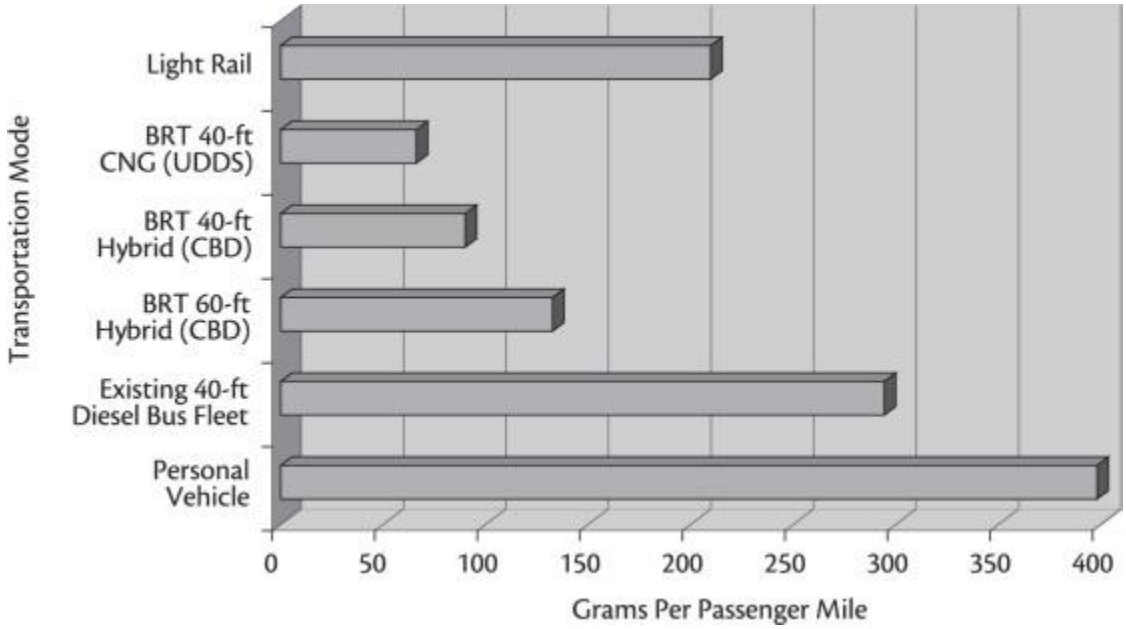
In addition, people who commute via public transit are also at less risk of being involved in a motor vehicle crash, which is the fourth leading cause of potential years of life lost in American citizens (Litman, 2016).

Public Transit Fights Climate Change

Public transportation and transit-oriented development offer significant climate benefits when compared to individual methods of transportation such as personal vehicles. Most of the existing literature separates trips made using passenger vehicles into several categories: work or school, social or recreational, family or personal business, shopping, and others. Of these categories, 'trips made to work and school' make up the largest proportion

(Vincent & Jerram, 2006; Ashik et al., 2022). According to the United States Environmental Protection Agency, the average passenger vehicle emits 4.6 metric tons of carbon dioxide per year (US EPA, 2016). In the European Union in 2006, domestic transport accounted for 21% of greenhouse gas emissions, rising 23% from the 1990 level of 16% of greenhouse gas emissions (CEC, 2006). The average personal vehicle occupancy for 'trips made to work or school' is 1.14 people, the lowest out of any category, whereas the average ridership on light rail and bus systems for the same category of trip is over 20 times higher at 23.23 people (Vincent & Jerram, 2006). As shown in Fig. 3, these researchers found that a bus rapid transit (BRT) system, using a model of bus released in 2000 using compressed natural gas (CNG) as fuel (BRT 40-ft CNG), results in six times less carbon dioxide emissions per passenger mile than typical personal vehicles.

Figure 3



Bar Graph of Grams Of Co_2 Per Passenger Mile Versus Mode Of Transportation

Ref. (Vincent & Jerram, 2006)

A study done in Dublin, Ireland echoed these findings and found that if 15% of people who commute via car switched to commuting via bus, total carbon emissions would drop by 5%. If the amount of people increases to 30%, total carbon emissions would drop by 10% (McDonnell et al., 2008). McDonnell et al. also believe that these values are lower bounds for the amount of actual reduction in carbon emissions.

Transit-oriented developments (TODs) also have a significant effect on carbon emissions. As mentioned above, TODs lead to lower rates of personal vehicle ownership, thus increasing the reliance on non-automobile methods of travel (Litman, 2024). Due to this increased reliance, TODs are considered to be one of the most sustainable transport patterns (Ashik et al., 2022; McDonell et al., 2008). For example, McDonell et al. (2008) also found that in Dublin, Ireland, in the absence of a Quality Bus Corridor, a form of TOD, carbon emissions would have been 50% higher. Similarly, in Dhaka, Bangladesh, researchers found that "for working and school trips, controlling for socio-demographics and spatial relationships, the levels of CO_2 emissions were significantly lower for residents in TODs compared to non-TOD residents" (Ashik et al., 2022). Overall, the consensus in existing academic literature is that public transit and TODs have a significant effect on reducing carbon emissions, and thus fighting climate change.

How are good public transit systems designed?

The Difficulties Behind Designing a Transit System

Planning, designing, and building new public transit infrastructure is a complex process that often spans decades. The number of variables to consider when designing a system is large, requiring immense research and development to be complete before real

planning can even begin (Avide, 2020). Some cities have been developing their public transit systems for over a century, like Paris, which opened its metro system in 1900, during the Paris World's Fair (Sununu, 2024). With transit systems often being built in cities that predate powered transport, building and maintaining public transit systems is an extremely complicated and expensive task, even in the grand scheme of city management. Given the complexity of systems and their long lifespans, it is no surprise that a complex analysis and design process must be completed to ensure costs, rider capacity, and other factors are all within acceptable ranges to ensure a viable system will be realized. In addition to the difficulty of physically planning a system, funding and physically building transit systems are often a politicized process, as they typically require heavy government subsidies (Eash, 1985). All of these complications together make transit system construction and management a complex problem for which workable solutions require decades of work.

The Pillars of a Useable Transit System

The four aspects of usable, user-oriented urban transit, as directly outlined by Levinger and McGehee, are ease of use, effectiveness, comfort, and aesthetics (Kennedy et al., 2005; Levinger and McGehee, 2008; Litman 2024). Ease of use, as described by Litman and Lynch, directly corresponds with the clarity of the system and cost of use (Litman, 2024; Lynch, 1960). For example, Levinger and McGehee ask: "What difficulties do new users face when trying the product for the first time? Are there different challenges for experienced users? Transit example: Are your timetables legible and easily decipherable?" (Levinger and McGehee, 2008). Since 'ease' as a concept contains several rooted opinions, it can be broken up further into ease economically, ease of achieving the destination goal, and ease from a comfort perspective. Litman also explains how the superseding concept of comfort is mostly

derived from the reliability and security of the system (Litman, 2024). The pillar of effectiveness pertains more to governments and management companies, which must ensure efficiency and cost-effectiveness. There are also other concerns that governments must consider when maintaining this pillar, such as reducing the number of cars on the streets or providing additional pedestrian accessibility improvements (Litman, 2024). Finally, the pillar of aesthetics treats transit systems as commodities, which means that a minimum sense of aesthetic design, customer appeal, and cleanliness can significantly benefit longevity and ticket sales (Litman, 2024).

Transit designers must balance all of these pillars as different categories and must weigh their significance across different groups of users. For example, a tourist who is only in a city for a weekend might prioritize ease of use because the system is still new whereas a local who has lived there for decades might prefer comfort and aesthetics. On average, however, as outlined in Iseki et al. (2007), transit riders rank the direct utility and safety of a system as their top priorities. In their survey, out of 16 ranked priorities for transit stations, they found that safety and security-related choices made up four of the five top priorities for riders, with number three being that transit ran on time (Table 1) (Iseki et al., 2007).

Table 1

Station Priorities Rankings

Question on the Survey	Category	Importance	
		Rating	Ranking
This station /stop area is clean.	Amenities	58%	13
There are enough places to sit.	Amenities	50%	15
There are places for me to buy food or drinks nearby.	Amenities	34%	16
There is a public restroom nearby.	Amenities	59%	12
There is shelter here to protect me from the sun or rain.	Amenities	69%	8
The signs here are helpful.	Information	69%	9
It is easy to get schedule and route information at this station.	Information	62%	11
I usually have a short wait to catch my bus/train.	Connection & Reliability	70%	6
My bus/train is usually on time.	Connection & Reliability	76%	3
It's easy to find my stop or platform.	Access	70%	7
It is easy to get around this station/stop.	Access	57%	14
I feel safe here during the day.	Security & Safety	77%	2
I feel safe here at night.	Security & Safety	78%	1
There is a way for me to get help in an emergency.	Security & Safety	74%	4
This station is well lit at night.	Security & Safety	73%	5
Having security guards here makes me feel safer.	Security & Safety	67%	10
This is an easy place to transfer to another bus or train.	Overall	73%	-

Ref. (Iseki et al., 2007)

Effectiveness and Efficiency

When designing a public transit system, examining quantitative factors such as travel times and capacity for any given mode of transit is useful to ensure the system's longevity and maintainability (Litman, 2024). Using trains as an example, part five of the *Transit Capacity and Quality of Service Manual 2nd Edition* states that "the only factor [in station design] that has a potential effect on the line capacity of a rail transit line is the rate of exiting from a platform. Adequate passageways, stairways, and escalators must be provided to ensure that a

platform can clear before the arrival of the next train." (Transit Capacity and Quality of Service Manual, 2016, p. 5-36). Railway schedule managers will take into account egress capacity from train platforms when determining how long a train will have to stay at any specific station, directly affecting the effective line capacity. If a designer fails to account for wait time data, the station could potentially experience delays, consumer frustration, or lost revenue from less-than-ideal utilization of rail lines.

However, quantitative factors go far beyond wait time. Designers must balance many different quantitative metrics, the interactions between those metrics, and how they will change over the lifecycle of a potential system. Some examples of these metrics are the number of different lines that connect a stop, the number of ticketing booths available, the maintenance costs for keeping the number of vehicles and facilities consistent, the variance in ridership per season, availability of alternative routes during outages, ticket prices, and more (Litman, 2024). Maintaining systems and providing several line options has the most direct impact on line capacity since the number of transportation units available directly affects line capacity.

Quantitative economic design is also important for management companies and governments working on a system as taxpayers are typically the ones fronting the initial cost of transit system construction. Usually, governments subsidize a portion of their tax revenue into transit systems since it provides benefits for the economy in the long run. However, companies that handle operations or marketing for these systems have to consider the total budget for projects, potential future investments, labor costs, and also model the effects the transport will have on the economy in the future (Litman, 2024). Furthermore, in economic design, the effects on competitors and market share are another consideration. The

introduction of services like Uber and Lyft has decreased ridership of public transit in general, and with this competition, rider fares paying for transit systems have become more distributed (Nwankwo, 2023). Similarly, the status of the TCL to its community is reflected in its market share. With more people using transportation, there is a higher likelihood of the market growing through families, friends, or external connections. Thus, the economic design and place in the market play a significant role in development, both socially and economically.

Finally, there are infrastructure-related metrics that need to be considered from different points of view. For example, the number of ticketing machines available, the number of entry passageways, or any alternative track routes are considerations that need to be done per station. Depending on the amount of foot traffic, to adhere to commuters, more machines need to be placed as well as more entrances or exits (Litman, 2024). Proper signs need to be placed for people to navigate as well as enough distinct maps so the travel is not confusing. Finally, in case of emergencies, there needs to be an adequate amount of alternative routes, communication intercoms, and first aid available to ensure the problems are handled swiftly. Considering these metrics ensures that systems can succeed beyond just efficiency and economics.

Comfort and Aesthetics for Users

It is equally important to have a well-designed transit system as it is to have a pleasant environment for the riders. A transit system design that is driven solely by cost optimization, rider capacity, or other numerical goals may lack essential considerations for the humans that use it. Designing a truly user-oriented transit system requires a delicate balance of architecture, economics, human psychology, urban planning, technology, and much more (Graziani et al., 2019). If citizens ride on public transit for its utility, the surrounding area

benefits through economic growth or health benefits. However, a system's influence can go further: if citizens enjoy riding public transit as well as its associated spaces, these systems transcend their purpose as a public space (Enright, 2022). This effect can be seen in numerous municipalities, like the New York subway system, which acts as a cultural staple that arguably approaches the same level of recognition as the city's other public spaces like Times Square or Central Park. When executed properly, transit systems fulfill an important cultural role that is vital for urban environments and their inhabitants (Alexander & Hamilton, 2015 pg. 6).

Ease of Use

However, stations are only one part of the larger perplex of urban transit. To design the best system possible, not only does physical infrastructure need to be treated as a public space, but people need to be able to use it as well (Levinger & McGehee, 2008). If the ticketing systems are difficult or confusing, they lack convenience. If trip planning is confusing or inconsistent, public transit may be avoided entirely. If schedules are different to understand, the transit system fails to be an efficient mode of transport. Transit, as a whole, must be easy to use and accessible to all, otherwise, those who could benefit the most from public transit (individuals with reduced mobility) will not be able to use it (Peña Cepeda et al., 2018). In summary, a system must allow for customers to easily be able to navigate public transit to justify its existence and any decisions made for the desire of aesthetics or consumerism must not interfere with riders.

Lyon's Public Transit System

An Overview

The Lyon Public Transit System, professionally known as the *Transports en Commun Lyonnais* (TCL) spans over 746 km^2 reaching 72 communities within the Auvergne-Rhône-Alpes region (TCL - Transports Communs Lyonnais | TCL, n.d.). The TCL utilizes four subway lines, seven tram lines, 140 bus and trolley bus lines, and two funiculars to serve 1.3 million residents within the Lyon metropolitan area and 1.7 million riders daily (TCL - Transports Communs Lyonnais | TCL, n.d.).

As the third largest city in France, more than five hundred thousand people share over 45 square kilometers of land in the Auvergne-Rhône-Alpes (Full Set of Local Data − Municipality of Lyon (69123) | Insee, n.d.). Residents of Lyon make a median of 25,430 Euros in disposable income each year and roughly 12% are unemployed as of 2020 (Full Set of Local Data − Municipality of Lyon (69123) | Insee, n.d.).

The transit system in Lyon began development in 1837 with the introduction of public omnibus lines (Keolis-lyon.com | Groupe Keolis, n.d.). These omnibuses, as shown in Fig. 4 were large horse-drawn carriages with a capacity of up to 20 passengers (London's Horse Bus Era 1829 – 1910, n.d.) and were operated by multiple private companies/individuals along the same route (Montagnon, 2000).

Figure 4

Image of a Lyon Omnibus in Operation Taken Around 1880-1890

Ref. (38PH/1/327, n.d.)

The installation cost of new electrically operated vehicles put major financial pressure on the transit organizations of Lyon before the 1910s, dwindling the competition and allowing larger companies, like the Compagnie des Omnibus et Tramways de Lyon (OTL), to prosper with the new technology (Montagnon, 2000; Cosmas, 2013). Lyon's use of electric transportation early, for example, the tram vehicle in Fig. 5, into the technology's popularity became an important building block of the modern system through prebuilt infrastructure and pathing (Cosmas, 2013).

Figure 5

Image of an Early Electric Tram Vehicle Drawn in 1894

Ref. (Le Tramways Sous La Neige., n.d.)

Public transit was unified under the OTL by buying the competition shortly after electric transportation became available within Lyon. Between the years of 1899 and 1911, OTL bought three transit companies: two tramways and one funicular service. The funicular as shown in Fig. 6, a future icon of Lyon, is a vehicle designed to connect two locations of varying elevation.

Figure 6

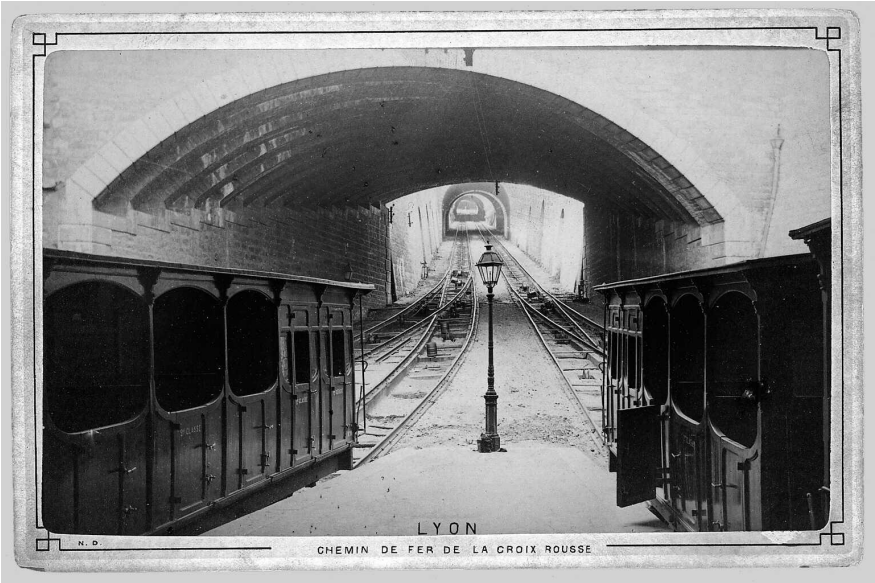


Image of the Funicular Station with Both Vehicles Taken in 1890

Ref. (1PH/600, n.d.)

