Available online at www.sciencedirect.com

ScienceDirect

Transportation Research Procedia 82 (2025) 989–1003

Transportation Research Procedia

www.elsevier.com/locate/procedia

World Conference on Transport Research - WCTR 2023 Montreal 17-21 July 2023

Covid-19 and CO_2 – impacts on and implications for rail

John Armstrong[a,]*, John Preston[a]

[a]*Transportation Research Group, University of Southampton, Southampton SO16 7QF, UK*

Abstract

In the early decades of the 21st century, railways had an established, small (relative to road transport) but significant share of the overall transport market, providing a combination of high-speed, high-capacity passenger services and high-volume, long-distance freight transport, with the balance between passenger and freight traffic varying by location. The passenger railway market was severely disrupted from early 2020 by the Covid-19 pandemic; traffic volumes have since recovered, but work-related travel volumes (and, importantly, revenue) have not returned to their pre-Covid levels, putting pressure on railways and their funders to restore revenue and/or cut their costs. As an energy-efficient and low-Carbon (assuming high levels of usage) mode of transport with a potentially vital role to play in addressing the climate crisis, increasing passenger and/or freight volumes (preferably via modal shift) and total revenue is clearly the preferred option, ideally in parallel with increased efficiency and reduced unit costs. To meet these objectives, the railway industry needs to provide high-quality, comprehensive and integrated (including other, complementary modes) transport options that are easy to plan and use, and which provide users (and funders) with good value for money.

Keywords: Railways; Covid-19; Demand; Carbon; Climate Change; Sustainability

1. Introduction

Railways were badly affected by the emergence of the Covid-19 pandemic in 2020, suffering dramatic declines in traffic and revenue, particularly in the passenger sector. Changes in work and travel patterns that were beginning to emerge prior to Covid were accentuated and accelerated by the pandemic, resulting in a massive increase in working from home and the use of 'virtual' meetings. While the rapid development and deployment of vaccines has enabled the world to largely 'live with Covid', and life has in many ways returned to something similar to the pre-Covid normal, railway passenger traffic has not, and railways need to adapt to their new circumstances and recover lost passengers and income and/or reduce their costs. Looking beyond the (hopefully short-term) impact of Covid, railways, like the rest of the world, are also faced with the larger issue of climate change. This presents challenges in terms of the impacts of severe weather on infrastructure and operations, but also opportunities for a transport mode with inherently low carbon emissions. This paper considers the challenges and opportunities facing the railway industry, and how they should best be met and pursued.

Following this introduction, the historic background to recent and anticipated future developments is set out. The impact of Covid-19 on Britain's railways, and the subsequent partial recovery of traffic, are then illustrated and described, establishing the context for the current situation. The ongoing implications of Covid for the railways, particularly in terms of the shortfall of revenue relative to costs, are then considered, together with planned organisational change, strategic objectives for the industry, and some emerging responses to the changed circumstances. The longer-term, 'bigger environmental picture' is then considered in terms of rail's role in a Net Zero Carbon context, and how the railway industry can and should use its environmental and other strengths to

* Corresponding author. Tel.: +44-23-8059-9575.
E-mail address: j.armstrong@soton.ac.uk

10.1016/j.trpro.2024.12.107

recover from Covid and provide high-quality passenger and freight transport in a warming world. Finally, some conclusions are drawn, followed by a list of references.

2. Background

Passenger and freight traffic volumes by mode in Great Britain between 1952 and 2020 are summarised in Figures 1 and 2, based on data from the UK Department for Transport (DfT; 2022a, 2022b). The growth and increasing dominance of road traffic in both the passenger and freight sectors can clearly be seen. The Covid-related decline in 2020 in passenger traffic across all modes, and in road freight traffic, is also apparent. In the passenger sector, it can be seen that rail traffic was in third place in 1952, behind the buses & coaches and the cars, vans & taxis categories, but by 2020 had approximately doubled in terms of passenger km and had overtaken buses & coaches, whose passenger km had declined by approximately two-thirds since 1952. Since the 1980s, rail- and bus & coach-based passenger km have both been an order of magnitude smaller than those for cars, vans & taxis.

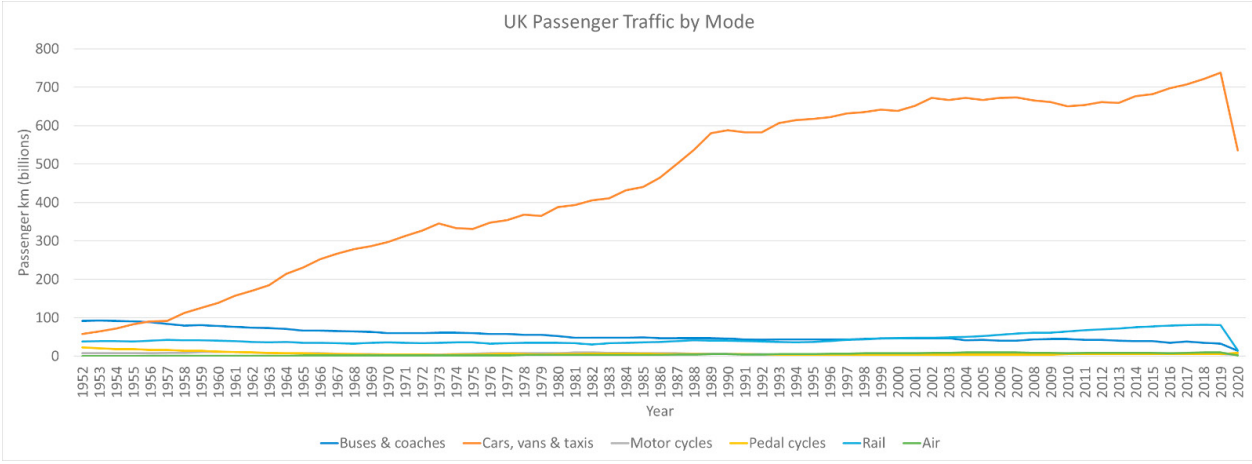

Fig. 1. GB Passenger Traffic by Mode, 1953-2020 (billion passenger km)

