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Examining Railway Infrastructure Recovery Levels in Urban Transport Post-Pandemic

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***Abstract*—The COVID-19 pandemic resulted in unparalleled disturbances to urban railway networks globally, impacting maintenance schedules, ridership numbers, and funding sources. This study investigates the recovery status of railway infrastructure within urban transport systems throughout Europe in the post-pandemic period. The research has three main objectives: first, to identify and analyze the pandemic's impacts on the operational, financial, and maintenance dimensions of urban rail systems; second, to evaluate post-pandemic recovery trends regarding infrastructure utilization; and third, to recommend strategies that bolster the resilience of urban rail systems against future disruptions. A quantitative analysis was performed utilizing annual passenger figures and passenger-kilometer data from chosen metro systems in prominent European cities to attain these aims. The information, The results indicate considerable discrepancies in recovery patterns among various cities and systems, shaped by elements such as governmental policies, funding distributions, and urban mobility practices. The study finishes by providing evidence-based recommendations to enhance the resilience of urban train networks. These solutions underscore the necessity for flexible funding models, enhanced maintenance procedures, and regulatory frameworks that prioritize sustainability and accessibility, guaranteeing urban rail networks can effectively endure and recuperate from future global crises.**

***Keywords*—railway infrastructure; post-pandemic; mobility patterns; metro**

I. INTRODUCTION

The COVID-19 pandemic has significantly affected urban transport networks, especially railway infrastructure, resulting in notable changes in travel behaviour, operational difficulties, and recovery methods. As urban areas start their recovery, comprehending these transformations is essential for efficient urban transportation planning and policy development.

The epidemic has significantly diminished passenger numbers, especially in train networks. Research demonstrates that the pandemic precipitated a decline in passenger travel, with postponed expenditures and obstructed projects intensifying the issue [1]. The implementation of rigorous measures during following pandemic waves further restricted mobility, leading to a persistent decrease in railway passenger transport performance [2]. This reduction has compelled urban planners to reevaluate transportation strategies, highlighting the necessity for specific solutions that account for diminished demand and regional requirements [2].

Furthermore, the pandemic has instigated a transformation in travel patterns, with several commuters articulating increased apprehensions regarding safety on public transit. Studies demonstrate that perceptions of infection risk substantially affected passengers' decisions, resulting in a notable rise in private car utilization and a decrease in dependence on rail transit [3]. This behavioral change highlights the necessity of addressing safety issues by effective communication and the execution of health protocols inside railway systems [4]. It is essential for public transport systems to adjust to these evolving attitudes to rebuild user confidence [5].

The epidemic has underscored the need for enduring infrastructure resilience, alongside acute operational problems. The railway sector must adjust to the persistent effects of COVID-19 as well as to overarching problems like climate change. Research underscores the necessity of including climate adaptation measures into railway infrastructure development to guarantee sustainability and resilience against future disruptions [6, 7]. This encompasses investment in infrastructure enhancements and maintenance strategies that consider climate-related hazards, including flooding and severe weather occurrences [7].

The epidemic has necessitated a reassessment of urban mobility strategies, highlighting the imperative for sustainable transport alternatives. The decline in motorised traffic during the pandemic has afforded urban planners the chance to advocate for active transport methods, such as walking and cycling, which can improve public health and alleviate congestion [8]. This transition to more sustainable transport alternatives corresponds with worldwide movements promoting environmentally friendly urban settings and enhanced living standards for inhabitants.

The restoration of railway infrastructure in urban transit during the pandemic necessitates a comprehensive strategy that tackles urgent operating issues, adjusts to evolving passenger patterns, and integrates long-term resilience measures. Utilizing insights gained from the epidemic, urban planners may develop more sustainable and efficient transport systems that address the changing requirements of urban populations.

The main objectives of the current study are presented below:

- Identify the impacts of the pandemic on maintenance, ridership, and funding.
- Assess post-pandemic recovery trends in urban railway infrastructure.