In 1941, The Syndicat des Transports en Commun de la Région Lyonnaise (STCRL) was founded as a public entity in the Rhone region and bought out the entirety of the OTL network (Keolis-lyon.com | Groupe Keolis, n.d.). During this time the OTL as a private company ran the vehicles and property owned by STCRL (later known as SYTRAL Mobilités) for 25 years before the OTL formally became the TCL in 1967 (Keolis-lyon.com | Groupe Keolis, n.d; Cosmas, 2013). This management structure, the first of its kind in the area, became the "benchmark in public transport management in major French cities" (Keolis-lyon.com | Groupe Keolis, n.d.).

The system contained only above-ground transportation (trolleybuses and buses), which greatly shaped the development of the city in the 20th century until 1978, when the first two subway lines were built and began operation (Keolis-lyon.com | Groupe Keolis, n.d.). The construction of these lines is shown in Fig. 7.

Figure 7

Image of the Construction of the Métro in Lyon

Ref. (8PH/3191, n.d.)

The metro system was updated in 1991 with the addition of two new subway lines and in 2013 with the expansion of one of the original metro lines (Keolis-lyon.com | Groupe Keolis, n.d.). Images of the modern vehicles used by the TCL are presented in Appendix E.

The modern system is operated in two major sections. The Syndicat des Transports en Commun de la Région Lyonnaise (SYTRAL Mobilités), a local public establishment funded by the French government, functions as the organizing transport authority and operates the business functions of the TCL, while the daily operations of the transport system are operated by the public service delegate, Keolis Lyon (Keolis-lyon.com | Groupe Keolis, n.d.). This agreement will be amended in 2025 when the operations of the TCL will be delegated

simultaneously to Keolis Lyon, which will retain bus operations and ticketing functions while the Régie Autonome des Transports Parisiens (RATP) will manage the "metros, funiculars and trams" (Gossart, 2024).

Lyon's transit is well connected inside the city, boasting four lines and 42 stations on the metro alone, making it only second to Paris as the largest metro system in France. Lyon is also well-connected outside its borders, with bus routes and high-speed train lines running throughout France, and even extending into neighboring countries. Lyon's train system allows direct access to Switzerland and Italy as well as other French cities like Paris, Marseille, and Lille (Seat61, n.d.). Lyon's transit system is incredibly well integrated into the city because the city planners ensure "urban planning is designed around public transport," (MassTransitMag, n.d.) according to SYTRAL's President, Bernard Rivalta. This strategy significantly prioritizes Lyon's transit system in city-wide goals, ensuring it remains a hotspot of mobility, creating a better experience for citizens and tourists alike.

Recent and Future TCL Projects

As of 2021, SYTRAL Mobilités has been instituting its Plan de Mandat 2021-2026, a large-scale addition to the TCL network on an expedited timeline (Public Transport Homepage - Sytral, n.d.). The mandate outlines the expansion of its tramway system, building two entirely new tramlines, extending a preexisting metro and tramway, implementation of a river shuttle along the Saône River, a new bus line, and the construction of a new tram station and maintenance bay (Public Transport Homepage - Sytral, n.d.). The project will expand the service by almost 45 km in total and each project is to be commissioned (if not completed) by the end of 2026 (Public Transport Homepage - Sytral, n.d.). The mandate additionally includes a study primarily focused on the feasibility and need for an express tramway line

between the Jean Macé train station and the Alaï/Libération district of Lyon, a project which will be consulted on for the second time until 2026 (Concertations - SYTRAL Mobilités, n.d.). The five-year plan is estimated to cost 2.55 billion euros.

In addition to this expansion plan, SYTRAL is currently in the process of modernizing both the TCL metro and bus systems (Public Transport Homepage - Sytral, n.d.). The metro system will become fully automated by 2025 with the replacement of all Line B trains, attempting to increase overall system efficiency. The remaining three metro lines will also have their rolling stock entirely replaced and/or increased (Public Transport Homepage - Sytral, n.d.). A new 'postes de commande et de contrôle centralisé' (PCC), a command post for the metro system, will additionally be built to replace the TCL's current PCC, which will be refurbished for emergency use (Public Transport Homepage - Sytral, n.d.). The metro revitalization alone is budgeted at 1.7 billion euros.

The metro automation program plans to install fully automated trains into the metro system without continual supervision by an onboard attendant. In general, the main factor pushing for fully automated metro systems is a net benefit for users and operators, "the low marginal cost of frequency possible with automated metro may unlock both users' benefits via reduced waiting times and crowding, and operator's savings via shorter trains and smaller platforms and stations" (Allen et al., 2022). Automation allows for a more comfortable and reliable experience for the user while providing monetary savings for the metro's operator. Opposition to automation mainly cites concerns over the safety of removing a large portion of human supervision from these systems and whether or not automation reduces expenses for the system. Autonomy for metro systems is classified by four grades: GoA1 through GoA 4. GoA1 represents that a driver performs most of the operation of a train installed with

automatic safety measures (red light detection, speed braking, collision avoidance, etc.) (Rizzi & Regan, n.d.). GoA2 represents a completely automated train in terms of travel operation with an attendant who is responsible for opening the doors to the train at each stop (Rizzi & Regan, n.d.). GoA3 represents a driverless train that supports staff presence for door functions and in the event of an emergency (Rizzi & Regan, n.d.). Finally, GoA4 represents an entirely automated train that requires virtually no interference by personnel (Rizzi & Regan, n.d.). The Lyon metro aims to achieve automation designated by the GoA3/GoA4 standards for its entire system by implementing the aforementioned metro modernization project.

For the TCL bus lines, SYTRAL aims to provide a competitive alternative to car travel by developing lines that travel more efficiently than cars. 15 of the most popular bus lines (140 in total) will be optimized to provide a more reliable and faster travel experience, paid for by a nearly two million euro grant from the French Transport Infrastructure Finance Agency (Public Transport Homepage - Sytral, n.d.). To improve the sustainability of the system, the TCL has begun slowly replacing its petroleum-fueled buses with either electric or natural gas-powered vehicles (Public Transport Homepage - Sytral, n.d.). SYTRAL promises that by 2026, 40% of the TCL bus/trolleybus fleet will be sustainably powered (Public Transport Homepage - Sytral, n.d.).

SYTRAL Mobilités, as both the management company of the TCL and the public transit authority for the Rhone region, is in the process of creating a mobility plan. To be finalized by the end of 2024, STYRAL will have a fully-fledged mobility plan devised in cooperation with the input of local residents, outlining how mobility infrastructure and operations should incorporate sustainability, accessibility, and usability factors (Concertations - SYTRAL Mobilités, n.d.). Finally, SYTRAL has developed the Urban Travel Plan for the

Lyon Agglomeration 2017-2030, an almost 250-page document discussing how transit systems in the Rhone region can make transit more user-focused, affordable, and sustainable in the long term.

Methodology

Methodology Goals

Our main project goals were to first understand the current expert consensus on what makes a public transit system "good," and then determine if Lyon fits within these ideals. To achieve this, we performed a multi-method research project based in Lyon involving quantitative and qualitative processes, archival research, interviews, and ethnographies. However, before conducting the research, we had to focus our research questions on Lyon's system so that the data collection and analysis could be directed by more concrete objectives. Our research questions, when looked at in the scope of Lyon, are as follows:

- How is Lyon's transit system organized?
- What makes a transit system "good", and does Lyon's system meet these criteria?
- How do transit systems in general benefit their communities, and how does Lyon's?

To answer these questions, we outlined the following primary objectives for our methodology:

- Acquire quantitative data on Lyon's transit system efficiency, efficacy, and accessibility
- Conduct field research on Lyon's public transit system to find how it services its people

Objectives

Objective 1: Acquire quantitative data on Lyon's transit system

Our first objective involves gathering and analyzing specific quantitative data on Lyon's public transit system. Through research, we found documents giving background information and concrete data about how the system was created, how it operates today, and how it serves the surrounding Lyon community. Most of this data has come from archival

research on Lyon's transit design, population statistics, and TCL website information, but it was also supplemented by data from field research ethnography.

Objective 2: Conduct Field Research on Lyon's system

Along with establishing a basic understanding of Lyon's system, the second objective contains several methods that will be performed on-site to support the quantitative data collected through archival and modern research. Primarily, the team will perform ethnographic observations on the stations and vehicles making up the transit system to ensure the archival data backs up the present structure of Lyon's transit system. Along with these ethnographic observations, qualitative data will be obtained through interviews with transit experts and local officials.

Overview of Methods

To achieve the outlined objectives, a considerable amount of quantitative research was completed. Quantitative research refers to research that yields numerical data, which is often analyzed using statistical methods. This form of analysis means that quantitative methods run into the same benefits and limitations of statistics in general, such as needing a fairly large data sample and being susceptible to skew. On the other hand, quantitative methods allow generalizations, help numerically establish causal effects, and are more easily replicable (Burrier, 2024).

However, not every topic can be described accurately by a number. Transit must also be analyzed qualitatively by studying variables such as cleanliness, ease of use, security, and density of stops. Qualitative research can fill the gaps left by purely quantitative research, offering "explanations for cases outside the normal distribution" (Burrier, 2024), although they are not as generalizable or replicable. Combining quantitative and qualitative methods in

a mixed-method research design allows the objectiveness of quantitative data while also incorporating the nuance of qualitative data.

Our team used a multi-method research design, consisting of archival research, semi-structured interviews, and ethnographies. The research was primarily conducted in the city of Lyon, France, between May 21st and July 4th, 2024. As Lune & Berg (2017, p. 14) write, "methods impose certain perspectives on reality." Our team chose to combine these research methods using a technique known as triangulation so that each method's benefits counteract another's shortcomings: "By combining several lines of sight, researchers obtain a better, more substantive picture of reality" (Lune & Berg, 2017, p. 14).

We conducted archival research in two forms. First, the team conducted a literature review, synthesizing background knowledge on the benefits of transit systems, transit-oriented development, global transit systems, and the lessons we can learn from them, as well as specific information on Lyon's public transit system, *Transports en Commun Lyonnais* (TCL). Archival research gave us a strong foundation of background knowledge and helped us develop the overall methodology of our research. Additionally, the team performed data scraping on the TCL website throughout the entire project as a secondary form of data collection. The team also conducted semi-structured interviews aimed at gathering an understanding of experts' opinions of the TCL (Lune & Berg, 2017) and public transit in Europe as a whole. These interviews helped contribute to our second objective by obtaining qualitative data on the overall standing of Lyon's transit system within its community. Lastly, the team also used ethnographies to complete both of our objectives by using the transit system and gathering quantitative and qualitative data.

Archival Research

Archival research involves synthesizing information from previous documents, such as peer-reviewed papers and those published in academic journals. In the words of Lune & Berg, "Only after you have immersed yourself in what is known about the topic, what is speculated about, and what is unknown can you define the useful angle for your study that can promise to make an actual contribution." (Lune & Berg, 2017). Archival research is unobtrusive, cost-effective, and helps to provide depth and establish the state of the field (Burrier, 2024). Thus, our team started with archival research to build a strong foundation of knowledge about public transit systems in general, as well as specific information about Lyon's transit system. This form of research helped us choose the best methodology to approach our research questions.

One of the first things we researched was the importance of these systems to the communities they serve, which helped us get an idea of how influential our topic could be. There was little information available about Lyon's system specifically, so we instead investigated the qualities that make public transportation as a whole good. Once we understood what differentiates strong and poor systems, we would be better prepared on what to look for in Lyon. We found a significant amount of existing research on all aspects of public transit systems including the importance of transit for low-income communities, its ability to yield a strong return on investment, its reduction of carbon emissions, and its impact on job availability (Sultana et al., 2021; Litman, 2005; Giuliano, 2005; Weisbrod & Reno, 2009; McGraw et al., 2021). Additionally, we looked into what companies are responsible for maintaining transit in Lyon and how to contact them to inquire about additional information. The information gathered during preliminary research was essential

in developing an understanding of public transit design that was necessary to conduct our research in Lyon.

However, at the same time, archival research does have some key limitations. Data can be outdated or simply missing, but most importantly, selection bias can be a problem. To combat selection bias, we did our best to aggregate a wide variety of archival sources that analyze the question at hand from multiple different perspectives. Language barriers can also limit our understanding of material, although new, more advanced translation tools and prior knowledge of the French language allowed us to avoid many issues with language barriers.

We also tried to collect recent archived data from the TCL website itself. The TCL website and app display data on the current status of the transit system, such as schedule delays, maintenance outages, the busyness of specific routes, and more information. We saved this data at regular intervals by simulating trips to and from a random distribution of coordinates within Lyon using the TCL itinerary planner. The resulting data was then stored in a database to analyze possible quantitative trends in the system as a whole (e.g. outage durations over time, common outage locations, distance from buildings to nearest transit station, etc.). To accomplish this, we employed data scraping, which allows us to save the raw data present on websites and apps without having to manually use the website interface. We used basic statistical methods like regression and probabilistic tests to analyze the data and look for relevant trends. These trends include outage patterns, significant congestion beyond peak times, or a consistent lack of capacity along certain lines in the system.

The main concern we must work to alleviate while using archival research is selection bias. If our research draws from a single source, we will take on all the bias of that one source. With that, we must make sure to triangulate different perspectives for our research, such as using papers that focus on different transit systems from different countries, or not solely relying on information from commercial entities. As we are using information from a variety of sources with different backgrounds, we have been able to look at our research from many different perspectives, and have theoretically been able to eliminate most selection bias in our archival research. All research sources were assessed for writing credibility as well as author credibility to ensure they gave valid scholarly facts and opinions. Other considerations include missing data, language barriers, and the fact that data can be outdated (Burrier, 2024). These issues can also be mostly mitigated by synthesizing information from several credible sources.

Semi-Structured Interviews

Our team also conducted semi-structured interviews, in which the team would ask some predetermined questions based on the author's background and expertise. These questions were typically asked in a set order, however, the interviewer would often delve deeper into certain topics by coming up with new follow-up questions on the fly (Lune & Berg, 2017). Semi-structured interviews help to fill gaps in existing literature and provide opportunities to test hypotheses (Burrier, 2024). For our interviews, specific individuals and organizations that have relevant knowledge on the topic, such as local transit experts, researchers, and labs, were contacted via email to request an interview. Synthesizing multiple experts' perspectives helped to build a more robust understanding of the big picture. The focus of our questions depended on the interviewee, but the main themes included their

opinion on Lyon's public transit system, what the system does well, what the system does poorly, and how the system is planned, constructed, and maintained. For interviews with public transit researchers and professionals, we also asked about general transit theory, such as what can make a transit system "good". A full list of interview questions, separated by interviewee, is available in Appendix A. If the respondents chose to speak in an alternative language to English, translation was performed either live on-site or through an offline translation application.

As Lune & Berg (2017) point out, interviews are well suited for cases where people are interested and less so for others. One of these cases is when we wish to discuss "what people want, like, or what they feel good or bad about" (Lune & Berg, 2017). For the purposes of our research, as we are aiming to understand public opinion, this is the kind of data that we want. However, semi-structured interviews also have their limitations. Memories may fade or change, and especially with our research, interviewees could be biased due to their relations and issues within industries or surrounding laws. For these reasons, we cannot be entirely sure about the sincerity or honesty of the responses in these interviews. Semi-structured interviews are also difficult to secure and time-intensive. There can be problems caused by language barriers and selection bias, although we attempt to mitigate these issues as much as possible by determining our questions beforehand and choosing individuals with different perspectives to interview. Triangulating multiple interviews allows us to avoid much of the bias contained in a single person's opinion, while also allowing us to find common points of agreement or disagreement among experts.

Ethnographies

Ethnographies aim "to understand another way of life from the native point of view" (Spradley, 1979, p.3). This method of research involves entering the natural setting of the research topic to conduct field research. Lune & Berg also mention "the power of ethnographic fieldwork to reveal hidden elements of otherwise poorly understood subcultures within our own societies" (Lune & Berg, 2017). Ethnographies are a form of primary research that "goes straight to the source" (Burrier, 2024). If done well, they provide authenticity. Our team aims to use ethnographies to gain a first-hand understanding of the Lyon transit system.

As stops are an integral part of any transit system (Iseki et al., 2007), the project team collected quantitative data about Lyon's transit stops on the field for dynamic variables such as the density of transit stations, transit cleanliness, availability of TCL representatives, and wait time for transit. These variables were recorded at different stops on a numerical scale in an attempt to quantify our observations. Each number had a specific rubric assigned for observations to ensure that results were as normalized as possible. The project team also noted any common trends noticed across stops or lines as well as any outstanding observations. The data was filled out by the team in an observation form, which can be found in Appendix F. This collection of data was then synthesized in hopes of establishing the reliability and usefulness of Lyon's system objectively. A visual analysis was performed on the quantitative data to identify areas of strength and weakness. Finally, the additional notes recorded were read to see if the numerical results supported or undermined the observations from our other methods.

Along with dynamic data, the team collected static (meaning it is unlikely to change) data available at every stop. This information included the number of ticketing

machines, the number of maps, the legibility of maps, the number of elevators, escalators, and their functional status, as well as any additional features to improve the stop's usability. Similar to the dynamic form, the static data was collected using an observation form the team filled out after going to a stop and finding the relevant information. The structure and text in the form can be found in Appendix F. The static data was combined with the dynamic to get a comprehensive understanding of how each station performed and was budgeted overall. Finally, this data was then overlaid with data given from the archival research to determine an overall relationship between ethnographic observations and actual system-recorded data.