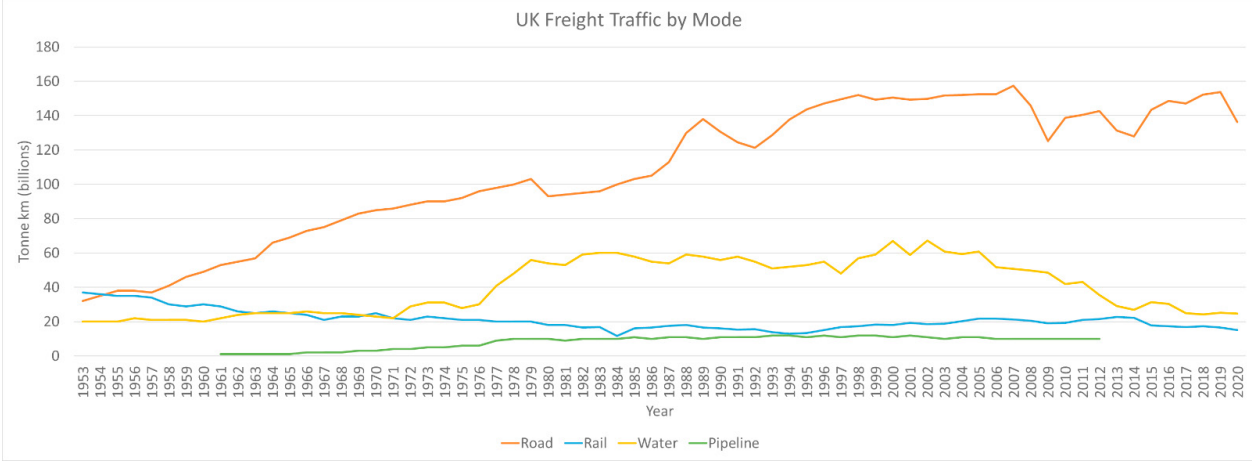

Fig. 2. GB Freight Traffic by Mode, 1953-2020 (billion tonne km)

Similar developments can be seen for freight, with road-based tonne km overtaking those for rail in the early 1950s and increasing quite steadily (with some fluctuations) since, while rail freight tonne km have approximately halved over the same period, reflecting declines in coal, metals and other 'traditional' mainstays of the rail freight sector, as well as the loss of wagonload mixed freight traffic. Waterborne domestic freight tonne km are also significant, having matched the traffic carried by rail in the 1960s and early 1970s, and since then exceeded it. The data for pipelines is incomplete, but pipeline traffic has been consistently less than rail-based traffic, although it almost matched it in the mid-1980s (probably due to the decline in rail-based coal traffic during the miners' strike) and mid-1990s.

Data on greenhouse gas emissions does not extend back as far as the data for traffic, and the available data (DfT, 2022c) from 1990 to 2019 for domestic transport-related emissions (i.e. excluding international aviation and shipping) for the UK as a whole

(i.e. for Great Britain and Northern Ireland) is summarised in Figure 3. It can be seen that road traffic is the overwhelmingly dominant source of transport emissions, followed by domestic shipping, rail, 'other' (mainly 'military aircraft and shipping', and 'aircraft support vehicles') and domestic aviation.

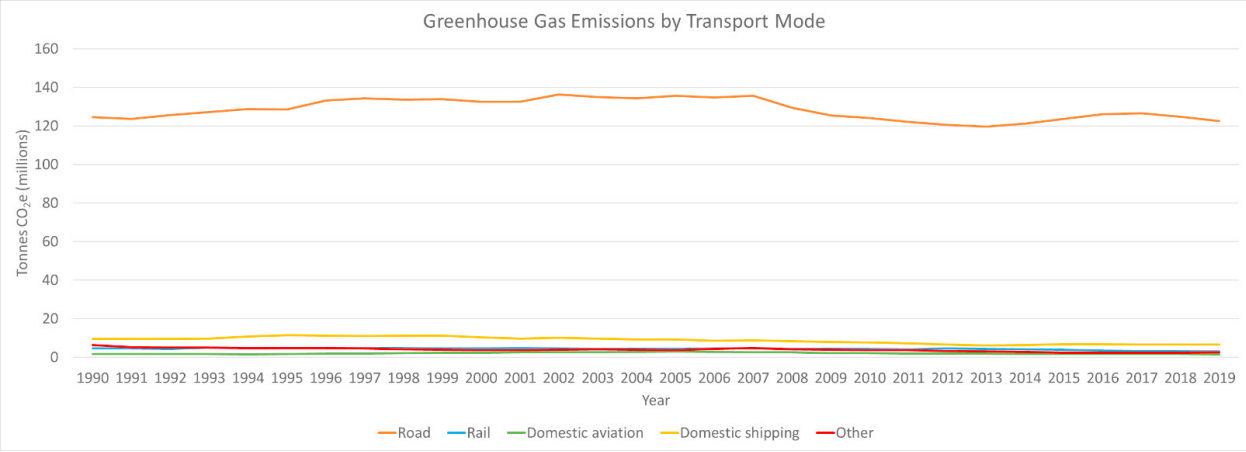

Fig. 3. UK Greenhouse Gas Emissions by Domestic Transport Mode, 1953-2019 (million tonnes CO_2e)

The emissions and traffic values were further disaggregated, using the DfT (2022c) dataset in conjunction with additional rail use and emissions data from the Office of Rail and Road (ORR; 2022a-d – note that the values for 2010 are missing from the emissions datasets and have been interpolated between 2009 and 2011) and then normalised by passenger and freight transport mode by dividing them by the corresponding passenger km and tonne km values equivalent to those illustrated in Figures 1 and 2. The results are shown in Figures 4 and 5 respectively for passenger and freight transport (these results slightly overstate the normalised emissions values, since the emissions data is for the UK as a whole, while the traffic data is for Great Britain only, but they enable a general comparison of normalised modal emissions). It can be seen that, with the exception of waterborne freight (and rail freight, which has remained fairly static, probably due to a continuing reliance in Britain on diesel traction), there have generally been steady, if sometimes slow, declines in emissions per passenger km and tonne km, and that, apart from pipelines, rail's normalised emissions are lower than those of the other mechanised passenger and freight transport modes. It can also be seen that, for passenger rail, emissions per passenger km increased dramatically in 2020, due to passenger numbers collapsing during the Covid pandemic, while a reduced-frequency but still-comprehensive train service continued to operate for key workers and other essential travel. The value decreased again in 2021 as passenger traffic recovered, but remained above the pre-Covid trend. At the time of writing, emissions data for the non-rail modes was not yet available for 2020 and 2021, but their vehicle km and emissions are perhaps likely to have declined more directly with passenger km, thus resulting in a less pronounced (or no) increase in emissions per passenger km.