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- Propose strategies to bolster resilience in future disruptions.

The remainder of this paper is organized as follows. The background section provides a comprehensive review of relevant literature and research related to the impacts of the COVID-19 pandemic on urban railway infrastructure maintenance, ridership and funding. This is followed by a detailed description of the methodological framework employed to analyze post-pandemic recovery trends in urban railway infrastructure.

The recovery strategies and challenges are presented according to a thorough review of the literature. Finally, the discussion and conclusion sections summarize the key findings, propose actionable recommendations, and outline the implications for future urban railway planning and policy development.

II. BACKGROUND

The maintenance of public transport services has been impeded by the significant decline in ridership. Numerous transport companies had financial challenges stemming from reduced fare receipts, which typically represent a substantial amount of their budget. Vickerman emphasizes that governmental financial assistance was crucial for sustaining services throughout these issues, as operators adapted to new social distancing protocols and a widespread decrease in public transport demand [9]. Christidis et al. [10] observe that the pandemic resulted in a complex impact on trains, characterized by reduced commuting and travel limitations, which required modifications in service delivery to accommodate altered riding patterns. This circumstance has compelled operators to reevaluate their maintenance techniques and operational frameworks to sustain viability in a post-pandemic context.

The pandemic caused extraordinary reductions in ridership, with studies showing falls of up to 90% in many areas [11]. Jenelius and Cebecauer's examination of ticket validations and passenger counts in Sweden demonstrates that the resurgence of riding has often been exaggerated, since conventional metrics did not accurately reflect the actual status of public transport utilization following the epidemic [12]. The apprehension over congested environments and the perceived threat of viral transmission have profoundly transformed travel behaviour, resulting in a lasting change in modal choices, as seen by Barbieri et al. [13]. This transition has coincided with an increase in telecommuting and other mobility methods, including cycling and walking, which have been advocated as safer alternatives during the pandemic [14].

Public transport funding has been significantly affected. The dependence on fare income has been questioned due to a substantial decline in ridership, prompting demands for further government assistance to maintain operations. Bauer and Bauer assert that diminished ticket sales will constrain income for transport service providers, which were already experiencing financial difficulties prior to the [15]. Furthermore, the requirement for supplementary money has been emphasized by the imperative to enforce health and safety requirements, including intensified cleaning procedures and social distancing measures, which exacerbate constrained finances [16]. The economic ramifications surpass immediate financial issues, since the long-term sustainability of public transport systems depends on their capacity to adjust to evolving ridership trends and finance frameworks in a post-pandemic context [17].

In conclusion, the COVID-19 epidemic has radically transformed public transportation, requiring a reassessment of maintenance protocols, passenger tactics, and financial structures. The combination of diminished ridership heightened operating expenses, and the necessity for financial assistance is a significant challenge for transport authorities as they seek recovery and aim to rebuild public trust in these vital services.

III. ANALYSIS OF POST-PANDEMIC RECOVERY TREND IN URBAN RAILWAY INFRASTRUCTURE

The COVID-19 pandemic significantly disrupted urban railway networks (such as metro, tram, etc.), requiring an essential examination of recovery trends as cities move towards post-pandemic operations. This section presents the ridership trends. Understanding the ridership pattens is crucial for directing resilient and sustainable urban railway development.

To study and analyze the post-pandemic recovery trends, a quantitative analysis of annual passenger numbers and passenger kilometers for selected urban rail systems (metro) in major cities of the Europe (EU) was conducted.

A. Data Collection and Methodology

The dataset that was utilized for the analysis was based on available data for urban rail public transport systems collected by the United Nations Economic Commission for Europe (UNECE) [18]. These data were collected by the UNECE in a questionnaire, asking for passenger numbers and passenger km, maintaining the city (or regional) breakdown and include two main metrics:

a) Passenger numbers, and

b) Passenger-kilometers

The first metric, total passenger numbers that use urban railway transport, is a basic yet effective way to determine the total number of people that utilize these services at any given time. However, to provide a comprehensive picture of urban rail public transport recovery trends, the analysis of passenger-kilometers is a more insightful metric. It encompasses both the overall number of passengers utilizing the means of urban rail public transport, and the distances they go within the system.