There are a few main considerations for ethnographies. First, they are less generalizable (Burrier, 2024), as all observations are specific to the system we are researching. Second, ethnographies are time-intensive. As Lune & Berg write, "We may spend time at a field site hoping to observe actions and encounters of a particular kind, and not find them. [...] Fieldwork research can be a long, slow process of immersion." (Lune & Berg, 2017). Lastly, observer bias can skew observations and misrepresent the reality of the system we are researching (Burrier, 2024). To reduce this innate observer bias as much as possible, the team used triangulation, combining multiple data sources and data collection methods to cross-verify findings.

Ethical Considerations

A major concern to the ethics of conducting our methods involved consent and privacy of other people. For methods like ethnographies, the team had to enter into a public environment to ride transportation, record data observations, and photograph anything outstanding. Thus, to maintain ethics, there had to be no significant setbacks or disruptions to

the people. Also, by French law, any photograph taken of others in public spaces must have every individual's consent who is "isolated and recognizable." (Castex, 2022). Finally, when interacting with others in an interview setting, there are regulations given by the Institutional Review Board (IRB) to have the interviewee accept a scripted consent form to ensure they know who and what their data will be used for. The consent script can be found in Appendix B, which explains how the team informed interviewees of their rights, as well as how their names will be used in official research documents. Along with consent and privacy of interacting with individuals, each separate method has its ethics and limitations to consider.

For the archival research performed during this study, all privacy, copyright, and reproduction policies were followed to ensure accurate and respectful use of sources. Limitations of this type of research include the availability of sources, both physically and virtually, as well as the existence of material pertinent to the Lyon Public Transit System as a whole. While these limitations were not significant throughout the project, they did exist.

All scraping of the TCL website and app was done responsibly, following appropriate limits set by TCL's web servers. All reasonable measures were taken to ensure TCL's services were not impacted in any way by the scraping. All this data is available publicly and contains no identifying information that could present privacy issues.

For the interviews that we conducted, all data from respondents were deleted such that only collective, synthesized results and summaries were published. During our interviews, we made sure to ask the interviewee if we could use their identity with the intent of potentially quoting them by their position, name, or organization. We separately asked for consent for each identifier so the subject could consent to one without consenting to all. These interviews required consent to be recorded so that their responses could be translated and reviewed.

Afterward, a group member translated the interview, and the audio file was saved to a password-protected computer belonging to one of our team members. If a translation was needed, offline programs were utilized to ensure the privacy of the interviewee. The audio was transcribed and both the audio and the transcription were deleted before departure from the project center.

Including qualitative data collected through ethnographies provided important context into the overall study of the TCL, however, due to the inherent variability within the method there were some notable limitations. The ethnographies performed were conducted at as many stations/stops/vehicles as possible. However, the majority of the data was taken on weekdays during daylight/business hours, excluding weekend and late-night schedules and programs. We collected data from two separate observation forms filled out by our group. The ethnographies were overall limited to the timeframes of when data was collected and the sample size of form responses.

Findings

Walking into our first TCL metro station, we were greeted by an entrance free of virtually any trash, with a working elevator going from the metro platform below up to the street above. There were two ticketing machines available for use, both of which provided several translation options to the user and multiple pages of tickets for purchase. We each bought our ticket and made our way down the stairs towards the platform.

On the platform, we again found clean floors and no sign of trash or debris, as well as a few rows of benches that were comfortable and aesthetically pleasing. The platform that we stood on felt like the antithesis of the typical Boston metro station we were used to: it was clean, not too crowded, had no foul smell, and actually felt welcoming. Exploring further, we found many maps on the walls of the platform, providing both metro line overviews as well as a view of all of Lyon and the transportation options offered therein. The platform was quiet and calm, with a handful of people waiting for the next train to arrive within two minutes posted on the timing board. From across the tracks, we could see the other side of the platform was quite similar in cleanliness and accessibility to our own. We thought that maybe, this example of a clean, friendly, inviting station was not a common occurrence but was simply an outlier and that as we continued using the system, the conditions would, for the most part, not live up to the standards shown in that first metro station.

We were proven sorely wrong. Virtually every station we entered at any given time of the day boasted a clean, helpful, and efficient system. Some even went above and beyond a typical metro stop, with marble walls, palm trees situated on each platform side, intricate floor and wall patterns, or, in some stations, large art installations. One such example of these aesthetically appealing stations is displayed in Fig. 8.

Figure 8

Image of a Platform in Stade de Gerland Station

Ref. (Station de Métro Stade de Gerland, Vue Intérieure., n.d.)

Our findings aim to provide objective evaluations of the TCL to back up our first-hand claims of quality within Lyon's system.

Overview of Method Results

Throughout our research, we continuously scraped and saved data from the TCL website's itinerary planner. Overall, we collected data on 501,615 simulated journeys using Lyon's public transit system, which were stored in an SQLite database. Each entry in this database represents a simulated journey. Each simulated journey contains an identifying number, the total duration, the departure and arrival dates and times, the amount of CO_2 emitted, information on air pollutants, duration by transportation method other than public

transit (walking, biking, ridesharing, and taxi), the distance by transportation method other than public transit, and what transit stops the theoretical traveler would pass through. This data was then analyzed both visually, using plots and graphs to see trends over time; and mathematically, looking at means, medians, and standard deviations.

Each of our interviews were insightful experiences that greatly impacted the outcome of our findings. The main goals of these interviews were to bridge gaps between our archival research, to develop a better understanding of how the TCL is managed both administratively and politically, and to understand what experts and specialists consider effective transit systems.

We began the task by compiling a list of 28 potential professionals, experts, or otherwise relevant individuals in the public transit area to reach out to via email. Many of these contacts were Lyon-specific and could potentially be communicated with in person for a semi-structured interview. On May 30th, 2024 we began contacting these individuals and entities over the following six weeks. We sent messages to a total of 21 contacts composed of public transportation experts, academic labs, government officials, and representatives from the TCL and its governing bodies. Out of the 21 emails sent, we received 13 responses, where five of those interactions led to an interview, producing a 61.9% response rate and a 23.8% interview rate in total. Many of the emails we received back declined an interview but did provide additional individuals to contact related to public transportation, most of which were subsequently contacted.

For the eight non-responses, we sent follow-up emails to each of these individuals, from some of which we received automated “out of office” responses. Out of these, three were involved with the Urban Mobility Readiness Index, a project by the Oliver Wyman Forum.

For five of the contacts we reached out to, we had the incredible experience of interviewing with them. Our interviewees are as follows:

- Corentin Gautier, a graduate student from L'université Claude-Bernard-Lyon-1 in the Laboratoire d'Informatique en Image et Systèmes d'information (LIRIS).
- David Levinger, President and founder of the Mobility Education Foundation and an urban mobility expert
- Olivier Klein, the deputy director of the Laboratoire Aménagement Économie Transports in Lyon (LAET), and an urban transportation planning expert
- Jérôme Berthonneau, the Operations Director of Keolis Lyon
- An anonymous public transportation researcher from LAET in Lyon

Another addition to our findings was any ethnographic research data the team collected. By riding the transit systems and making observations, the team could make generalized statements about the system as a whole. This was mainly due to collecting several quantitative data points of both numerical data, such as the time between trains arriving, as well as categorical or discrete data such as the cleanliness or crowdedness of the system. During the entire project duration, the team collected 82 dynamic data points at different times in different stop locations. Additionally, the team recorded 36 static data points, which included data for almost every single metro station. For both of the observation data forms, the team had to discuss appropriate descriptions of quality ratings to ensure everyone was on the same page to ensure standardization of the data. This had to be done to ensure there was no bias within the team towards specific numbers, primarily in the categorical data. Despite this, a second iteration still had to be done part-way through to add more descriptors since the responses were still vague. Some things added were the specific type of TCL representative at

a station, images for the type of transportation, and more categories for cleanliness. The finalized version of these forms can be found in Appendix F.

After recording the results, the team determined that the static data was sufficient to make conclusions with, but that there were alternative ways to gather the same data points that may have been less time-consuming, such as archival research. The dynamic data, however, was not even close to enough to be statistically sufficient. The team could make blanket statements that applied to a large majority of the observations, but to find statistical trends across different times of day, each stop had to be recorded multiple times for each specific time slot to be analyzed; it would result in thousands of observations altogether. Thus, there was a lack of dynamic data to use as a strong supportive base for any time-based trends, but there was sufficient enough data to make generalized overarching claims.

Presenting Findings Through Research Questions

In the beginning of this paper, we defined three main research questions:

1. How is Lyon's transit system organized administratively, politically, physically, and economically?
2. What are the characteristics of a "good" public transportation system?
3. What are the benefits of having a "good" public transit system?

In our previous sections, we provided context to begin to answer these questions while looking at transit systems as a whole. We now answer these questions based on the research and data collection we have conducted, limiting the scope of each question to Lyon specifically.

How is Lyon's transit system organized administratively, politically, physically, and economically?

Overview of Administrative Structure

Being a corporate entity that is influenced by the government through a third party, the structure of the TCL is rapidly changing and heavily based on its inter-company relations. Through our archival research, we learned that the structure between Keolis, SYTRAL, and the government is handled differently from operations, business, and political fronts. Keolis, as a larger international operations company, has access to funding for producing railways and buses. However, this funding is not received from the corporation itself: the money is instead subsidized through the SYTRAL Mobilités organization and the government, who ultimately decide on Keolis' operations. In our interview with Jérôme Berthonneau, he explains that Keolis has "the role of advisor," while SYTRAL has "the role of operator." (Berthonneau, personal interview, 27 June 2024). He further explains that SYTRAL ultimately makes the decisions for production plans, investments, and any operations Keolis performs. Meanwhile, Keolis can only "propose to SYTRAL either investments in new lines, supply development, or new schedules." (Berthonneau, personal interview, 27 June 2024). Thus, from the business front, SYTRAL has essentially all power in dictating project economics and needs. Finally, from a political front with the government, Jérôme Berthonneau explains that for Lyon, "political [terms...] are six years," while, for example, "the Metro Etramouet project is at least 10 years." (Berthonneau, personal interview, 27 June 2024). The point made is that Keolis Lyon and SYTRAL have to adapt to political changes that occur on a fixed six-year cycle while their projects can last "10 years, but sometimes [even] 20, 30 years." (Berthonneau, personal interview, 27 June 2024). It could be that a project planned and worked on for over a

decade is scrapped by new government funding standards or laws, which means planning is significant to the relationship between the three fronts. Thus, the companies behind the TCL have to adapt to the changes while maintaining communication and relations to ensure the group as a whole can benefit.

Another integral part of the structure of the system is the economic relation between the city, people, and third-party companies like SYTRAL. According to Jérôme Berthonneau, "the user of public transport pays for 30% [...] the ticket, the subscription is 30% of the service [cost]." (Berthonneau, personal interview, 27 June 2024). Therefore, for maintenance and operational costs, the majority comes from other sources, primarily the city's government. "The user also pays by [their] taxes. [It] is the 70% remaining." (Berthonneau, personal interview, 27 June 2024). With taxes making up the other 70% of costs, most of the responsibility for keeping the system running is down to SYTRAL's distribution of the subsidized money they gain from taxes on Lyon citizens.

Political Influence on the TCL

In recent years, there have been many significant improvement projects initiated in the TCL system. With the aforementioned new tramlines, upgrades and restocks of the metro, and an increase of sustainably fueled vehicles, one important question arises: who pushed these initiatives?

The city of Lyon has had four mayors since 2001, all of which were aligned with centrist/left-wing political parties. Lyon's current mayor, Grégory Doucet, is a part of The Ecologists (or The Greens) party, whose platform puts a major focus on environmental and social issues and has had a major impact on TCL projects. Lyon, as a city with a strong public transit system and efficient management structure, provided an ideal location for this party to

enact its mission for environmental and social focus. For instance, Keolis Lyon, the current operational company for the TCL, must obtain a certificate of origin for the fuel used within the system (Berthonneau, personal interview, 27 June 2024). As Jérôme Berthonneau explained in our interview, “It’s because of the color of our politics here, they are a green party, an ecological party. So they demand that we use only green certified energy” (Berthonneau, personal interview, 27 June 2024). Politics greatly affect the TCL, as the system must follow European, national, and local policy, the last of which is the main level of politics explored in our research. Laws that are enacted within the city of Lyon are the most direct and specific policies that the TCL has to abide by. As Berthonneau elaborated about local regulations, “A law cannot be against the law of the national government, but it can be stricter” (Berthonneau, personal interview, 27 June 2024). With a longstanding history of central to left-leaning parties in power in Lyon, the local governing body for the TCL, these parties have a major and pointed impact on the future of the system.

For some policies regarding public transit in Lyon, politicians put initiatives into law to preserve the rule for the next group of elected officials. One example of this is a policy from The Green party limiting the ability to purchase petroleum-fueled buses for the TCL. As Jérôme Berthonneau explains “changing our buses from diesel to electric is mandatory, and I think in five years they won’t be able to buy diesel buses,” and that the party “did it in advance, so that in the law, new elected people won’t change that” (Berthonneau, personal interview, 27 June 2024). From these examples, it became clear that much of the ongoing expansion and innovation projects for the TCL are produced by Keolis Lyon and SYTRAL Mobilities, while the need/motivation for these projects is pushed by the local government.

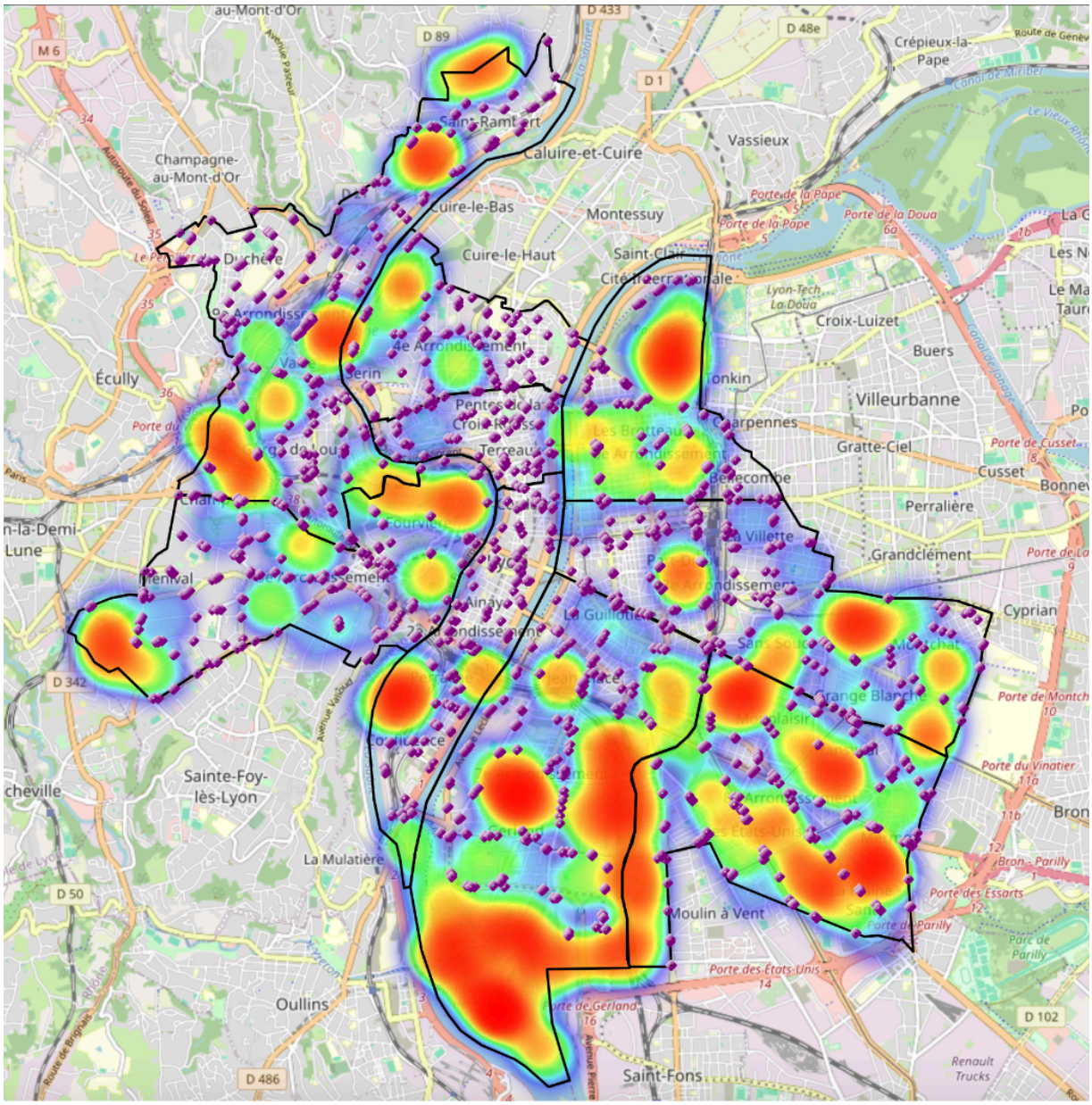
Does Lyon demonstrate the characteristics of a good transit system?

We found that the TCL, in most areas, excels as a public transit system. We believe it demonstrates many positive characteristics from the discussed scholarly and expert consensus on transit systems.