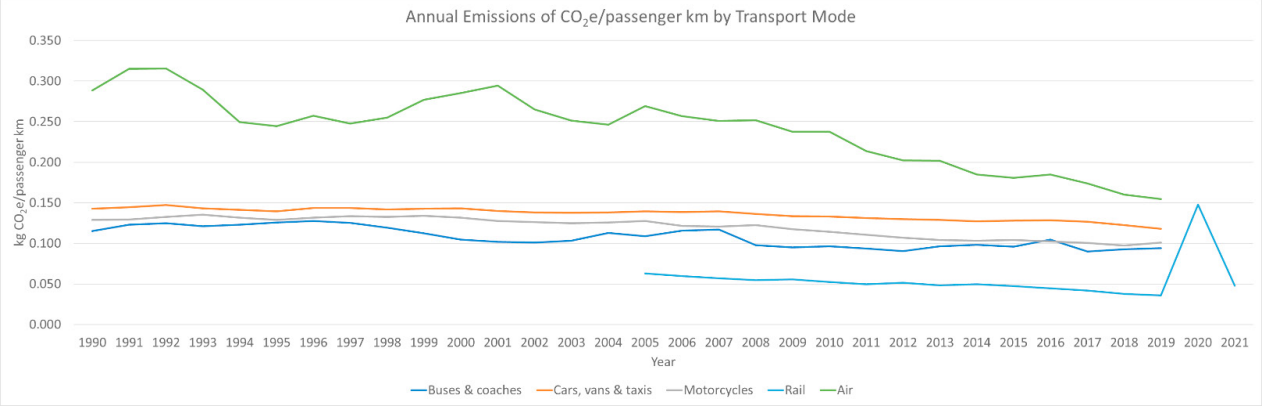

Fig. 4. Normalised UK/GB Greenhouse Gas Emissions by Passenger Transport Mode, 1953-2021 (kg CO_2e/passenger km)

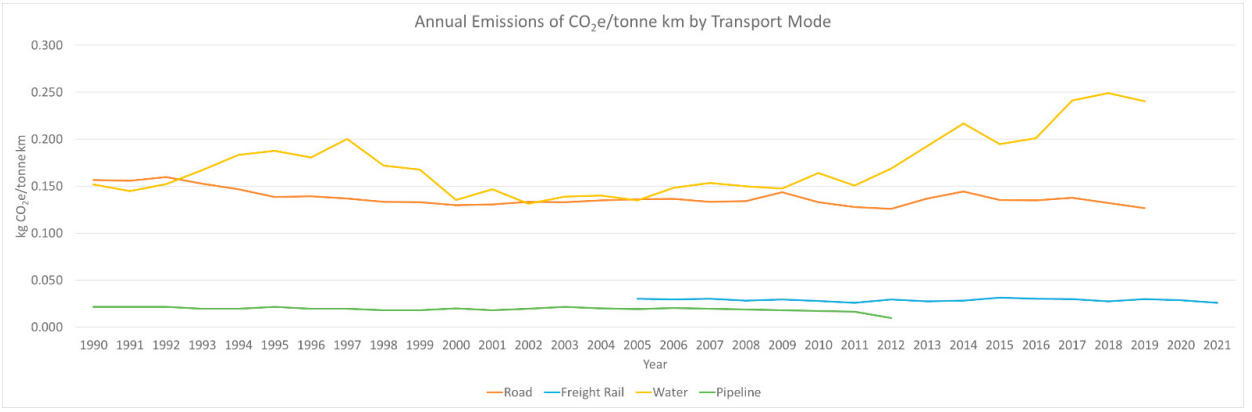

Fig. 5. Normalised UK/GB Greenhouse Gas Emissions by Freight Transport Mode, 1953-2021 (kg CO_2e/tonne km)

3. Context – Covid-19 and Britain's Railways

Quarterly passenger and freight traffic volumes by sector on Britain's railways between 2000-01 Quarter 1 (Q1, i.e. April – June 2020) and 2022-23 Q1 inclusive are shown in Figures 6 and 7 respectively (ORR; 2022e, 2022b). The passenger traffic data shows steady growth for most of the period, seeming to reflect a wider early "21st century … renaissance for public transport" (Veeneman, 2022), but there were some signs of growth slowing in the years prior to the Covid outbreak, particularly for the commuting-dominated London and South-East operators. A fluctuating partial recovery can be seen since the Covid-induced collapse in passenger traffic in 2020. The freight traffic data shows more fluctuation in the decades before Covid, related mainly to the changing fortunes and ultimate decline of coal traffic, slower declines in the other 'traditional' rail freight sectors of metals and oil traffic, and steady growth in construction and intermodal (container) traffic, interrupted only briefly and slightly in 2020-21 Q1 by Covid. According to Modern Railways (2020a), passenger demand on Britain's railways had fallen by 70% by 23 March 2020, and "by early April the number of passenger journeys was down by 95% year-on-year." At the same time, international train services across Europe were greatly reduced, and "by early April Eurostar traffic [between Britain and continental Europe] was down by 99%" (Modern Railways, 2020b). These declines are at the upper end of the international range reported by the International Union of Railways and McKinsey (UIC and McKinsey, 2022), with declines "in ridership of between 40 and 100 percent, with a global average of approximately 70 percent." In East Asia (Japan, South Korea and Taiwan), as reported by Lai (2022), high-speed and airport express railway patronage was particularly badly affected, with high-speed ridership declines ranging between 72% and 92%, and airport express declines of up to 76% (Japan) and 85% (Taiwan). Khadem Sameni (2022) reported similar impacts in the Middle East, with passenger numbers falling in Iran and Saudi Arabia by 71% and 60% respectively. In Turkey, passenger km fell by 45%, although, in the rail freight sector, tonne km increased by 5% (tonne km in Iran also increased from 2019 to 2020, by approximately 7%).