The measurement of passenger-kilometers provides a comprehensive perspective on mobility patterns, facilitating a more thorough assessment of recovery magnitude. It offers essential insights regarding whether travelers are undertaking brief excursions or resuming extended commutes and frequent travels. This data is essential for comprehending the evolving dynamics of travel demand and the overall efficacy of public transport systems throughout recovery phases, providing insights that mere passenger counts cannot provide.

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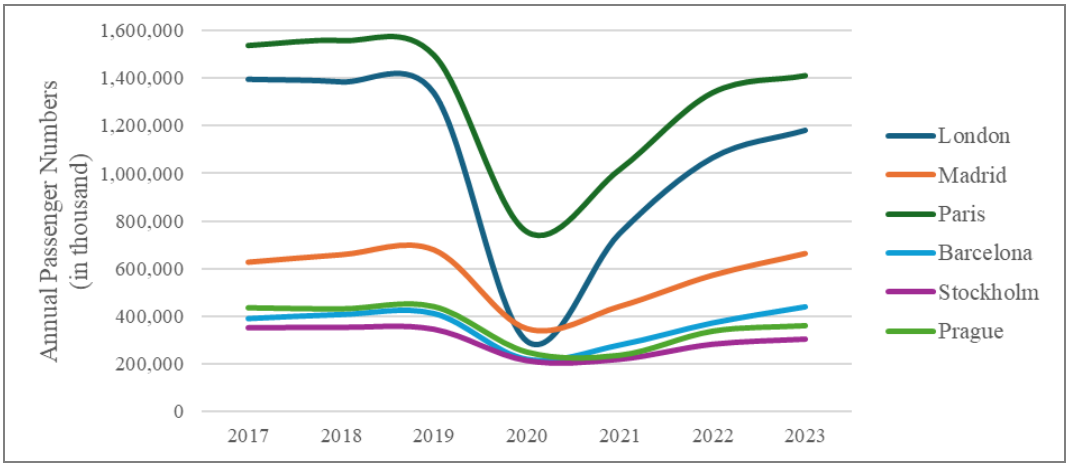

Fig. 1. Annual ridership (number of pasengers) of metro systems for major EU cities (2017 – 2023).

As nations try to accomplish the United Nations Sustainable Development Goals (SDGs), the value of urban rail transport statistics has expanded dramatically. This data plays a critical role in measuring progress toward SDG 11, which focuses on establishing sustainable, inclusive, and resilient cities and communities. By closely monitoring urban rail passengers and system use, regulators and planners can receive crucial insights into how well cities are advancing toward the objective of providing accessible, eco-friendly, and efficient public transportation. This data not only indicates the efficacy of existing urban mobility initiatives but also highlights opportunities for enhancement, guaranteeing that urban transport systems significantly contribute to sustainability and resilience in expanding cities.

B. Analysis of Data

The comparison of current (2023) metro ridership levels to pre-pandemic levels for the metro system of major EU cities is presented in Fig. 1.

The COVID-19 pandemic significantly impacted total ridership, resulting in a marked and sudden fall, seen as a distinct dip in the trends illustrated in the image. This rapid decline underlines the immediate and profound impact of the pandemic and the associated mobility limitations on transportation systems globally. However, beginning in 2021, there is a substantial and sustained growth in ridership demand. This recovery correlates with the easing and ultimate dismantling of restrictive measures, such as lockdowns and travel bans, which had been established to stem the spread of the virus. The gradual increase indicates the restoration of normal mobility patterns as individuals return to their daily commutes, social engagements, and travel habits, signifying a modest yet consistent return to pre-pandemic transportation levels.