Mobility

In part due to the political support of the system, the TCL is able to provide significant mobility to the residents of Lyon. As discussed previously, this level of mobility can bring significant benefits to Lyon and its community. With the data we gathered, we created multiple maps to show the density of stops and lines within the City of Lyon and the larger Lyon metropolitan area. Specifically, we looked at the distance from buildings (as well as just residential buildings) to the nearest station on the network. This represents the distance from any given building that riders would have to travel before being able to access the TCL. With this data, we generated multiple maps to represent different areas and types of buildings. As can be seen in figures 9, 10, and 11, the red locations represent areas where buildings are further from transit stations, and the purple markers/blocks are stations in the network. To see hotspots of further distances, only the 90th percentile of farthest buildings are shown on the city-specific maps, and only the 99th percentile of buildings are shown on the Lyon Metropolis maps. As seen in Fig. 9, there are few hotspots where there is poor access to TCL stations within just the city. Within the city, 90% of buildings are 264 meters or less from the nearest TCL station. This is an incredibly low barrier to access for the system, demonstrating the great amount of possible mobility provided by Lyon's system in the city.

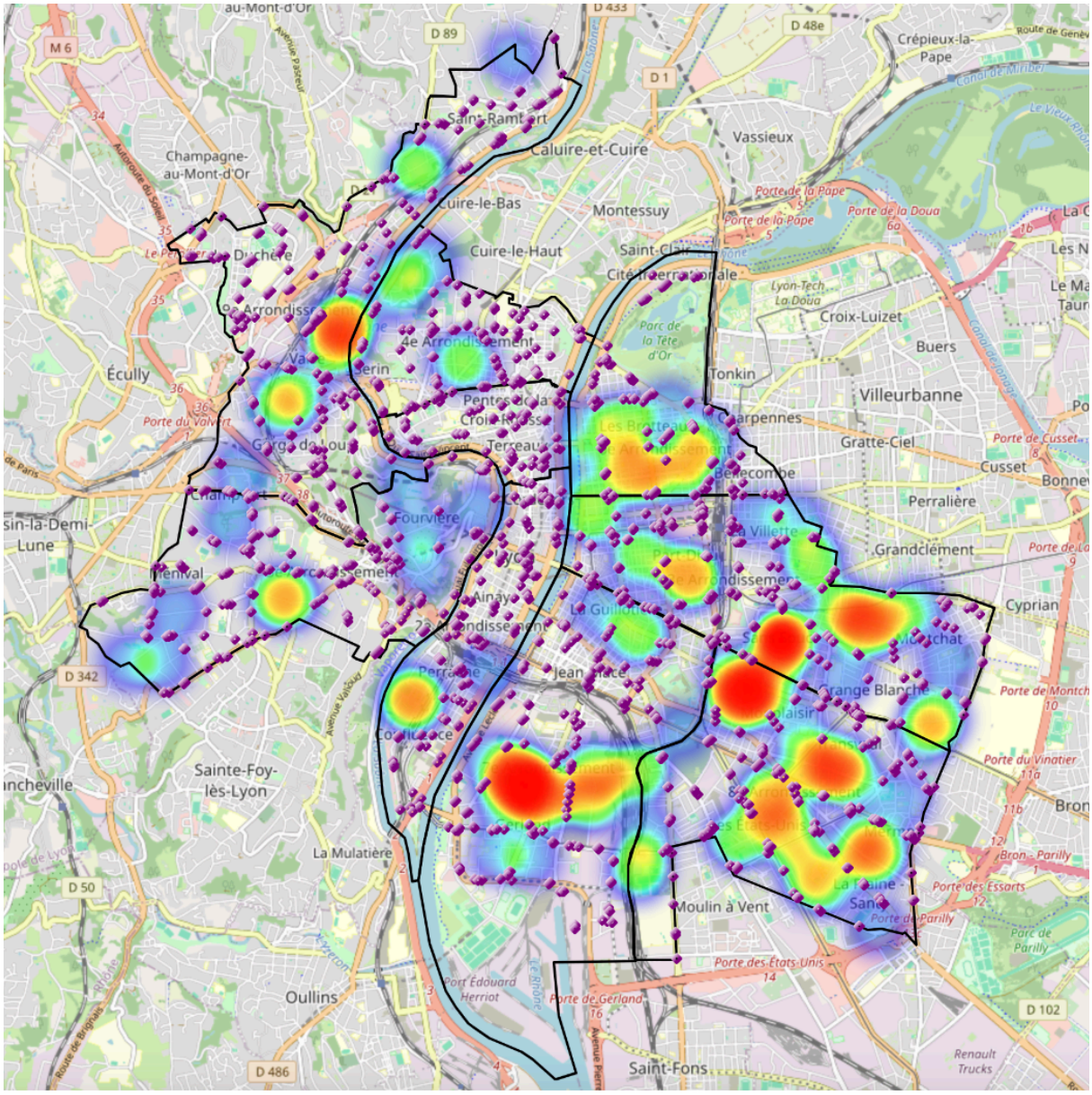
Figure 9



Heatmap of Distance From Buildings to Transit Stops (All Buildings, Lyon City)

Additionally, as seen in Fig. 10, the coverage of specifically residential buildings in Lyon is even better than when looking at all buildings. The corresponding statistic for residential buildings is 252 meters (or 0.156 miles).

Figure 10



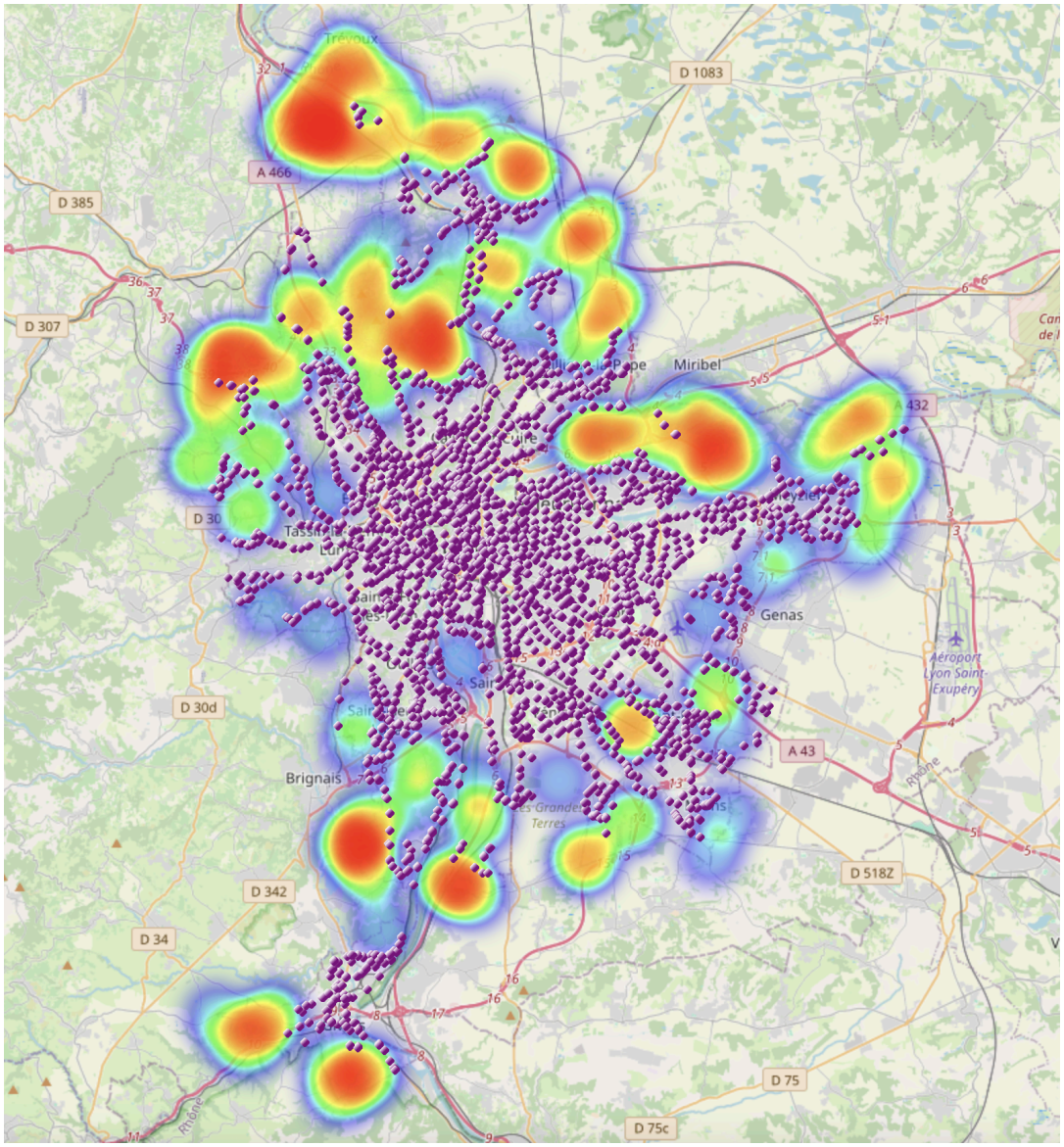
A Heatmap of Distance From Buildings to Transit Stops (Only Residential, Lyon City)

While we do not have this distance data to compare to other systems, it is clear that the TCL has been successful in providing a dense network in the urban areas of Lyon. Having to walk less than 250 meters from the vast majority of residential areas to gain access to the TCL

makes it incredibly convenient to use and allows for many new opportunities for residents that they may not otherwise have without easy access to transit (Gautier, personal interview, 12 June 2024).

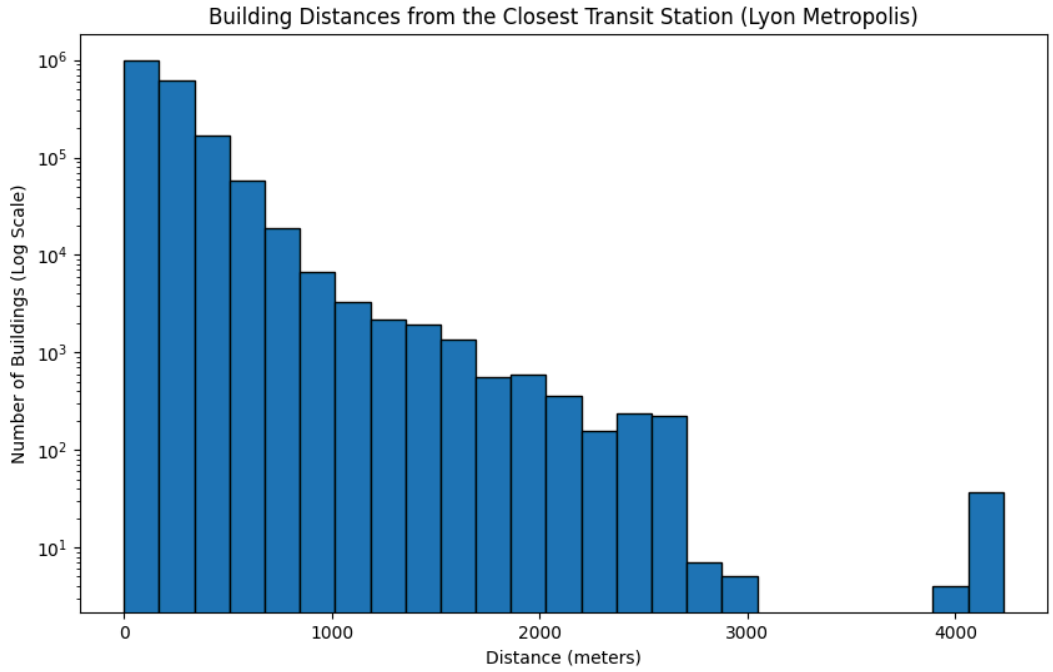
However, it is important to remember that the TCL also serves the extended Lyon Metropolis region. As seen in Fig. 11, there is moderate coverage in most areas in the greater Lyon region. There are still some suburban areas that are less served and would be difficult to walk or bike from, however. As seen in Fig. 12, some buildings are over four kilometers (2.48 miles) away from the nearest station in the less connected regions of the Lyon suburbs. The TCL is actively working on expanding, though, so we expect that these worst-case distance statistics will come down in the future (Berthonneau, personal interview, 27 June 2024; Klein, virtual interview, 2024). Despite the current issues, the TCL allows for access to Lyon from cities as far as 40 km away, which makes commuting into Lyon via the system very common and relatively easy. We do not have numbers on commuters that come into the city from neighboring suburbs, but from our interviews, we were told it is significant (Berthonneau, personal interview, 27 June 2024; Klein, virtual interview, 2024). Given this data, we believe the TCL exceeds expectations of a medium-sized city's transit system when it comes to system coverage and mobility.

Figure 11



Heatmap of Distance From Buildings to Transit Stops (All Buildings, Lyon Metropolis)

Figure 12

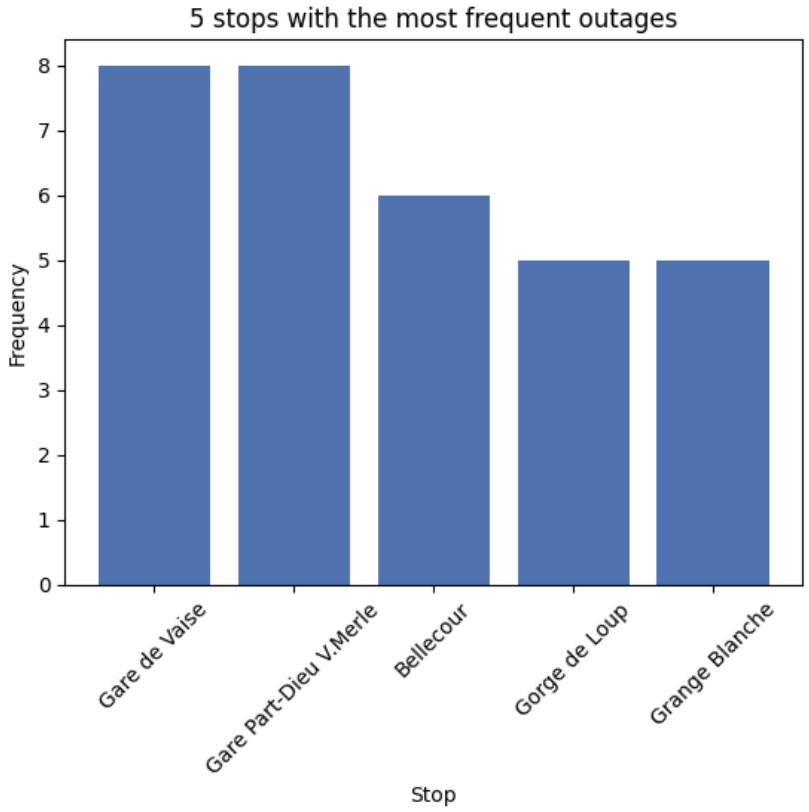


A Histogram of Distance From Buildings to Transit Stations (All Buildings, Lyon Metropolis)

While outages in the TCL are uncommon, outages that have a significant effect on mobility are even less common. Throughout the entire time that we spent in Lyon, we recorded 203 outages through our data scraping. Of these 203 outages, only 91 (44%) had a tangible effect on mobility; the rest indicated that something was broken or out of service that did not affect mobility. Of these 91 outages, 53 (58.2%) occurred between the hours of 12 am and 5 am, while the system is closed for maintenance. Only 14 of these 91 outages occurred during peak hours (7-9 am and 5-7 pm). Of these 14 outages, 6 involved a broken elevator or escalator, meaning that over a period of ~7 weeks, there were only 8 outages significantly affecting travel times during peak hours in the entire metro system (~4% of all outages). We also noticed that even when traveling through a station was impossible, the TCL provided a relay bus or shuttle to the next available stop along the line.

We also found that outages tend to occur at points of intersection and stops that offer multiple modes of transport. As is visible in Fig. 13, the 3 stops with the most outages are Gare de Vaise, which connects the metro line D, bus lines, and regional train lines; Gare Part-Dieu, which connects the metro line B, bus lines, tram lines, and national and regional train lines; and Bellecour, which connects metro lines D, A, and bus lines. This correlation between multimodal hubs and frequent outages likely reflects the high volume of traffic these stops handle. As major interchange points, Gare de Vaise, Gare Part-Dieu, and Bellecour serve a large number of passengers daily, facilitating transfers between different modes of transport. The increased foot traffic, frequent vehicle stops, and constant use of facilities at these locations may contribute to accelerated depreciation on equipment and infrastructure.

Figure 13



Bar Graph Of The 5 Stops With The Most Frequent Outages

Community and Political Support

We were consistently told by experts that one of the most important contributing factors to a transit system's success and continued quality is public support (Berthonneau, personal interview, 27 June 2024; Levinger, personal interview, 20 June 2024). A transit system could be technically perfect, but if there is no social support amongst the riders it serves, it still fails to serve its community, resulting in less political support, and, eventually, less funding. According to David Levinger, "If you have a bus system where upper middle class people ride the bus, then you end up having a dignified bus system." (Levinger, personal interview, 20 June 2024). However, if the transit system "is always viewed as a lower [...] or working class thing, [...] then you end up having a system that is bifurcated." (Levinger, personal interview, 20 June 2024). Levinger claims that social class plays a large role in political support for systems. If people believe that their status, money, or time are at risk using a transit system, regardless of the truth behind those beliefs, the system will see less political support, possibly crippling its funding.

In Lyon's case, the TCL is generally well-supported politically and socially. As previously discussed, under the Green Party, the TCL has seen many initiatives to expand and improve the system (Berthonneau, personal interview, 27 June 2024). While public opinion of the system is far from perfect, the ridership of the system speaks for itself, with the TCL supporting 1.8 million rides daily. Notably we were told that many of these rides were not from repeat users using the system to commute every day, but that there were a lot of inconsistent rides, meaning that the system is often used for non-routine trips instead of just for commuting. This difference in population and ridership implies significant public adoption

of the system as a replacement for car travel for outings like grocery shopping or social gatherings.