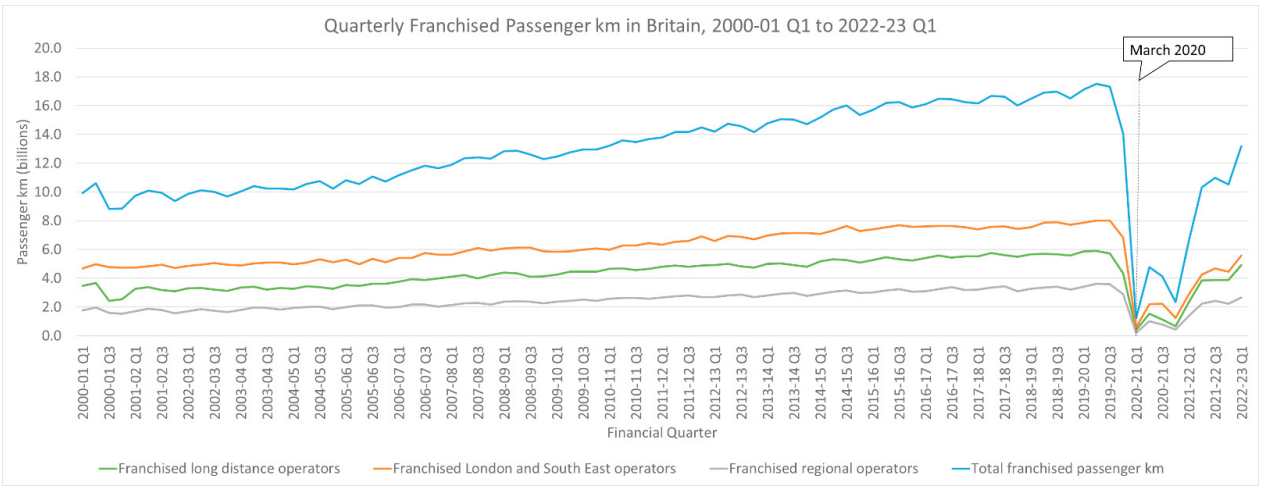

Fig. 6. Quarterly Franchised Rail Passenger km by Sector in Britain, 2000-01 Quarter 1 to 2022-23 Quarter 1

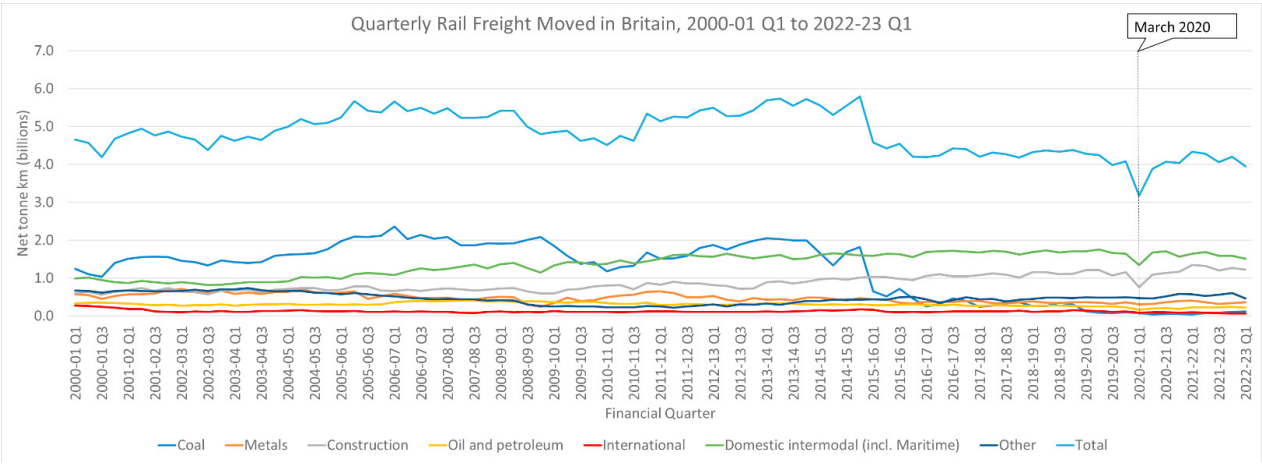

Fig. 7. Quarterly Rail Freight Moved by Commodity in Britain, 2000-01 Quarter 1 to 2022-23 Quarter 1

Railway passenger revenue data disaggregated by ticket type is only fully available from 2010-11 (ORR, 2022f), and is shown by Quarter since then in Figure 8. It can be seen that total franchised ticket sales revenue increased steadily during the decade prior to Covid, but that the rate of growth decreased approximately halfway through the decade, due mainly to a slow decline in Season ticket sales, whose revenue can be seen to be steadily falling behind that from Off Peak and Anytime or Peak ticket sales.

Since the Covid-caused collapse in passenger rail travel and revenue in 2020, the graph shows that Advance and Off Peak ticket sales revenue are quite close to their pre-Covid peaks, but that the recovery in Anytime and, especially, Season ticket revenue continues to lag behind that of the other categories. This reflects the faster recovery in the cheaper leisure rail travel sector than in the more flexible and expensive business and commuter travel categories, and means that, while total passenger journeys in 2022-23 Quarter 1 have recovered to "75.8% of pre-pandemic journeys[, passenger revenue] over the quarter was at 70.4% of the same quarter three years ago" (Modern Railways, 2022f), placing continuing pressure on railway finances, already hard-hit by the loss of revenue during the lockdowns caused by the Covid pandemic.