However, the repercussions of the COVID-19 pandemic remain profoundly experienced by numerous significant metropolitan train networks. In Paris, the metro system, which had previously transported nearly 1.5 billion passengers yearly, experienced a 50% reduction in ridership in 2020, declining to merely 750 million passengers. Although the system has exhibited indications of recovery, by 2023, it has yet to revert to its pre-pandemic ridership levels.

The circumstances in London were far more severe, as metro ridership in the city decreased by 80% according to 2018 statistics. Although some recovery has transpired, London's metro system remains operational at markedly diminished capacity, much below pre-pandemic levels. In smaller cities such as Prague and Stockholm, the recovery has been notably slower and less substantial, indicating that both major and small urban areas are persistently encountering difficulties in reinstating their public transport usage to pre-pandemic levels.

Table 1 presents the absolute annual ridership of metro systems for the major EU cities in 2019 and compares it with the values of 2020 (during the pandemic period) and 2023 (post-pandemic period). According to the results, in all cases except Barcelona, none of the major EU cities received pre-pandemic ridership in the metro system.

Passenger counts indicate the volume of individuals utilizing public transport systems, whereas passenger-kilometers provide a more nuanced insight on the degree of recovery. This measure indicates both the number of individuals returning to public transport and the distance they are travelling, providing a more thorough understanding of system use (Table 2).

In London, the metro system was distinguished by the extensive distances traversed by passengers. In 2019, London's metro documented more than 11.7 billion passenger-kilometers. Nonetheless, this figure declined by over 77% in 2020 because of the pandemic.

TABLE I. COMPARISON OF ANNUAL NUMBER OF PASSENGERS FOR MAJOR EU METRO SYSTEMS

City	Annual Ridership of Metro Systems		
	2019	*2020*	*2023*
London	1,337,000,000	-77.8%	-11.7%
Madrid	677,476,000	-48.4%	-2.2%
Paris	1,497,660,000	-49.7%	-5.8%
Barcelona	411,945,000	-47.1%	+6.8%
Stockholm	347,000,000	-38.6%	-12.1%
Prague	440,500,000	-42.9%	-18.0%

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TABLE II. COMPARISON OF ANNUAL PASSENGER KILOMETERS FOR MAJOR EU METRO SYSTEMS

City	Annual Passenger Kilometers of Metro Systems		
	2019	*2020*	*2023*
London	11,754,000,000	-77.3%	-10.0%
Paris	7,802,850,000	-49.7%	-12.1%
Stockholm	1,895,000,000	-39.3%	-11.5%
Prague	6,684,800,000	-75.2%	-64.4%

As mentioned before, by 2023 London's metro had not entirely recovered. Total passenger kilometers are 10% less than the pre-pandemic period. Therefore, bearing in mind the reduction of almost 12% of total ridership, it is concluded that the mobility patterns in London started to cover longer distances.

On the other hand, although 82% of passengers have returned compared to pre-pandemic levels in Prague, the total passenger kilometers have seen a dramatic decline of nearly 65%. This suggests that the overall distance traveled by passengers has significantly decreased, likely influenced by changes in travel behavior, reduced trip frequency, and shorter journeys. The data underscores that the reduction in total distance traveled goes beyond just the diminished demand, reflecting broader shifts in mobility patterns and passenger preferences in the post-pandemic period.

Figure 2 depicts the patterns in passenger kilometers among major cities, offering a more distinct perspective on the recovery of these systems over time.