Public support and adoption of transit, though, is not a guarantee of political support. As a representative democracy, (similar to the United States) the length of a term in local governments for mayors and their administration is six years. These term limits mean that mayoral administrations of French municipalities will typically pursue shorter-term political goals, which can sometimes be incompatible with expansions of transit systems (Berthonneau, personal interview, 27 June 2024; Levinger, personal interview, 20 June 2024). Additionally, the Lyon government takes the initiative to support city infrastructure around transport, such as encouraging lower-emission transit modes like bikes by building safer bike lanes and supporting the bike rental program in Lyon, called Freevélo'v (as seen in Fig. 14) (Berthonneau, personal interview, 27 June 2024). In summary, Lyon's government has been very progressive in developing policies to further urban mobility and transit development (Berthonneau, personal interview, 27 June 2024; Levinger, personal interview, 20 June 2024).

Figure 14

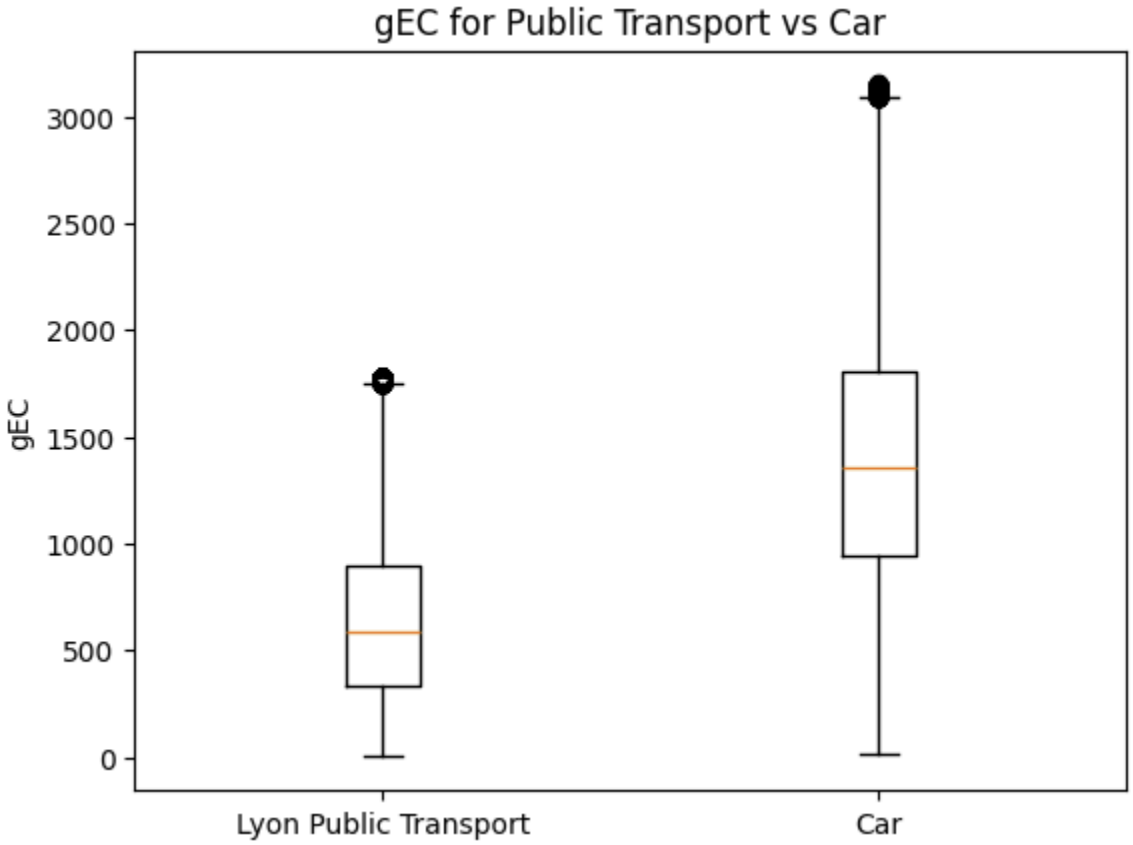
An Image of a Freevélo'v Bike Stand In Garibaldi

Sustainability

With the data obtained from scraping the TCL website, we show how using public transit in Lyon results in significantly reduced carbon emissions. The API response from the TCL website contains data on grams of emitted carbon (gEC) per passenger per trip. For an average distance per trip of 8.18 kilometers, we found the average gEC using public transportation to be 636.41 grams of carbon or about 77.72 gEC/km. The U.K. government estimates the average petrol car emits 170 gEC/km (*Greenhouse Gas Reporting*, 2022), backed by a study done on the European car fleet (Fontaras et al., 2017). Using this value, we added a new column to our journeys database that contained the gEC if the journey had been

taken with a car instead of using public transportation. These values were calculated by multiplying the total distance of the journey by 170, as mentioned previously. Thus, we find the average gEC using a car to be 1391.92 grams of carbon per trip. The difference between the two groups is shown in Fig. 15.

Figure 15



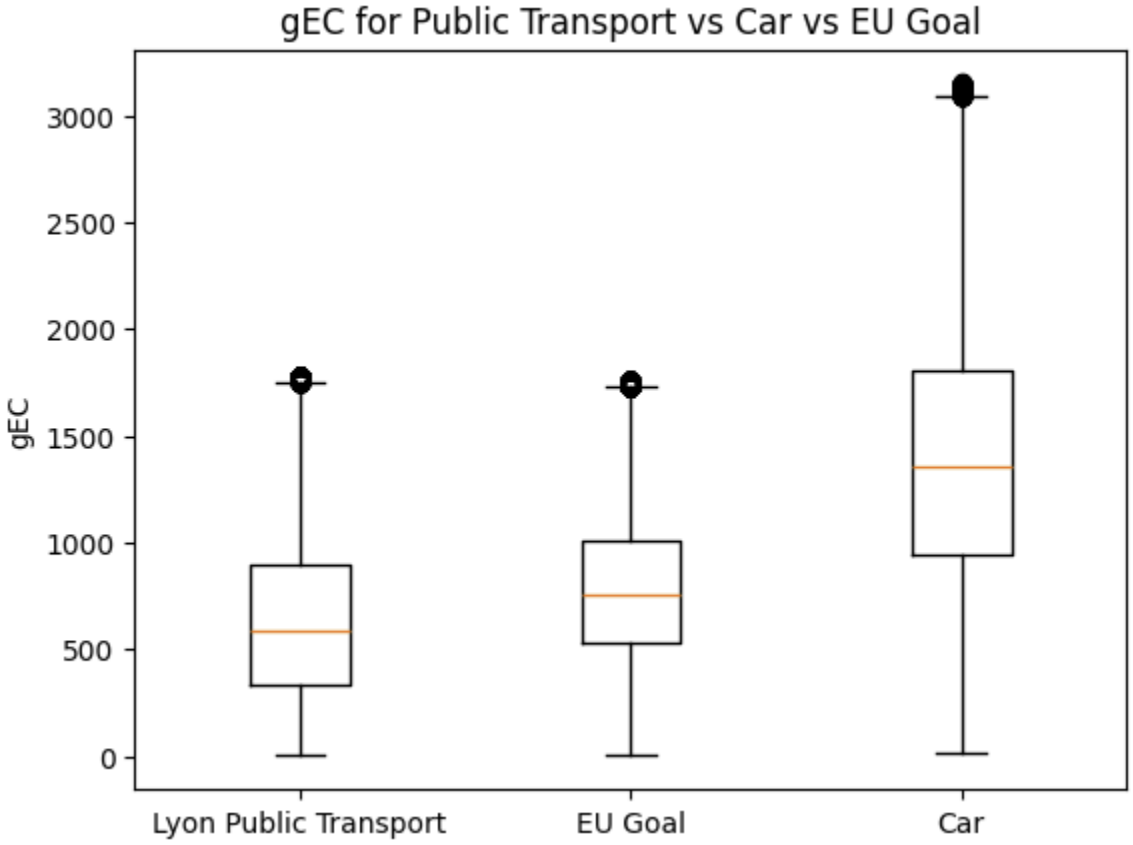
Boxplot of Lyon Public Transit gEC vs Car gEC

We then conducted an independent two-sample t-test at a confidence level of 99% with $\sqrt{n}$ (691 after removing significant outliers) random observations to determine if there is a statistically significant difference between the two groups. Due to our extremely large sample size, we can forgo testing for the assumption of normality. Levene's test for equal variances returned a p-value of 1.59e-30, meaning we cannot can not assume equal variances.

Therefore, we used Welch's t-test for unequal variances. The resulting p-value was well below our threshold alpha value, leading us to be 99% confident that using public transit in Lyon results in statistically significant reductions in carbon emissions. The results of these tests are available in Appendix G.

Additionally, in 2020 the European Union set a new emissions target for passenger cars at 95 gEC/km for 2024 (European Environment Agency, 2024). Using this value, we added another column to our database, containing the gEC if the journey had been taken with a car that emits 95 gEC/km. We then re-conducted the same test above using $\sqrt{n}$ (691) randomly sampled data points from our database. Once again, at a confidence level of 99%, Levene's test does not show equal variances with a p-value of 2.29e-8, so we used Welch's t-test for unequal variances. Our final computed p-value is 4.02e-7, which is less than our alpha value of 0.01. Therefore, we can be 99% confident that taking public transit in Lyon results in statistically significant reductions in carbon emissions when compared to a car that meets the EU 2024 goal for carbon emissions. While this goal set by the European Union would be a significant step in the right direction, as seen in the boxplot displayed in Fig. 16, this goal has not been achieved yet. Once again, the results from Levene's test and Welch's t-test are available in Appendix G.

Figure 16



A Boxplot of Grams of Emitted Carbon (gEC): Public Transit vs Car vs EU Target

We also noticed a positive correlation between gEC (public transit) and total travel duration ($R^2 = 0.691$), as well as a positive correlation between gEC (public transit) and travel distance ($R^2 = 0.436$), both of which we were expecting.

In an attempt to compare Lyon to other transit systems, we compared our carbon emissions data to data available on Numbeo, a source used by many major U.S. news outlets (Numbeo, 2024). When combining our average grams of emitted carbon (gEC) using public transportation and our average gEC using a car, we calculated the total average gEC for a trip to be 1,014.17 gEC over 8.18 kilometers, or about 123.8 gEC/km. Numbeo provides gEC in the form of a CO_2 emissions index, from which we can calculate the gEC value for a one-way

trip by dividing the index number by two (Numbeo, 2024). As seen in the equation below, we then divide by the average trip distance, also given by Numbeo, to calculate gEC/km for each city:

$$gEC/km = \frac{emissions\ index}{2} \times \frac{1}{average\ trip\ distance}$$

In our literature review and background, we outlined three cities that are well-known for having excellent public transit systems that we would like to compare Lyon to: Hong Kong, Istanbul, and Paris (Mohr et al., 2021). During our interviews, we also learned that Seattle has an excellent public transit system (Levinger, virtual interview, 2024). Lastly, we would also like to compare Lyon to Boston, as our university is located in Massachusetts and the entire team has some experience using its system.

Numbeo's CO_2 emissions index for Lyon is 4,370.44 for an average trip distance of 16.03km (Numbeo, 2024). Dividing this number by four (two to make the average distance equal, then two to calculate the gEC), we obtain 1092.61 gEC, which is similar to our data. These values and all values calculated in the following paragraph can be seen in Table 2.

Hong Kong's CO_2 emissions index is 1,624.0 with an average trip distance of 15.3 km (Numbeo, 2024). Dividing the emissions index (1624.0) by two gives us 812 gEC/15.3km. Hong Kong's gEC/km was then calculated to be 53.07 using the formula above, which is 42.86% of our calculated value for Lyon. Istanbul's CO_2 emissions index is 7,329.36 with an average trip distance of 20.09km (Numbeo, 2024), giving us 3,664.68 gEC/20.09 km, or 182.41 gEC/km. This data shows around a ~1.5x (147.3%) increase from our calculated gEC/km value for Lyon. Paris's CO_2 emissions index is 2,896.07 with an average trip distance of 14.14km (Numbeo, 2024). Following the same formula, this gives us 1,448 gEC/14.14km or 102.41 gEC/km. This gEC/km value is around 82.7% of our calculated gEC/km value for

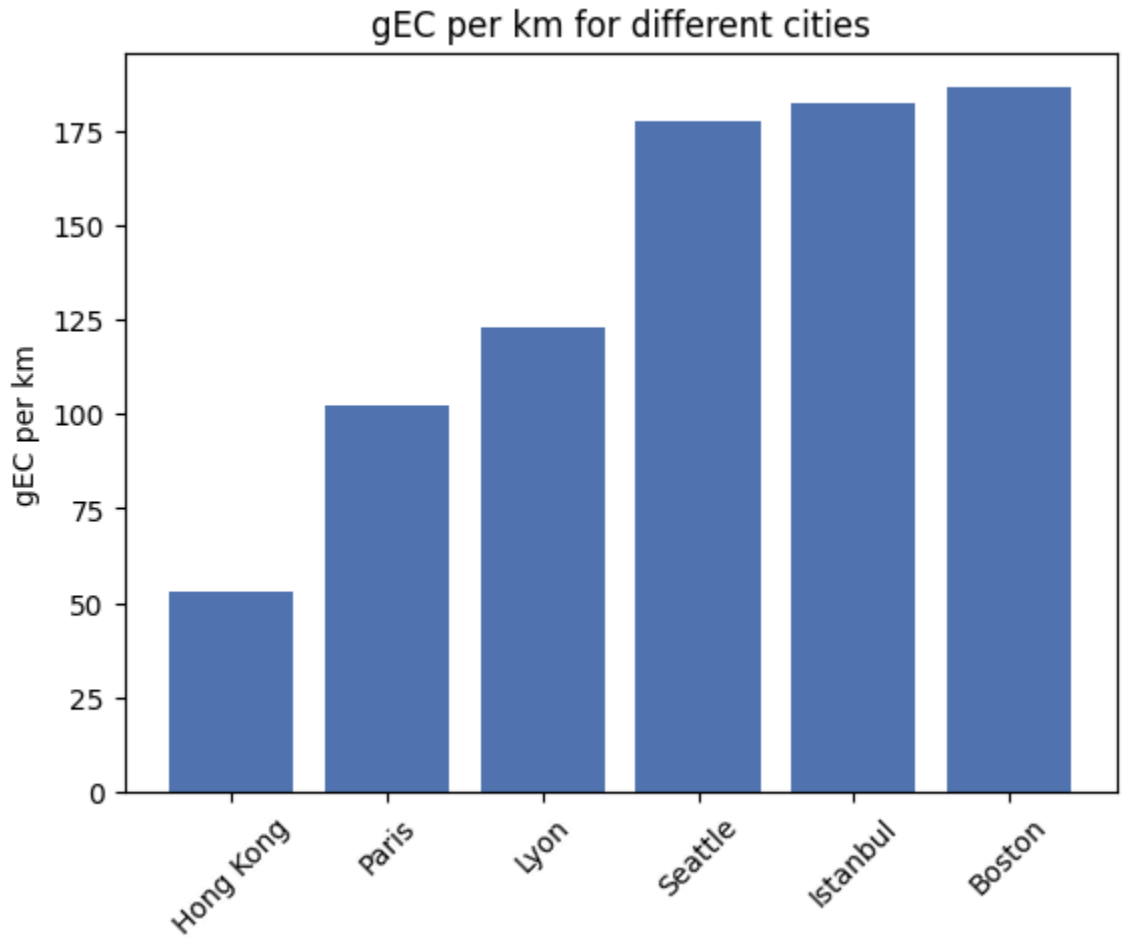
Lyon. Boston's CO_2 emissions index is 8,324.02 with an average trip distance of 22.34km (Numbeo, 2024). This then gives us 4,162.01 gEC/22.34km or 186.3 gEC/km. This value is around a 1.5x (150.45%) increase from our calculated value for Lyon. Seattle's CO_2 emissions index is 7,893.64 with an average trip distance of 22.27km (Numbeo, 2024). This then gives us 3,946.82 gEC/22.27km or 177.23 gEC/km, representing a ~1.4x (143.12%) increase from our calculated value for Lyon. We then present a visual representation of the differences in Fig. 17.

Table 2

Comparison of gEC and gEC/km

City	gEC	Avg. Distance	gEC/km
Hong Kong	812.0	15.3	53.07
Paris	1448.035	14.14	102.41
Lyon	1014.17	8.19	123.83
Seattle	3946.82	22.27	177.23
Istanbul	3664.68	20.09	182.41
Boston	4162.01	22.34	186.3

Figure 17



Bar Graph Comparison of gEC/km for Hong Kong, Istanbul, Paris, Lyon, Boston, and Seattle

Usability - Four Pillars

As mentioned in our literature review, Levinger & McGehee (2008) categorize the four aspects of usable public transit to be ease of use, effectiveness, comfort, and aesthetics. Criteria for a good experience will vary from person to person but overall, we believe that Lyon's system does a good job of incorporating each of these aspects.

Ease of Use

We found that Lyon's public transit system is easy to use for all riders. Tourists or non-native speakers of French can easily select different languages on ticketing machines. Announcements and signs, which have large and legible text, are provided in both French and English. Metro B is installed with small LCD screens lining the top edges of each vehicle, providing audible announcements with translation and a visual representation of upcoming stops and arrival time at the final stop, as shown in Fig. 18.