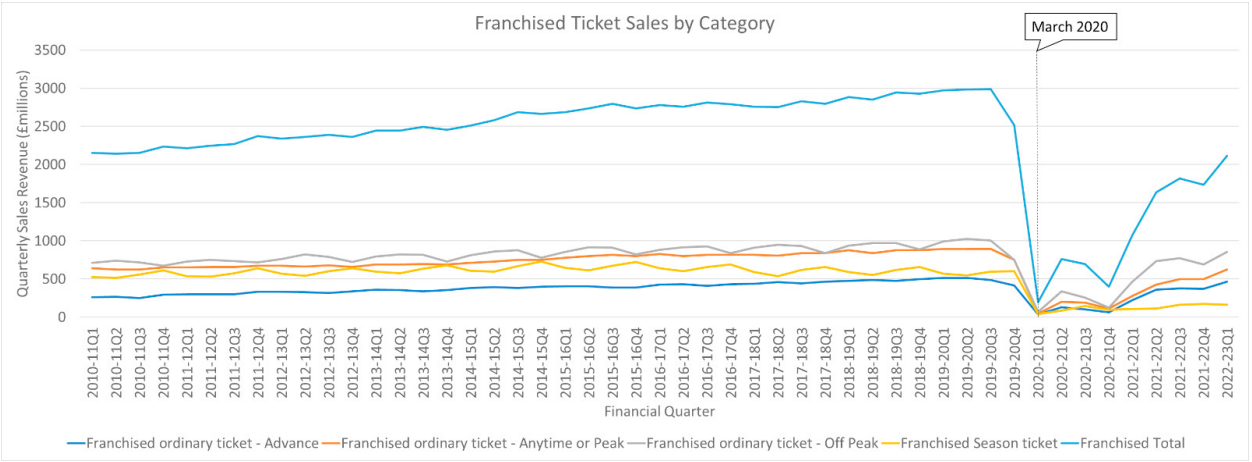

Fig. 8. Quarterly Rail Passenger Revenue by Ticket Type in Britain, 2010-11 Quarter 1 to 2022-23 Quarter 1

The decline in season ticket revenue seen in Figure 8 mirrors the reduced growth in passenger traffic seen from 2015 in Figure 6, particularly in the London and South East sector. This is likely to have been due to a combination of factors: on the one hand, increasing costs and inconvenience of commuting by rail, exacerbated in some cases by service reliability issues associated with timetable changes and industrial action; on the other, the increased ability of white-collar, office-based workers to meet and work remotely and from home (see, for example, Brunel, 2022; Soza-Parra et al., 2022), enabled by tele- and video-conferencing and other improvements in information and communications technology. According to Brunel (2022), a similar pre-Covid "latent trend" was also becoming apparent elsewhere in Europe. This development was, of necessity, greatly accelerated by the impact of successive Covid-triggered lockdowns, and demonstrated the feasibility of these new working and (non-)travel patterns. Despite a with-/post-Covid return to something like pre-Covid normality, there is (understandably) some reluctance to return to pre-Covid work and commuting patterns (Guardian, 2022b), with continuing implications for railway traffic and revenue (it is perhaps ironic

and unfortunate that the mode of mechanised transport with the smallest environmental impact has been hardest hit, patronage- and revenue-wise, by the effects of Covid, but this reflects rail's pre-Covid dependency upon the white-collar commuter market).

4. Post-Covid – Implications and Challenges for Rail

As indicated above, the Covid-19 pandemic, as well as directly causing a collapse in the use of passenger rail services, amplified and accelerated some trends in work-related travel that were emerging pre-Covid. These trends are unlikely to be reversed easily or quickly, even if this were desirable: requiring people to spend a significant amount of time and money each working day, travelling to, from and for work in often uncomfortable and unproductive conditions, is not necessarily a good use of time and resources, whatever the implications for railway revenue, and it may in any case have been that "the costs of providing [capacity] for the peak at the margins were outstripping the revenue [generated]" (Marsden et al., 2022). While the recovery of leisure travel by rail is welcome, it, combined with current levels of commuting and business travel, does not fully compensate for the loss of pre-Covid commuting and business travel revenue (it also has implications for the 'traditional' approaches to maintaining and renewing the railway, which have typically involved weekend and holiday closures on the network, to the detriment of leisure travellers). The situation is not helped by rising energy and other costs, feeding through to cost-of-living increases for railway users and staff, and being partly responsible for widespread recent outbreaks of industrial relations problems in the railway sector, reducing the quality and reliability of the service available to users (Modern Railways; 2022d, 2022e) as the industry emerges, and seeks to recover, from the effects of Covid. The continuing imbalance between railway costs and revenue presents the industry with an ongoing challenge, and pressure to reduce costs and/or increase revenue.

These challenges have been and are shared (and sometimes more imaginatively and proactively addressed – see below) by railways in other countries. However, alongside the impacts of Covid and inflation, Britain's railways are facing the additional challenge of major organisational change and the further uncertainty that it brings. In the years prior to the Covid-19 pandemic, the problems arising from the fragmented nature of Britain's privatised railways were increasingly apparent, exemplified by the failure of several passenger service franchises, and the industry was the subject of a series of reviews and strategy documents, most recently the Williams Rail Review, whose findings were eventually published by DfT (2021) in the form of the Williams-Shapps plan for rail. The plan sets out a range of strategic objectives for Britain's railways, including:

- The post-Covid re-building of public transport
- Contributing to national economic recovery and improving their financial sustainability
- Improved efficiency and network expansion
- The railway as the backbone of a cleaner, greener, integrated public transport system
- Improved delivery of railway system enhancements
- The prioritisation of track access in the public interest
- Enhanced service for and focus on users

These are all long-term challenges for the railway industry, but the re-building of public transport and its improved financial sustainability, not least through improved user focus and service provision, are all urgent priorities in the short term, too.

The Williams-Shapps plan includes the reorganisation of Britain's railways from the comparatively fragmented situation that existed with franchised passenger rail operations since privatisation of the industry in the 1990s, to a more unified structure under Great British Railways (GBR). The transition to GBR includes the consultation on and development of a Whole Industry Strategic Plan (WISP) by the Great British Railways Transition Team (GBRTT, 2022a), addressing "five key strategic objectives" reflecting those listed above:

- Meeting customer needs
- Delivering financial sustainability
- Contributing to economic growth
- Supporting 'levelling up' and connectivity
- Delivering environmental sustainability

These plans and objectives are broadly consistent with a series of strategy documents and plans that were developed and published prior to and since Covid, including a series of iterations of the Rail Technical Strategy (RTS, 2022), the Rail Delivery Group's (RDG; 2021) 'More than a journey' report, and the Rail Safety and Standards Board's (RSSB; 2014) Operational Philosophy for the GB Mainline Railway.