C. Discussion

In numerous cities, ridership witnessed a sharp and considerable fall during the outset of the pandemic, but since then, recovery rates have varied considerably. These disparities in recovery can be linked to numerous reasons, including the extensive use of remote work habits, the rate of economic restoration, and shifts in population distribution. As some people shifted to working from home, the demand for commuting and public transportation in specific locations remained down for extended periods. At the same time, the speed at which economies reopened, and limitations were eased also had a crucial effect in shaping ridership trends. Moreover, shifts in residential and occupational locations, including relocations from highly populated urban areas, have further impacted transportation usage patterns in various cities. Moreover, The COVID-19 pandemic served as a catalyst for substantial alterations in transportation preferences, resulting in changes in individuals' travel choices. This has led to a significant rise in the utilization of private vehicles, cycling, and walking in various places, as individuals aimed to evade congested public transport due to health apprehensions. This shift from public transport has necessitated a reassessment of commuting patterns and travel behaviour. Comprehending the impact of these changes on railway ridership is essential for forecasting the long-term demand for rail services. By examining these shifting travel patterns, planners and policymakers can more effectively predict future rail usage trends and modify infrastructure and service provisions to accommodate the developing requirements of passengers.

IV. RECOVERY STRATEGIES AND CHALLENGES

The COVID-19 pandemic has prompted a reassessment of global public transport networks, resulting in the formulation of diverse recovery strategies and the recognition of critical difficulties. This answer consolidates results from much research to offer a thorough assessment of the recovery plans and obstacles encountered by public transport networks following the epidemic.

Baig et al. [19] emphasize that a significant difficulty is the pandemic's economic repercussions on public transit, resulting in diminished service quality owing to decreased income fee. The authors contend that transport authorities should reevaluate tariff structures, especially in relation to off-peak and peak hours, to accommodate the unique travel patterns that have arisen due to the epidemic.

Naveen and Gurtoo advocate adaptable pricing structures, proposing an epidemic prevention framework that prioritizes agility and integrated mobility in public transport networks [20]. Their paradigm proposes that public transport solutions be classified into three tiers: strategic, tactical, and operational, to adeptly address the issues presented by the epidemic.

Moreover, Barbieri et al. [21] have established the long-term consequences of the pandemic on mobility behaviour, highlighting the imperative for transit operators to cultivate public trust and adjust to shifts in mode preferences.

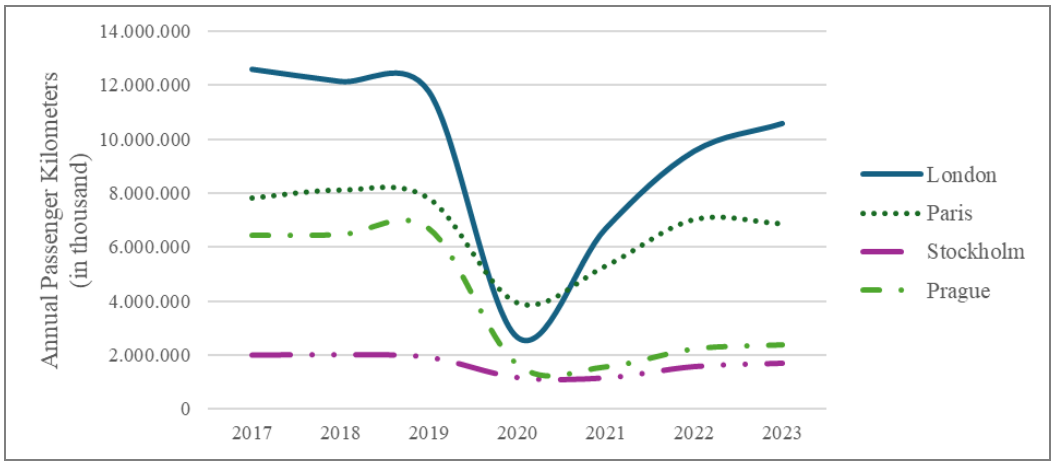

Fig. 2. Annual number of passenger kilometers of metro systems for major EU cities (2017 – 2023).

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The pandemic has served as a catalyst for transformation, necessitating a reassessment of travel patterns and the imperative for public transport systems to enhance their resilience and responsiveness to user requirements. Nian et al. assert that the pandemic offers researchers and practitioners a chance to investigate creative solutions for urban mobility systems [22]. They promote the creation of sustainable and resilient transport networks capable of enduring future disturbances.