Figure 18

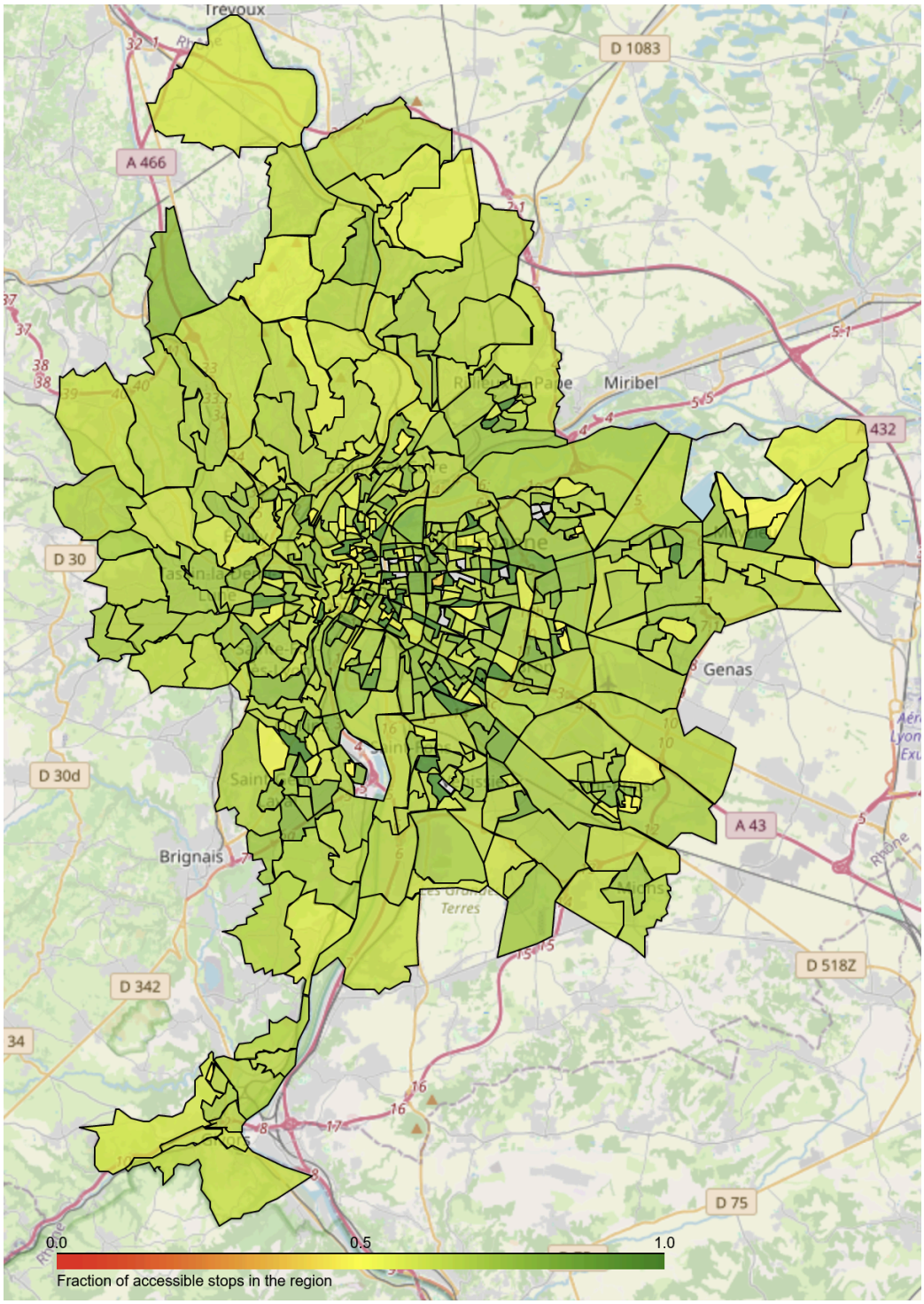
Image of an LCD Screen Installed on a Metro B Vehicle

As mentioned previously, the TCL network is built from the ground up to be multimodal. This means TCL tickets work for all TCL vehicles, schedules are aligned to allow for easy transfers between different lines or even different modes of transit, and expansions are designed and built to seamlessly integrate with the existing transit lines. These considerations, along with effective scheduling and vehicle allocation, make the TCL an incredibly easy-to-use system for users, leading to few circumstances where riders wait for a vehicle for an excessive time. The system as a whole, due to an abundance of signage and

maps, is also incredibly easy to navigate regardless of trip distance, number of vehicle transfers, or prior experience with the system (static data collection).

Lyon's public transit system also offers an excellent level of accessibility for individuals with reduced mobility, such as wheelchair users, making the system easy to use for everyone. To show and quantify this level of accessibility, we combined the data obtained by scraping the TCL itinerary planner with Lyon's IRIS contour data to create an interactive map. IRIS is a database managed by the French government that divides municipalities with over 10,000 residents into geographical zones for census data (*Contours... IRIS - Data.Gouv.Fr*, para. 2). Scraping the TCL itinerary planner gave us data on stop accessibility, such as whether wheelchair boarding is possible from a given stop's platform. We used these two datasets to create the interactive map shown in Fig. 19, where each region is shaded based on the fraction of wheelchair-accessible transit stops within that region. Lyon does well in this regard, only having a single region (Richerland-Petites Sœurs) with a ratio of less than 50%. This region only covers eight city blocks, yet contains five transit stops, of which two have wheelchair-accessible boarding.

Figure 19



Accessibility Map of Lyon Generated Using TCL and IRIS Data

Additionally, we found that 71% of metro stops had at least one escalator per platform, and 88.6% of metro stops had at least one elevator per platform, providing mobility for those who are not able to take the stairs. We also noticed that there tended to be a ticket scanner/turnstile per entrance to each platform specifically designed for wheelchair users to be able to pass through easily, as shown in Fig. 20.

Figure 20

Image of a Wider Turnstile Allowing for Wheelchair Users to Pass Through

However, Lyon's system still has room to improve in a couple of areas. First of all, the TCL offers two mobile apps: the Lyon Public Transport app (Fig. 21) and the TCL E-Ticket app (Fig. 22).

Figure 21

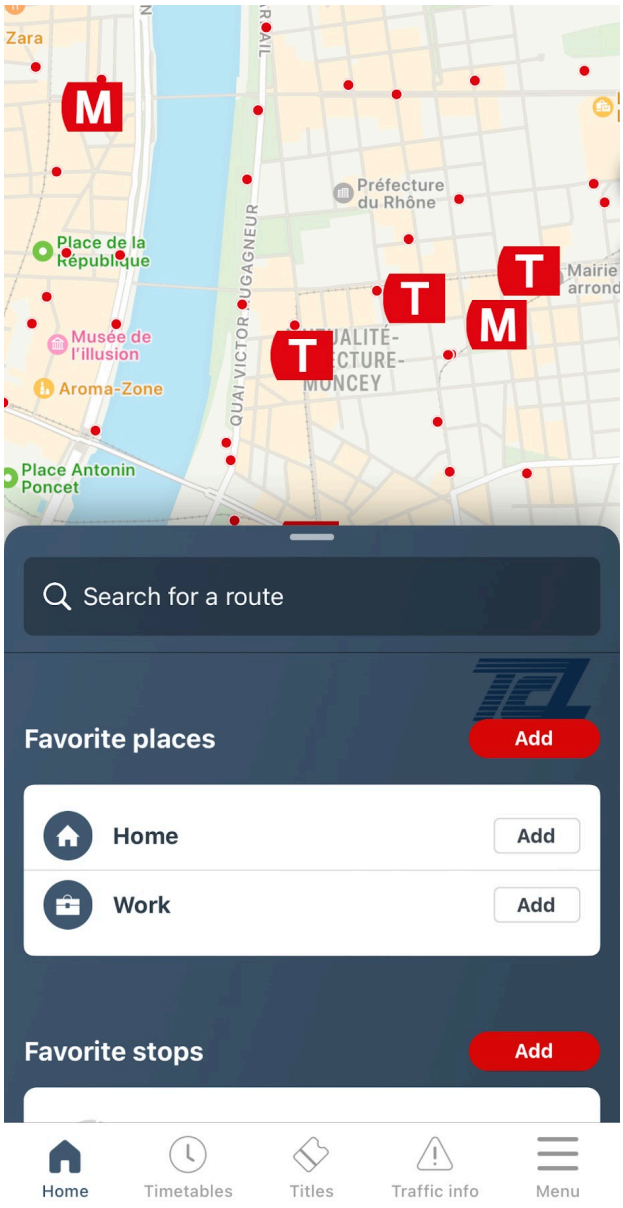


Image of the Lyon Public Transport app

Figure 22

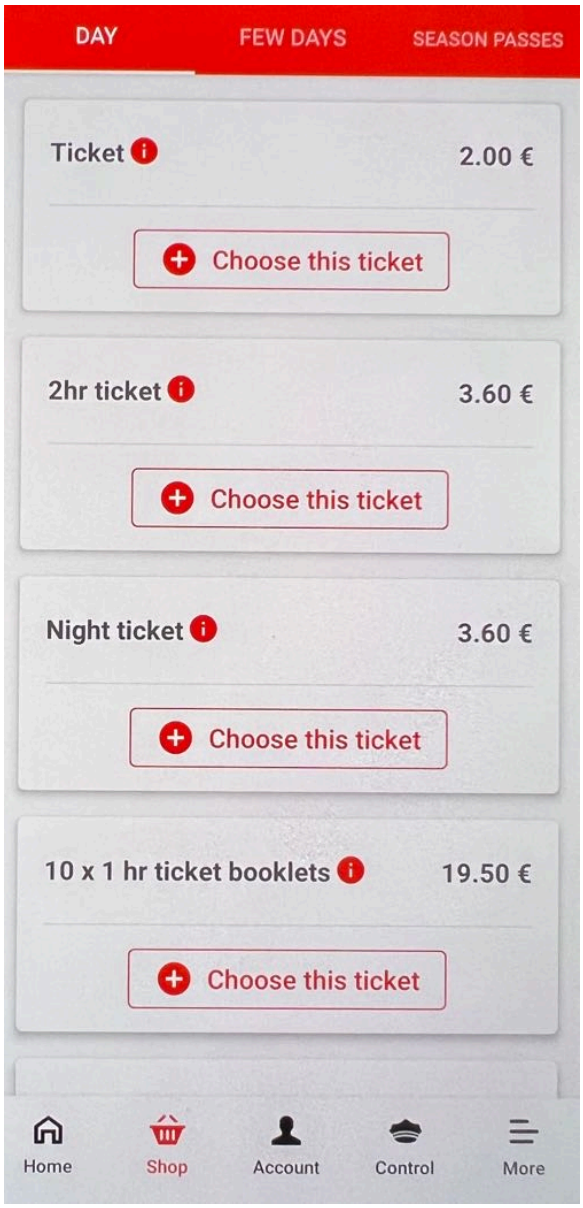


Image of the TCL E-Ticket app

The former is available for both iOS and Android users, while the latter is only available on Android devices. The TCL E-Ticket app, as the name implies, allows users to purchase "specialty" tickets or passes (like monthly passes, special discounted tickets or passes, and reloadable accounts) for the TCL without having to visit a ticketing office and pay an extra five euros for a physical card. It should be noted that you can purchase specialty tickets

online, however they require a mailing address as specialty tickets cannot be dispensed digitally. Globally, Android devices dominate the market holding 70.93% of the market share, to Apple's 28.32% (iPhone vs Android User Stats (2024 Data), 2023). However, in countries like Japan, Canada, Australia, the United Kingdom, and the United States, iPhones are the most prevalent mobile devices (iPhone vs Android User Stats (2024 Data), 2023). By not allowing iOS users to access digital ticketing services, the TCL alienates large parts of its foreign and tourist user base. Introducing iOS compatibility for the E-Ticket app would greatly increase the accessibility of online ticketing sales and would provide convenience for many TCL users.

Systems as large and complex as the TCL are also bound to face challenges within both the organizational and operational structures of the service. Like all transit systems, the TCL experiences regular disruptions, concerns about facility cleanliness and safety, as well as controversy regarding ticketing prices and models. As one Lyonnais writes, "The tram is not reliable: If I can't know in advance whether my tram will take ten or 25 min to go from A to B, I risk being late to work," and "during rush hour […] you'll always be faster if you walk. And outside of rush hour they only come once or twice an hour" (Montanari, 2018). There is serious concern from daily commuters regarding the reliability, scheduling, and availability of TCL-offered transportation methods during peak times of travel and dissatisfaction with long waiting periods between vehicles during low usage times. It is useful to mention that the TCL does have an itinerary planner mobile application, but it does not take into consideration real-time congestion and/or outage data, and many users find the app to be unreliable and in some cases unusable as the app is rated 3.7/5 on the Google Play Store and 2/5 on the Apple App Store. Additionally, according to the Tribune de Lyon, the TCL faces "recruitment

difficulties, unattractive salaries, increasingly poorly organized days, [and] higher than average absenteeism rates" (Gossart, 2022). The TCL faces large, but not uncommon, operational hurdles like understaffing within the system which in some part has accelerated the frequency at which transit lines are non-functional (Gossart, 2022).

Aside from problems regarding the system's structure and complexity, locals of Lyon have expressed their own set of issues. One way they did this is by creating Facebook groups to complain about their experiences. Price is a common complaint among users. Some posts describe the tardiness of bus routes and tramlines not being reliable. While we did not extensively study buses and trams in this report, a distrust in any part of the system is still bad for public perception. Public perception is incredibly important for a service that is funded by the government, and it could be argued that perceptions of quality, or lack thereof, matter more than data-driven analysis of quality.

Additionally, many residents and employees of the Lyon public transit system are unhappy with the general management of the service in addition to physical inconveniences. A recent development split ownership and management of the TCL between multiple organizations. In response to this development, union organizations in a 2022 strike explained that they "fear a breakdown in the management of metros, funiculars, tramways and others" and "question the future of the company's many drivers" (Soudani, 2022). While there is a consensus that riders are satisfied with the current system, there is a trend of increasing discontent with the quality of transportation offered, and those who are most satisfied with the system are riders who only take the occasional trip on the TCL.

A common theme that was covered across our interviews was a lack of integration between the TCL and regional train lines. Olivier Klein and Jérôme Berthonneau both touched

on this when we asked them what they believed was the biggest weakness of Lyon's public transit system. As Klein said, "we are not at the level of Switzerland or Germany. In France, it is not very specific to Lyon. It is the lack of integration of all transport systems. We have urban public transport (TCL), TER, and regional trains. We have auto-cars, and it is completely separated. There is very little technical integration. In other countries, in particular in Switzerland, things are much more advanced." (Klein, virtual interview, 2024). Jérôme Berthonneau re-iterated this point: "one of the weaknesses, clearly comparing to other networks, not in France because it's never the case, but internationally, it's the lack of complementarity between the TCL network and the network of regional trains" (Berthonneau, virtual interview, 2024). Integrating local and regional transportation would make public transit easier to use for longer-distance travel, allowing users to not only connect between metro, bus, and tram with the same ticket, but potentially also regional and national rail lines.

Effectiveness

In general, transit stops in Lyon see many departures per hour and provide more than enough capacity. Riders typically wait less than 10 minutes for a vehicle to arrive (even less for the metro - 3 or 4 minutes), and it is rare it is full even during peak hours. This is not always the case, however, and there are sometimes delays in transit, especially with the bus lines. Metro lines also occasionally experienced delays, and our team was caught in these delays a handful of times, as seen in Fig. 23.

Figure 23

Image of a Delay Message on the Metro, "Line A - Traffic Disruption"

For prolonged delays, alternative transit options are made available to ensure major delays are prevented for riders. Even during peak hours (which we observed to be 7-9 am and 4-6 pm from our TCL scraping data and dynamic data collection), we rarely saw vehicles too full to serve all the passengers on a station platform. It did happen occasionally, but was still mostly painless as a new vehicle would arrive shortly afterward to serve those left behind.

We found that, for all modes of transit, different amounts of vehicles were run based on time of day or overall demand. The TCL would operate fewer vehicles simultaneously at less busy times of the day to prevent unnecessarily empty rides. This results in somewhat longer waits during these off times, but even with the limited capacity, there is still a consistent stream of vehicles to serve riders. This saves money and prevents unnecessary pollution, so we believe that it is a worthy tradeoff, despite the mild inconvenience for riders.

As mentioned previously in our findings, the density of transit stations in Lyon is excellent. The system as a whole is extremely intermodal, allowing transfers between metro, bus, tram, and trolleybus with ease, even for those with reduced mobility such as wheelchair

users. When speaking with Jérôme Berthonneau, we asked what he believed the greatest strength of Lyon's public transit system is. He responded by talking about the multi-modality of the system and how each method of transportation connects the others (Berthonneau, virtual interview, 2024). Taking the metro or the tram is quick and efficient, but these lines are time-consuming and expensive to build, so buses and trolleybuses provide the system with more granularity. By combining the efficiency and speed of metro and tram lines with the granularity of buses, the TCL becomes an incredibly effective system, no matter where a user's final destination may be.