While the consistency of these objectives is encouraging, and the move towards a more integrated industry structure with a 'single guiding mind' is welcome, additional upheaval at a time of financial and industrial relations difficulties is less so, and an example of "'year zero' thinking" (Modern Railways, 2022a), rather than the continuity and consistency that the railway and its users need. Ongoing reorganisation reduces the railway industry's ability to focus on major, longer-term challenges, including, for example, decarbonisation and fares reform, creating something of a "vacuum of decision-making" (Modern Railways, 2022b). The situation has since been exacerbated by delays to the legislation required to bring GBR into being, with the result that its (and

GBR's) future is "unclear" (Modern Railways, 2022c), while the WISP "has been rebadged as the Long-Term Rail Strategy." In the same article, it is argued that, rather than "'a guiding mind'[, the] creation of a new railway requires a firm controlling hand", reflecting the difficulty of identifying and achieving agreed industry objectives and outcomes in the absence of a single, controlling entity. This is in some ways analogous to the distinction between 'government by steering' (the provision of high-level guidance for implementation by others) and 'government by rowing', involving direct involvement in service delivery (Rhodes, 1996; Marsden and Reardon, 2018).

The financial and other challenges facing passenger railways in the with- and post-Covid environments are readily apparent, but reduced passenger traffic volumes and train numbers have also had some positive implications for the industry, in the form of released capacity (or, as Kanoshima et al. (2022) put it, "the margin generated by the reduction of travel demand"), and have provided operational and performance benefits, notably for freight traffic. This can be seen clearly in Figures 9 and 10, showing traffic volumes and performance for the passenger and freight sectors respectively: the fall in traffic volumes during the first Covid lockdown (2020-21 Q1, i.e. April – June 2020) is accompanied by equally dramatic improvements in performance, which have since dwindled as traffic has been restored. In the case of Figure 10, it can be seen that, while freight traffic has remained quite steady since its recovery from the initial impact of Covid, its performance has continued to decline, reflecting the restoration of passenger traffic and its impact on freight performance.

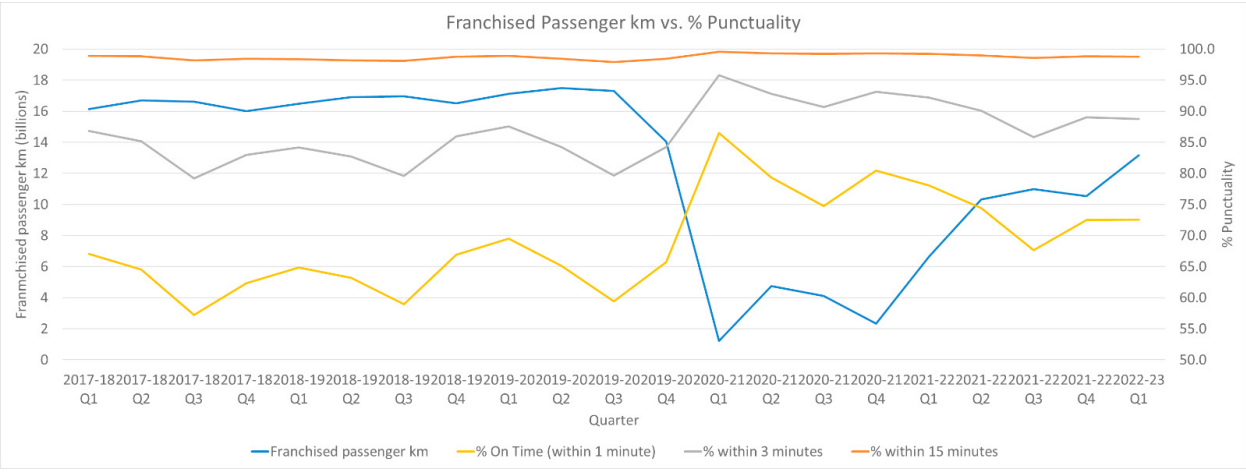

Fig. 9. Franchised Passenger km and Punctuality at Recorded Station Stops, 2017-18 Quarter 1 to 2022-23 Quarter 1 (ORR, 2022e and 2022g)

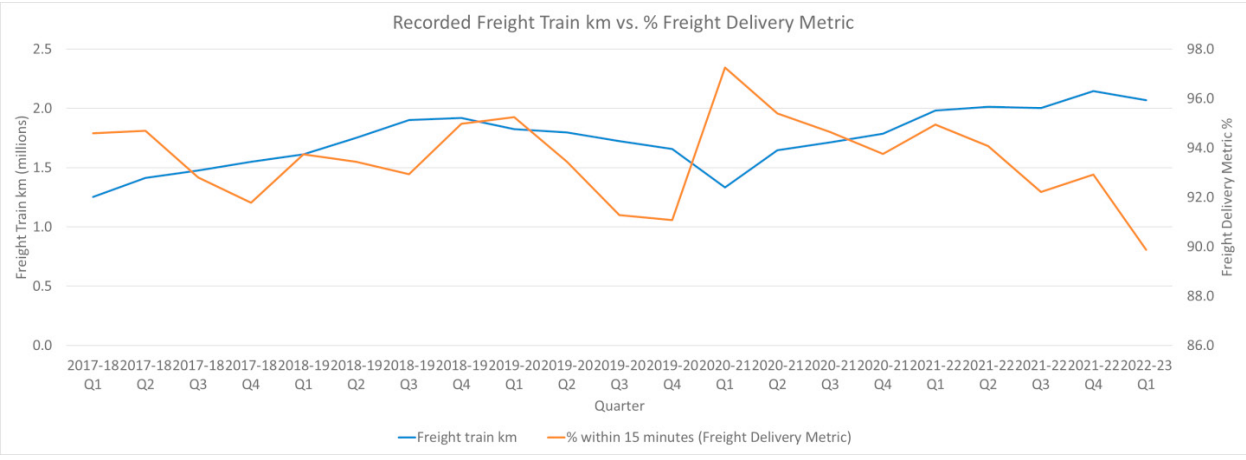

Fig. 10. Freight Traffic and Performance, 2017-18 Quarter 1 to 2022-23 Quarter 1 (ORR, 2022h and 2022i)

In its December 2020 issue, Modern Railways (2020c) noted the advantages of "running a simpler timetable with fewer but longer trains and [improved] performance." Elsewhere in the same issue (Modern Railways, 2020d), identified benefits to freight operations resulting from reduced passenger traffic levels included: shorter, faster routes through parts of the network that were previously too busy to accommodate freight traffic; improved productivity of rolling stock and crew; and reduced fuel consumption and environmental impacts resulting from freight trains having to stop and wait in freight loops, sometimes for extended periods, to be overtaken by faster passenger trains.