Compliance with health standards, including social separation and mask usage, has become an essential element of rehabilitation treatments. Dzisi and Dei emphasize the necessity of adhering to these precautions to mitigate the risk of heightened infections in public transport systems [23]. This compliance is crucial for passenger safety and the broader view of public transit as a viable alternative in a post-pandemic context. Khairunnisa et al. underscore the necessity of effective communication and enforcement of health regulations, highlighting the significance of public knowledge in maintaining compliance with safety measures [24]. It is essential to acknowledge that the reference cited by Khairunnisa et al. is not directly pertinent to public transit recovery measures and should thus be excluded.

The incorporation of technology into public transport networks, with health measures, has been seen as a crucial approach for rehabilitation. Park and Kim have created a model to evaluate the risk of COVID-19 transmission in public transit, highlighting the significance of data-driven decision-making in improving safety and efficiency [25]. Technology use may enhance crowd control and elevate the passenger experience, therefore promoting a resurgence in public transport usage.

Furthermore, the pandemic has necessitated a reassessment of urban transportation methods, as demonstrated by the research of Christidis et al. [10]. The diverse effects of the pandemic have resulted in substantial alterations in travel behaviour, requiring a transformation in the planning and provision of public transport systems [10]. The authors promote a more cohesive strategy for urban transportation that addresses the changing requirements of commuters in a post-pandemic environment.

Notwithstanding these methods, the issues associated with finance persist as a substantial concern. Vickerman emphasizes the essential requirement for public financial assistance to sustain services considering significantly diminished ridership and fare revenues [9]. Dependence on government financing will be crucial for maintaining public transport operations, especially as several systems contend with the financial repercussions of the epidemic.

The notion of public transit as a hazardous environment owing to Covid-19 persists in obstructing rehabilitation initiatives. Munawar et al. assert that the perceived hazards of public transit may compel consumers to choose more energy-intensive transport modes, such as private vehicles, thereby worsening congestion and environmental challenges in urban settings [26]. This alteration in travel behaviour highlights the necessity of addressing public perception and ensuring that public transit is regarded as a safe and dependable choice.

The restoration of public transport networks following the COVID-19 epidemic necessitates a comprehensive strategy that tackles economic, health, and behavioral obstacles. Strategies like flexible fare structures, compliance with health norms, technological integration, and effective communication will be crucial for restoring public trust and guaranteeing the long-term sustainability of public transit. As transport authorities address these difficulties, the insights gained during the epidemic will be vital in influencing the future of urban mobility.

V. CONCLUSIONS

The COVID-19 epidemic presented unparalleled challenges to urban train networks, affecting operations, ridership, and finance throughout Europe. This study presents notable findings and offers practical insights on the recovery path of urban rail infrastructure in the post-pandemic period.

The data indicates that although ridership has exhibited indications of recovery, pre-pandemic levels have not been consistently reinstated across cities. Local regulations, economic recovery rates, and changes in travel behaviour have led to disparate recovery patterns. Metrics like passenger kilometers highlight significant changes in mobility trends, with certain cities observing a marked transition towards shorter travel distances or alternative transportation options.

Secondly, the pandemic highlighted the necessity for resilience in urban train networks. The results underscore the necessity of versatile maintenance plans, adaptive finance structures, and technology integration to maintain operations amid crises. Strengthening public trust by comprehensive safety protocols and honest information is essential for restoring faith in public transport.

This research emphasizes the necessity of synchronizing urban rail recovery efforts with overarching sustainability and resilience objectives. Utilizing learning from the epidemic, policymakers and planners should prioritize cohesive urban mobility solutions that address evolving passenger requirements, promote environmental goals, and strengthen systems against future disruptions.

The revitalization of urban railway networks necessitates a comprehensive strategy that integrates prompt operational modifications with enduring strategic planning. By adopting these principles, urban rail networks may enhance their resilience, efficiency, and alignment with the changing requirements of urban mobility.

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