Comfort

The TCL offers fairly basic but well-maintained amenities within the system. For physical conveniences, most stations and vehicles have seating areas installed as seen in Fig. 24, including upholstered benches. All TCL stops have maps of the system present on the platform. In addition, all TCL vehicles are accessible with wheelchair access and designated spaces for wheelchair users. There are also projects in the TCL to include air conditioning on most vehicles and water bottle fillers (Fig. 25) in large metro stations (Public Transport Homepage - SYTRAL, n.d.). These programs are in response to an increase in heatwaves in the Lyon area due to climate change, as reported by SYTRAL Mobilités (Public Transport Homepage - SYTRAL, n.d.).

Figure 24

An Image of the Seating Available in the Saxe Gambetta Station

Figure 25

Image of a Water Bottle Filler in St-Genis-Laval Hôp. Sud Station

While these initiatives are helpful, it is important to note that they are currently quite limited. The water bottle filler program is currently installed in 11 of the 42 metro stations with on average, one filler per station, but is expected to be expanded in the future. As for metro cars with air conditioning, it is currently only installed on Metro B with no publicly announced plans to expand the initiative.

In addition to physical installations, one major aspect of comfort within a transit system is user density. As Corentin Gautier explains, “in the other city like Paris, there are too many people. So in Lyon there is not a lot of people.” (Gautier, personal interview, 12 June 2024). Compared to the public transportation in Paris, Lyon has a relatively “quiet” system. Vehicles that are crowded are often uncomfortable and can often dissuade a potential rider from utilizing the system, which is why the TCL’s ability to keep vehicles relatively uncrowded outside of absolute peak times is a large benefit to the system.

At stops, staff are primarily present to perform periodic checks dedicated to reducing fare evasion. Additionally, there are security, information, and emergency personnel, as well as help buttons present throughout the metro system, as seen in Fig. 26.

Figure 26

An Image of a Help Button in the Garibaldi Station

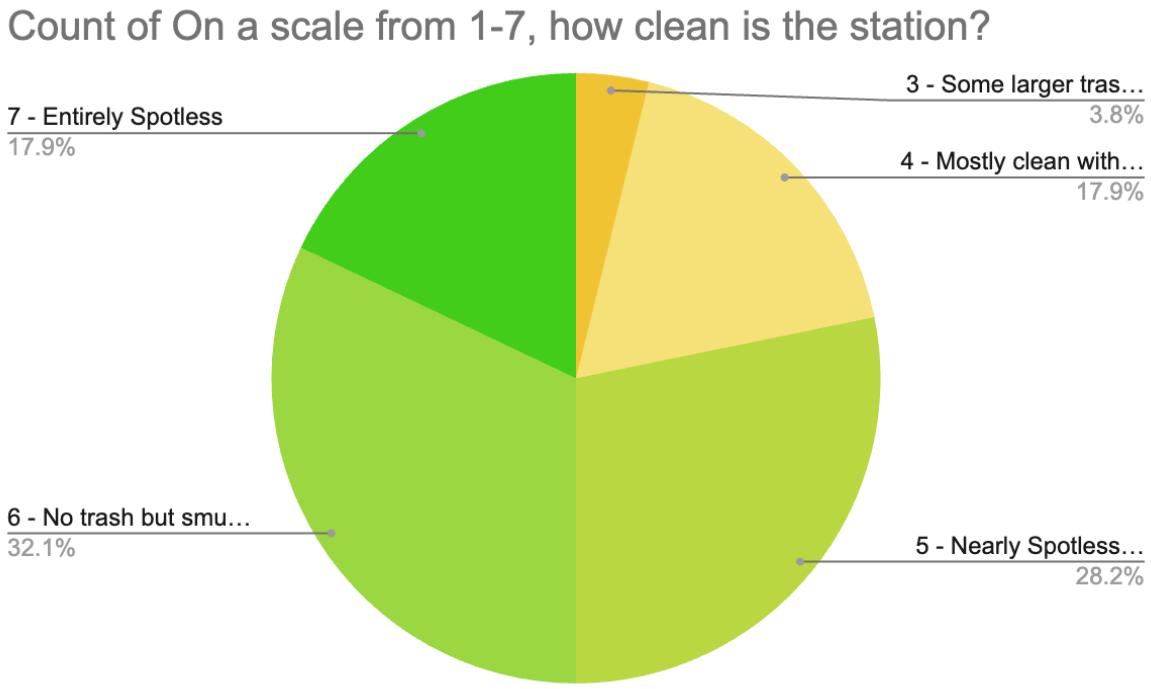
These buttons are available for the TCL's operating hours and can be crucial for emergencies where no security personnel or staff are present. Overall, the TCL provides adequate amenities, personnel, and initiatives to serve its riders with a safe and comfortable experience within the system.

Aesthetics

The final pillar of usability is 'aesthetics', or how appealing something is to the senses. From the outside, the names and colors of stations are portrayed clearly and professionally. Stations are designed in a way that is easy to navigate without overloading the user with visual information. Lighting is not bright but enough to make a way clear, and some stations

have windows or are open to the air. Many platforms are symmetrical so riders get a similar experience regardless of which direction they are going. The train stations themselves are quite clean as evidenced by our dynamic data. Fig. 27 demonstrates that 78% of the stations we visited scored a "5 - Nearly Spotless" or above, meaning riders will encounter at most a few pieces of trash that are out of the way.

Figure 27



Pie Chart of Dynamic Form Responses to the Cleanliness Question

For example, in one station, we found a large piece of trash littered beside an elevator as shown in Fig. 28.

Figure 28

Image of a Piece of Litter in the Gare d'Oullins

But from a wider perspective, the rest of the surrounding area and station were almost completely devoid of trash debris, as shown in Fig. 29.

Figure 29

Image of a Piece of Litter in the Gare d'Oullins

The lack of trash shows that the TCL cares about maintaining visual standards and notices when something is lacking. The stations *Valmy* and *Mermoz Pinel* are two examples of the many stations with art on display, such as designs on the floor or painted colors on the walls. *Saxe. Gambetta* even has a large suspended sculpture, which is shown in Fig. 30.

Figure 30

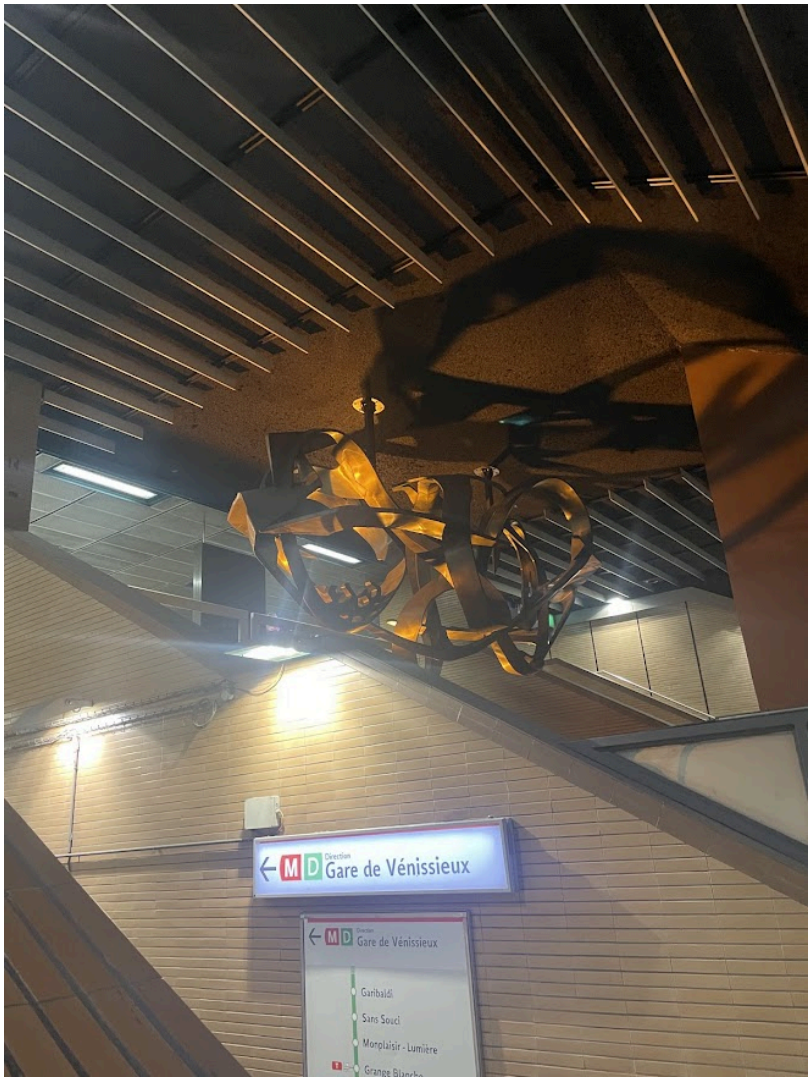


Image of the Sculpture at Saxe Gambetta Station

The main source of noise within the platforms and trains is that of people with the occasional announcement made over the speaker, neither of which are offensively loud. While

on or navigating the platforms, our group noted that there were never any unpleasant odors. A positive atmosphere is incredibly important in transit, and Lyon's stations present one that is pleasant and welcoming, and therefore, unlikely to ward off potential riders.

What are the benefits of the public transit system in Lyon?

Benefits to Commuters & Residents

As seen in the above heatmaps on network density, the TCL provides an incredible amount of mobility to its residents. It is common for commuters to take the TCL to work whether they live in the city or the surrounding Lyon metropolitan area due to the ease of use and relatively low price of a longer commute. Some students we talked to shared that they thought the price was too high, and they often chose to bike instead, but compared to other European systems like Paris or London, the TCL is still reasonably priced for what it offers.

Most transit systems offer a ride to and from work to significant portions of their population, and Lyon is no exception. However, Lyon has also gained significant adoption for non-work rides as it provides a cheap, mostly reliable option to residents who may not want to drive or do not own a car at all. This spurs significant economic opportunities for businesses and provides the ability for residents to travel farther than they otherwise would for social outings. We were told the system is incredibly convenient for traveling to the city center for food or drinks, and, without much planning, getting back home safely and efficiently (Gautier, personal interview, 2024). This ability and confidence from users gives many residents opportunities that are otherwise unavailable for some, due to the high costs of car ownership in French and European cities.

Benefits to Tourists

Similarly, having an easy-to-use transit system for non-French speakers is a huge boost to tourism. As newcomers to France and Lyon, our team found it easy to travel anywhere throughout Lyon on the TCL, which boosted our confidence in exploring the city immediately. It cannot be understated how much a competent transit system improves the experience of tourists, as confidence in navigation encourages spending more time out and about in the city. When tourists have a positive experience outside of their residence, they are much more likely to spend money and support local businesses, and that is exactly what we saw during our time in Lyon (Gautier, personal interview, 12 June 2024; Klein, virtual interview, 25 June 2024).

Benefits to the Economic and Urban Activity

As stated in our background research, an investment in public transit yields a great return on GDP. Cities often occupy massive swaths of land that are dense in places of commerce and services. However, when branching from the city out towards the suburbs, these amenities become sparse and difficult to travel to. Based on our interview with Jérôme Berthonneau, in the city of Lyon, the full TCL transit structure is made in a web-like design such that it is easy to enter into and out of the city as well as between different parts of the suburbs through tram or bus routes (Berthonneau, personal interview, 27 June 2024). With more accessible transit design, people can commute further, which can allow for the purchase of necessary goods at distant malls, stores, restaurants, etc. From our own experience, traveling to the rich restaurants near Bellecour, the artistic museums like the *Musée des Beaux-Arts*, or the high-class wineries in the old city were all made possible due to the mobility transit provided. Also, in our interview with Corentin Gautier, he mentioned that he often used the system to “go to the center and drink some beer” or “go shopping, for

example." (Gautier, personal interview, 12 June 2024). Restaurants and shops rely on foot traffic in their area to survive, and as explained through our research, public transit provides a cheap and accessible option for people to find and visit new things.

Placing transit stops at strategic locations also allows for a hub to be created where members from different regions of Lyon can converge socially. Attendees of festivals, concerts, and other large gatherings often rely on public transit, especially if they live locally. Our team and cohort could attend some of these gatherings with ease by using the transit system, such as a recent concert by music producer *MC Solaar*, a rave at the *Musée des Confluences*, or a famous yearly festival called the *Lyon Street Food Festival*. While the social impact of public transit is more difficult to measure and collect data on, in an urban community focused on gastronomy, wineries, and festivities like Lyon, it is one of the more important aspects.

Conclusions

Culmination of Research

We find that Lyon's TCL is a case of excellent transit design, management, and operations, especially when considering its status as a non-capital, medium-sized city. The TCL may not be flashy, but it easily fulfills its job as a transit system and provides immense value to its community. During our time in Lyon, we became more confident in this conclusion with every piece of data we collected. We feel that we have been able to confidently answer our research questions with this data as well as our personal experience with the system.

Our first research question was simple: how is Lyon's transit system organized? While a large amount of data is available online to answer this question, there are many other factors to think about when considering the full story. The TCL is composed of two main companies: Keolis and SYTRAL Mobilités, where Keolis is the private advisor and operations company while SYTRAL is the public authority and marketing company that is funded directly by the French government. From our interviews with TCL officials, we found that SYTRAL dictates most of the project decisions since they control the money. Approximately 30% of the money the company gains as revenue comes from ticket costs, while the majority of the system's function is funded by taxes the government collects and subsidizes towards urban development. Since the government has direct control over the bulk of the earnings, politics play a major role as well. When the TCL considers future projects, they often can take 10 to 20 years to plan, construct, and execute, which is more than double the length of a political term in France. Thus, we also learned that most of the strength of the TCL comes from

maintaining good political relations with the people and elected leaders, such that their investments and projects can come to full fruition.

Our next goal was to determine how "good" the TCL is as a transit system by looking for characteristics commonly seen in other well-regarded systems. Overall, we find that Lyon excels as a transit system and demonstrates many of these traits. Signage, ticketing machines, and announcements were displayed in multiple languages, making the system quite easy to use and navigate. Furthermore, the TCL is completely intermodal: metro and tram lines provide a high level of efficiency, and bus and trolleybus lines supplement the metro to provide significant density. We found that significant efforts are taken in operations and planning to ensure the multimodality of the network is utilized to its fullest. This multimodality is a large part of what allows the TCL to be effective in serving Lyon and its riders. The design allows for low wait times across all systems and alternative routes when prolonged delays eventually do occur. Network accessibility is also strong due to these efforts since buses are used to connect further regions where building a connecting metro line is not feasible.

As discussed previously, the four pillars that define usability in urban transit systems are ease of use, effectiveness, comfort, and aesthetics. By using this as a basis for how a user-oriented system is designed, we found that Lyon exhibited all of the pillars of usability to a decent degree. For ease of use and effectiveness, the transit was found to be reliably fast, carbon-efficient, far-reaching, and accessible around the entire metropolis. For comfort and aesthetics, we found the TCL to possess clean and odorless stations, driven by the efforts of the TCL janitors and Lyonnais culture. Also, a considerable amount of funding was put into security, decongesting traffic, and creating artistic displays at stations to improve the overall

experience. Thus, the TCL, with its success in all four of the pillars of usability, shows significant thought for user-oriented design patterns.

Our final research question was to evaluate how the TCL benefits its riders, as well as Lyon as a whole. We found that the TCL's impact on Lyon was immense, not just in its service to riders, but also by indirectly promoting economic growth through tourism and easier access to inner-city businesses. On average, the TCL services 1.8 million trips per day with just 1.4 million residents within the greater Lyon metropolis (Berthonneau, personal interview, 27 June 2024). These commuters reaped the benefits of efficient travel to their work, school, social gatherings, and more. Tourists also reaped these benefits, and there was enough simplicity in the multilingual design to make purchasing tickets and riding the system easy for most travelers. Finally, being a gastronomy hotspot, Lyon's urban transit improved the quality of travel to restaurants and social destinations. The TCL offers many benefits in different transport contexts to riders, and in doing so, benefits Lyon as a whole.

Limitations & Future Work

While all of our results point to positive traits of Lyon's urban transit system, several limitations within our project may confine our full understanding. First, only one team member spoke French, so the majority of our reviewed literature was either in English or had to be translated. Also, we were only able to study the system in-person for two months, which was enough to generate a snapshot of the inner workings of the system but too little to identify meaningful trends over longer periods of time. While we did collect insightful data about the system from field experts, gaining a consensus on the general population's opinion towards the TCL was difficult and likely biased without speaking to a diverse group of locals. Lastly,

our perspective is that of American outsiders, therefore we cannot analyze Lyon's public transit through a lens that is culturally French.

During our time in Lyon, we intended to travel to stations throughout the TCL and collect data such as wait times, platform cleanliness, transit vehicle crowdedness, and more. We began this data collection via a Google Form, shown in Appendix F, that allowed team members to input this data for every station and transit ride. However, we quickly realized that it would take an immense amount of data, perhaps somewhere in the thousands of data points, to draw useful statistical conclusions or find time-based trends. When establishing this method, we knew we would have to visit every station multiple times, but did not account for having to record different periods of the day several times. Carrying out this amount of data collection simply was not feasible during the short time we were in Lyon, so we eventually dropped this method of data collection after collecting 82 data points.

While our ethnographic data provided useful blanket insights, our group also wanted to better understand what other data could be accessed. We started this project hoping that the TCL would be willing and able to provide hard data on the system for analysis. Unfortunately, SYTRAL, the managing body of the TCL, did not respond to our emails so we were unable to compare our data to theirs. As such, we have relied solely on the data gathered from ethnography, web scraping, archival research, and interviews. While useful, not having access to any private data from the source means that any conclusion drawn as to why the system is as it stands may be incomplete.