More recently, on the passenger side of the railway, Southeastern, the train operator providing commuter and other services between London and Kent, to the city's south-east, has been restructuring its operating plan in anticipation of the December 2022 timetable change (Modern Railways, 2022g). As indicated above, post-Covid demand is smaller and is also less 'peaked' than was the case prior to the pandemic, with peak-period travel "at around 50-60% of 2019 levels." Service patterns are becoming more standardised throughout the operating day, and conflicting train movements are being reduced in number, to improve service reliability. Some of the conflict reduction is being achieved through operational simplification, by reducing the number of London termini (Southeastern serves Cannon Street, Charing Cross and Victoria stations with its 'classic' services, as well St Pancras International with its high-speed trains) served directly from individual stations on the network, and requiring users to interchange *en route* as necessary to reach their preferred destinations. This approach is facilitated by several factors: by reduced passenger numbers in total, making interchange easier; by the fact that fewer people are commuting five days per week, thus reducing the impact on users of having to interchange; and also by new and improved interchange opportunities on the routes served, including a connection at Abbey Wood station with the recently-opened Elizabeth Line (the east-west Crossrail service through central London), easier interchange at the rebuilt London Bridge station, and improved timings of connections on some less busy parts of the network. Reduced peak period demand thus provides an opportunity for significant operational efficiencies and performance improvements, partially compensating for and offsetting its revenue impacts.

5. Net Zero Carbon – Implications and Opportunities for Rail

5.1. Rail's environmental vulnerabilities and strengths

The impacts on railway and other infrastructure systems of the extreme weather associated with climate change are becoming increasingly apparent, as shown by the impacts of flooding in Germany and elsewhere in 2021, with the estimated costs of repairs running to billions of euros (RailTech.com, 2021). On a smaller scale, the importance of resilient infrastructure was also tragically illustrated by the fatal Carmont derailment in Scotland in 2020, following very heavy rain and the washing of debris from an incorrectly-installed drainage system onto the track, as reported by the infrastructure manager (IM) of Britain's railways, Network Rail (2022), and by the Rail Accident Investigation Branch (RAIB; 2022). Because of their age, extent, and their original construction to comparatively primitive engineering standards, railway earthworks are particularly vulnerable to flooding and the increased intensity of rainfall associated with climate change. As noted in Network Rail's (2018) Earthworks Technical Strategy (ETS), they are also affected by increased 'shrink-swell' behaviour resulting from alternating wetting and drying, as both heavy rainfall and drought become more common. Earthworks and other infrastructure therefore need to be adapted, at considerable cost and difficulty, to these new circumstances. However, such adaptation has the additional potential advantage of improving infrastructure system resilience under less extreme circumstances. The issues of earthworks performance, deterioration, intervention and investment prioritisation are being investigated by the UK's ACHILLES (Assessment, Costing and enHancement of long lIfe, Long Linear assEtS; ACHILLES, 2022) research programme.

On the other hand, railways are inherently energy-efficient, with comparatively low greenhouse gas emissions rates, even in Britain (see Figures 3-5), where electrification of the system is less comprehensive than in many other European countries. This means that they have a valuable role to play in mitigating climate change, by reducing transport-related carbon emissions: as Zhang (2022) observes, "if rail transport could replace road transport, transport efficiency could be greatly improved and carbon emissions could be significantly reduced." Zhang and Hayashi (2022) advocate a post-Covid "transformation of transport policymaking", including the optimisation of the "spatiotemporal distribution of regular activities" to minimise the need for private car use, alongside the introduction of "more affordable, accessible and comfortable public transport systems" and the promotion of "active transport modes, such as walking [and] cycling."

While 'climate change as opportunity' is a somewhat uncomfortable concept, the railway sector is thus presented with a post-Covid opening for a restored and enhanced role in passenger and freight transport provision (the International Union of Railways (UIC; 2022) has explicitly referred to such an opportunity, and has identified "passengers' environmental concerns [as] contributing to the upswing in rail transport"). This is acknowledged in the UK government's Net Zero Strategy, produced by the Department for Business, Energy & Industrial Strategy (BEIS; 2021), which describes rail as being "already the greenest form of motorised transport[, despite less than] 38% of the network [being] electrified" at the time of publication. The objectives for rail set out in the strategy include:

- Further electrification of the network, and the use of hydrogen, battery and other power sources as necessary and appropriate, with a view "to remov[ing] all diesel-only trains by 2040"
- Provision of "extra capacity on [the] rail network to meet growing passenger and freight demand and support significant shifts from road and air to rail." This is to be achieved through a combination of new, high-speed lines, the re-opening of previously-closed routes, and improvements to the public transport networks of regional cities
- Fares and ticketing reform to "encourage a shift to rail"
- Improved "walking and cycling routes to and from stations"
- Incentives for increased use of rail for freight traffic

5.2. Capacity and service quality challenges in Great Britain

These are all sensible and worthwhile objectives, but, as with the legislation enabling the formation of Great British Railways (GBR), their implementation is subject to delay and uncertainty, with electrification proceeding slowly and in a somewhat piecemeal manner (except in Scotland, which has a rolling programme of electrification), and planned new routes being cut back due to financial pressures, as reported by New Civil Engineer (NCE; 2021, 2022). Given rail's comparatively small existing share of the transport market (see Figures 1 and 2), significant modal shift from air and, especially, road will require the construction of new capacity, although this itself has a climate change impact, in the form of 'embodied carbon' generated in the production of concrete, steel and other building materials, and in the construction process itself.