Another method we attempted, which we originally intended as our primary final deliverable, was the Urban Mobility Readiness Index (UMRI) calculation for Lyon. The UMRI is a concretely defined framework to compare and study public transportation systems

for their preparations and design done for future mobility and sustainability (Thibault et al., 2022). For this project, we had hoped to conduct several semi-structured interviews with people from the Oliver Wyman Corporation to learn about the methodology behind the index. Through archival research, we found a list of several metrics they used per category when measuring the mobility readiness of cities. However, these metrics did not have concrete formulas to calculate the final values. Oliver Wyman, the publisher of the index, is a private consulting firm, making it unlikely they would be willing to share these formulas. Our numerous requests for interviews were ignored, and we were unable to complete this method.

To avoid this limitation in the future, using an open-source index might yield more productive accessible results. In our interview with David Levinger, he provided insight into another index designed by a former colleague at the University of Washington, Maggie McGehee. Her developments involved evaluating walkability, which is available at the website walkscore.com. Along with the walk score, the work has a Transit Score in its methodology. Using this metric could be a useful alternative to the UMR Index. Along with the transit score, more research can be done to locate other indices, or better, one could be created and applied to several project sites, including Lyon.

Another form of comparison we originally intended to complete was an analysis of public sentiment toward different transit systems on social media platforms. We made progress on this goal but began too late in the project cycle to complete our work. If given more time, we would have liked to find common complaints amongst multiple transit systems to find what their largest issues are. This data would be useful for analyzing Lyon's quality of transit by having common issues to look for, as well as having comparative data on whether Lyon has fewer complaints around serious issues. This method of comparison would have

relatively little bias compared to simple sentiment analysis of comments, as we would be looking for complaints that multiple, separate users had made about a system.

The team had started work on comparing trips to the same destination by car and by the transit system in Lyon, using the Google Maps API to provide information about trip durations, carbon emissions, and pathing of different modes of travel. With this, the team could determine information about non-TCL-owned vehicles according to Google's estimation. Thus, when given a journey from start to finish in the TCL itinerary planner, it can be compared to cars traveling along a road path for their carbon emissions and time efficiency. With an ideal system, public transportation will be faster than driving a car and also yield fewer grams of emitted carbon per person. Ultimately, calculating the actual experimental values of car trips was unnecessary due to a bounding problem. Within the paper, the total distance of each journey was calculated by using the shortest distance between each transit line stop. While vehicles cannot directly travel on the transit lines, using this as an estimate provided an absolute lowest bound for error given by the Google Maps API. As stated earlier, even with the lower bound, cars experienced significantly higher carbon emissions, which means any additional error would only solidify the proven statistical point. Also, from the perspective of health, the data points used limited the accuracy of the amount of walking a person would perform. Since our journeys only contained directions from stop to stop rather than arbitrary locations, the Google Maps API would suggest that, by car, there is zero walking performed. In practice, people have to walk much more: walking to reach where their vehicle is parked and to arrive at their destination after parking somewhere. Thus, we realized that no conclusive statement could be made using this method, so the process was ultimately stopped.

Starting in 2025, the TCL will begin to see significant administrative changes. The operations side of the TCL will be split between Keolis and RATP going forward, which is sure to bring some changes to the system. Our analysis in this paper is as current as it can be, but there is no telling what the future may have in store for the state of Lyon's public transit. We think it would be interesting to re-evaluate our findings in this paper by looking at the state of the TCL in five or ten years. We worry that these changes could cause issues by introducing extra administrative overhead during the handoff, leading to less care for the user experience and overall quality of the system. However, this change could also allow for a reinvigoration of the system by bringing new staff with a fresh perspective and outlook on the future. It is difficult to predict how these changes will play out, so we can only hope that the TCL will uphold or improve its quality of service in Lyon going forward.

Project Reflection

At the end of any large project, it is important to reflect on our successes and failures as well as any lessons learned. Being a team full of students with academic backgrounds in engineering and science, we were required to adapt to the challenges that came with producing a social science research project. First, the group found that effectively utilizing different members' skill sets, whether they be social or academic, played a large role in achieving the goal of the project. The team had to utilize organizational skills by delegating tasks among individuals as well as structuring notes, documents, objectives, and deliverables together. Also, since the project was based in France, our group had to gain an understanding of the French language for interviews and research, which was heavily aided by our single fluent speaker. Finally, being that members possessed different technical skills, such as digital

art and web data archiving, learning how to work together to best harness and utilize those skills within the project's scope was paramount to its success.

There were no ultimate 'failures' the group encountered, but there were unanticipated limitations. The primary issues came down to interview responses and time management. Originally, we outlined four objectives for our research, but these were eventually condensed to just two. One of the objectives had to be cut due to time constraints with finalizing and executing our methodology, while the other heavily hinged on interviewing a source who never responded. Despite these challenges, our group still had overall success since we planned several objectives covering different veins of research such that the likelihood of all of them failing was near zero. Thus, when considering future projects, our team has learned the importance of planning thoroughly and covering as many areas of research as possible while still paying attention to organization, team dynamics, and individual capabilities.

Conclusion Statement

As this project progressed and we gathered more data and personal experience, our confidence grew to the degree that we now feel secure in saying the TCL is an admirable model for effective public transit systems. It is not without flaws, but it is undoubtedly an efficient, effective, and easy-to-use transit system that provides significant value to the community it serves. We hope that the TCL can maintain its quality of service in the future, especially with its upcoming organizational changes.

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Appendix A - Interview Questions

Interview Question Preamble

Here is a list of the interview questions we asked interviewees. This list represents fundamental questions that were asked, although follow-up questions, which are an integral part of semi-structured interviews, did come up in the interviews. In this case, these questions were evaluated on the spot. Any additional material will follow the appropriate guidelines.

Interview Questions Per Person

Corentin Gautier (Interview conducted in French)

1. Quel est le sujet de votre recherche?
    - Qu'est-ce que vous avez appris au cours de votre recherche?
    - Quelles données avez-vous recueillies au cours de vos recherches?
2. Est-ce-que vous aimez le système de transport public ici à Lyon?
    - Qu'est-ce que vous aimez dans le système de transport en commun de Lyon?
    - Pourquoi?
3. Est-ce-que vous utilisez les transports public pour vous rendre au travail?
    - Si oui, pourquoi utilisez-vous les transports public au lieu d'une voiture?
    - Si non, pourquoi utilisez-vous une voiture au lieu des transports public?
4. À ton avis, qu'est-ce qui fait que les transports publics sont bons?
    - Est-ce que votre recherche informe votre opinion sur cette question?
5. Si vous avez le pouvoir de changer une seule aspect du système de transport public Lyonnais, que changeriez-vous?
    - Comment changeriez-vous le système de transport en commun de Lyon?

6. Quelle est, à ton avis, la plus grande faiblesse du réseau de transport en commun lyonnais?
7. Quelle est, à ton avis, la plus grande force du système de transport en commun lyonnais?
8. Comment les transports en commun de Lyon se comparent-ils à ceux d'autres villes que vous avez étudiées ou visitées?
9. Est-ce-que vous avez des autres commentaires?

David Levinger (Interview conducted in English)

1. What is your background in Urban Transit and Mobility?
    a. What kind of work are you doing today on mobility systems?
    b. What does the Mobility Education Foundation do?
2. You co-authored your Usability Approach article in Community Transportation about 15 years ago, have you noticed any large changes in transit usability since then?
3. What systems or regions did you analyze for your research on the usability of a transit system?
    a. What has this city done specifically to make its system 'good'?
4. Looking beyond Usability, in your experience, what do *you* believe makes a transit system "good" or "bad"?
5. What do you believe is the most important factor in the long-term success of a transit system? Not just success economically, but also success in its ability to serve users efficiently long-term.

6. Is there a certain index or rating system for urban transit that you work with today that you like?

Olivier Klein (Interview conducted in French)

1. Comment en êtes-vous venu à étudier les transports urbains ? Quel est le sujet de votre recherche?
2. Dans le cadre de votre recherche/expertise, qu'est-ce que le système de transport public fait de bien ici ?
3. Quelle est, selon vous, la plus grande force du système de transport public lyonnais par rapport à d'autres systèmes ?
4. Si vous aviez le pouvoir de changer un seul aspect du système de transport public de Lyon, que changeriez-vous ?
    a. Comment feriez-vous ce changement ?
5. En tant qu'habitant de Lyon, comment utilisez-vous les transports en commun à Lyon ? Travail, plaisir, etc.
6. Le système de transport en commun de Lyon sert-il bien les habitants en général?
    a. Quel sont les choses qu'il fait bien ou qu'il ne fait pas bien, et comment peut-on les ameliorer?
7. Avez-vous d'autres commentaires ?

Anonymous LAET Researcher (Interview conducted in French)

1. Comment en êtes-vous venu à étudier les transports urbains ? Quel est le sujet de vos recherches aujourd'hui ?
2. Que fait votre laboratoire? (Laboratoire de transport et d'urbanisme)

    a. Suivi: Que faites-vous ?

3. Quelle est l'importance de ce type de recherche pour le développement de "bons" systèmes de transport en commun ?
4. Dans le cadre de votre recherche/expertise, qu'est-ce que le système de transport public fait de bien ici ?
5. Quelle est, à votre avis, la plus grande force du système de transport public de Lyon par rapport à d'autres systèmes ?
6. Si vous aviez le pouvoir de changer un seul aspect du système de transport public de Lyon, que changeriez-vous ?
    a. Comment feriez-vous ce changement ?
7. En tant qu'habitant de Lyon, comment utilisez-vous les transports en commun à Lyon ? Travail, plaisir, etc.
8. Le système de transport en commun de Lyon sert-il bien les résidents en général ?
9. Avez-vous d'autres commentaires ?

Appendix B - Informed Consent Form

Below is the consent and privacy script that we read to each person we interviewed. The script was originally written in English, then translated to French and read to interviewees. Both the English and French translations are included.

In English:

Your participation is voluntary and you can withdraw at any time. You also have the right not to answer any or all of the questions asked. Everything you say remains confidential and will not be publicly released unless you otherwise authorize us to do so. We will record the audio of this interview to be able to reference it at a later time. We will store it on a locked computer and then will delete it when our research is concluded. Do you understand and agree to these terms?

How would you like us to reference you in our final paper? We can use your name, title, or keep you entirely anonymous. If anonymous, do we have permission to use an anonymized version of the transcript of this interview for our final paper? Do you have any other objections or comments?

In French:

Votre participation est volontaire et vous pouvez vous retirer à tout moment. Vous avez également le droit de ne pas répondre à tout ou partie des questions posées. Tout ce que vous dites reste confidentiel et ne sera pas rendu public, sauf autorisation contraire de votre part. Nous enregistrerons l'audio de cet entretien afin de pouvoir nous y référer ultérieurement.

Nous le conserverons sur un ordinateur fermé à clé et l'effacerons à la fin de nos recherches. Comprenez-vous et acceptez-vous ces conditions ?

Comment souhaitez-vous que nous fassions référence à vous dans notre document final ? Nous pouvons utiliser votre nom, votre titre ou vous garder entièrement anonyme. Si vous restez anonyme, avons-nous la permission d'utiliser une version anonyme de la transcription de cet entretien pour notre document final ? Avez-vous d'autres objections ou commentaires ?

Appendix C - Pre-Project Timeline

Task	Week							
	WPI D-Term	May 21-24	May 27-31	June 3-7	June 10-14	June 17-21	June 24-28	July 1-5
	ID 2050/ PQP	1	2	3	4	5	6	7
Find the names and send emails to relevant figures								
Convenience sample interviews								
Sit at stops/ride transit and record quantitative and qualitative data								
Schedule and execute the interviews for those who responded and consented								
TCL Website data scraping								
Social Media Analysis								
Analyze TCL Data, if given								
Compare & perform Mixed Analysis on Lyon's data								
Finish Writing Paper								

Appendix D - Updated Timeline after Project Completion

Task	Week								
	WPI D-Term	May 21-24	May 27-31	June 3-7	June 10-14	June 17-21	June 24-28	July 1-5	July 8-12
	ID 2050	1	2	3	4	5	6	7	8
Archival Research									
Find the names and send emails to relevant figures									
Schedule and execute the interviews for those who responded and consented									
Sit at stops/ride transit and record quantitative and qualitative data									
Convenience sample interviews									
TCL Website data scraping									
Web Data Scraping Analysis									
Social Media Analysis									
Finish Writing Paper									

Appendix E - Images of TCL Vehicles in use as of 2024

Image	Vehicle
	Metro
	Funicular

	Tram *Ref.* (Ligne de Tramway T4., n.d.)
	Bus *Ref.* (Unsplash, 2023)

Trolleybus *Ref.* (Place Saint-Paul, Bus Des Transports En Commun Lyonnais, Ligne C3., n.d.)

Appendix F - Ethnographic Observations (Google Forms)

Unless otherwise specified, questions are single response only. Blank lines represent short answers.

Static Form

- What is the name of the station?

  _____

- How many machines/booths to purchase tickets are there?
  - 0
  - 1
  - 2
  - 3
  - 4
  - 5+
- Ticketing Machines – Extra Notes

  _____

- How many escalators are there?
  - 0
  - 1
  - 2
  - 3
  - 4
  - 5+

➢ Escalators – Extra Notes

_____

➢ How many elevators are there?

- 0
- 1
- 2
- 3
- 4
- 5+

➢ Elevators – Extra Notes

_____

➢ How many wheelchair ramps are there?

- 0
- 1
- 2
- 3
- 4
- 5+

➢ Wheelchair Ramps – Extra Notes

_____

- How many maps are available?
    - 0-2
    - 3-4
    - 5-6
    - 7-8
    - 8-10
    - 10+
- Where are the maps available (select all that apply)
    - There are maps by the ticketing machines
    - There are maps on the platform
    - There are maps on both sides of the platform
    - There are maps in places other than the platform or ticketing machines
- Which of these are not operating, broken, or otherwise problematic?
    - Maps
    - Ticket Machine
    - Escalator
    - Elevators
    - Other:
- What types of maps are available? (select all that apply)
    - Line-Specific Maps
    - Whole TCL Maps
    - Transit type specific maps

Dynamic Form

- Are you on a metro or tram station?
    - Metro
    - Tram
    - No
- What station are you in?

  _____
- On a scale from 1-7, how clean is the station?
    - 1- Absolutely disgusting
    - 2- Lots of large visible pieces of trash on floor, walls, etc. (e.g. bottles, cups, straws, boxes)
    - 3- Some larger trash in major spaces (e.g. bottles, cups, straws, boxes)
    - 4- Mostly clean with some trash out of the way
    - 5- Nearly Spotless with only a couple of pieces of trash
    - 6- No trash but smudges/evidence of foot traffic
    - 7- Entirely Spotless
- On a scale from 1-6, how crowded is the station?
    - 1- Almost no one on platform
    - 2- Could do a cartwheel with available space
    - 3- Busy but could spin in place with arms extended
    - 4- Crowded with some people within arms reach
    - 5- Quite busy and pretty close to people on all sides
    - 6- Very busy and shoulder to shoulder with multiple people

- ➢ Did you see a TCL representative in the station? (select all that apply)
    - ○ Security
    - ○ Information
    - ○ Yes, but unsure
    - ○ No
    - ○ Other:
- ➢ Any Extra Comments

  _____

- ➢ Are you taking a form of transportation soon from this station?
    - ○ Yes, Metro
    - ○ Yes, Bus
    - ○ Yes, Funicular
    - ○ Yes, Tram
    - ○ No
- ➢ What station did you depart from?

  _____

- ➢ What line are you on?

  _____

- Approximately how long, in minutes, did you wait for your transit to arrive?
    - 1 or less
    - 2
    - 3
    - 4
    - 5
    - 6
    - 7
    - 8
    - 9
    - 10 or more
- Was the station (not the transport) cleared with your departure?
    - Yes
    - No
    - Maybe
- On a scale from 1-6, how crowded is the transport?
    - 1- All the people could be seated with extra seats available
    - 2- Very few people on the transport
    - 3- Busy but could spin in place with arms extended
    - 4- Crowded with some people within arms reach
    - 5- Quite busy and pretty close to people on all sides
    - 6- Very busy and shoulder to shoulder with multiple people

- Is the transport clean?
    - No
    - Sort of
    - Yes
    - Other:
- Any Other Comments?

_____

Appendix G - Levene's Test and T-test Results

Comparison Between Public Transportation and Car

Levene's test:

F-value: 138.43174306072305

p-value: 1.5949749132090505e-30

Welch's t-test:

t-statistic: -27.542861446667967

p-value: 5.986266981046135e-129

Comparison Between Public Transportation and European Union Car Emissions Goal

Levene's test:

F-value: 31.595273210062363

p-value: 2.2946633860161312e-08

Welch's t-test:

t-statistic: -5.0933891375417835

p-value: 4.026306046630545e-07

Appendix H - TCL Scraping SQLite Database Schema

Simulated Journeys Table	CREATE TABLE journeys (id INTEGER PRIMARY KEY, total_duration INTEGER, departure_date_time TEXT, arrival_date_time TEXT, co2_emission REAL, air_pollutants TEXT, durations TEXT, distances TEXT, stops TEXT);
Stops Metadata Table	CREATE TABLE stops (id TEXT PRIMARY KEY, name TEXT, coord TEXT, equipments TEXT);
Recorded Outages Table	CREATE TABLE outages (id TEXT PRIMARY KEY, stop_id TEXT, status TEXT, updated_at TEXT, info TEXT);