As shown in Figure 4, rail's environmental benefits depend upon the loadings of passenger services, with emissions per passenger km having been similar during the first Covid lockdown to those for air travel pre-Covid, and restoring train loadings would provide wider environmental benefits (especially in the event of modal shift to rail), as well as improving the railway's financial position. There is, however, a balance to be struck: pre-Covid, crowded, short-formation trains made financial sense for operators in Britain, but resulted in uncomfortable travelling conditions, which may have contributed to the plateauing of passenger traffic seen in Figure 6. As also noted above, the operation during the early stages of Covid of fewer, longer trains resulted in improved system performance, while also providing sufficient capacity on trains to enable social distancing between the remaining passengers. As passenger numbers recover and society learns to 'live with Covid', social distancing is no longer generally required, but service quality and reliability, and space and comfort aboard trains, remain important, and are likely to be increasingly so, given the growth in discretionary, leisure travel, and the desire to attract new users and encourage modal shift.

As noted above (and widely observed), the loss of traffic and revenue during and since Covid has put pressure on Britain's railways to reduce their costs, which has in turn contributed to industrial relations problems and further disruption to services. In the short term at least, it is difficult to reduce costs without affecting the quantity and quality of services provided, which in turn is likely to deter existing and prospective users of the railway, with the risk of a 'spiral of decline' in demand and service provision, just when railways have an important role to play (and an opportunity) in the provision of high-quality, high-capacity and low-impact public transport.

The alternative, preferable option is for railways to restore patronage and revenue by improving the quality, value and attractiveness of the services they offer to users. Again, rapid, short-term change in the nature of services provided is difficult, given the long lifecycles of railway infrastructure and rolling stock, and the high costs of upgrading and replacing (or refurbishing) them, whereas ticketing and marketing initiatives can be introduced comparatively quickly and easily. Some limited attempts were made to promote rail travel post-Covid, for example in the forms of the 'Great British Rail Sale' (National Rail, 2022) and 'flexible season tickets' for part-time commuter travel. Some train operators (e.g. LNER on the East Coast Main Line between London and Scotland) ran their own promotions, and discounted advance-purchase peak period tickets are now available on at least some commuter services, reflecting the changed nature of travel demand, with "even the commuting market [having] become elastic [i.e. sensitive to price]" (Modern Railways, 2021).

5.3. Lessons from elsewhere

These initiatives, while welcome, have been limited in scope (and apparently in impact), and contrast with the more ambitious and comprehensive approaches that have been taken elsewhere in Europe, with the primary aims of addressing environmental and cost-of-living concerns, while also helping to promote the use of public transport in the post-Covid environment. As Rothengatter (2022) observes in the German (and perhaps wider) context,

> *public transport by railways, buses, metros will need some more years to regain the lost patronage from car travel and biking. Massive state support will be necessary for reviving the confidence of customers in public transport and motivating them to prefer this mode over individual transport modes.*

The approaches taken in Germany and elsewhere to enable and encourage the use of public transport include:

- The 9-Euro-Ticket (Germany) allowed unlimited use of regional public transport (excluding inter-city rail services) for €9 per person per month, and was available between June and August 2022. Urban Transport Magazine (UTM, 2022) listed a range of proposals for its continuation/replacement, including a simple continuation, or more expensive alternatives.
- The 49-Euro ticket, or 'Deutschlandticket', (Germany) emerged as the planned successor to the 9-Euro-ticket, due for introduction from January 2023 (Reuters, 2022).
- The 'KlimaTicket' (Austria; KlimaTicket, 2022). The KlimaTicket Ö covers "all public transport in Austria with a single ticket" costing €1095 per year, aiming to be "simple and inexpensive [and] a valuable contribution to the climate of our planet."
- 20% reduction in public transport fares (Ireland) – according to Transport for Ireland (TFI; 2022), "public transport fares have been reduced by an average of 20% across Transport for Ireland bus, train and tram services."

- Free short- to medium-distance rail journeys (Spain) – following the introduction of a "30% discount on all [local] public transport, including metros, buses and trams", the Spanish government introduced a 100% rail travel discount on "multi-trip tickets on … commuter services [and] medium-distance routes (less than 300km)" from 1 September to 31 December 2022 (Guardian, 2022a). The scheme was subsequently extended to December 2023 (Euronews, 2022).

Clearly, reducing fares also reduces the revenue per individual trip, but the added incentive to travel should increase traveller numbers, restoring at least some of the total revenue foregone (except, obviously, in the case of 100% discounts). Indeed, Germany's 9-Euro-Ticket scheme was to some extent a 'victim of its own success', resulting in some regional services operating at and beyond their capacity limits, with resulting overcrowding and delays, particularly at weekends (UTM, 2022). While the planned increase in the price of the successor scheme from €9 to €49 per month has triggered some complaints (Independent, 2022), the schemes are expensive to implement, with the €9 scheme said to be costing "over one billion euros per month" (UTM, 2022). The Spanish scheme is to "be funded by a new windfall tax on banks and energy companies that have profited from rising interest rates and energy prices" (Euronews, 2022), to be introduced from 2023 and anticipated to raise "up to €7 billion in two years" (the tax will also be used to fund other social initiatives). In Germany, it has been suggested that "reduction or even abolition of the company car privilege" (UTM, 2022) might be used as a funding mechanism for the reduced public transport fares.

As indicated above, the 9-Euro-Ticket scheme encouraged a resurgence in the use of public transport, with the scheme having "had as big an impact on passenger numbers as the Covid-19 pandemic, but in the opposite direction", according to the International Railway Journal (IRJ; 2022). The same source reports that

> *the 9-euro ticket shows that mobility behaviour can be changed with a simple and clearly understandable offer, low prices and … extended nationwide validity[, and that, for the duration of the scheme,] in the summer months, the trend caused by the pandemic to increase car use [had] been stopped.*

However, it also cautions that, to enable the longer-term continuation of that trend, and to increase the number of non-leisure trips made by public transport, it is necessary "to have good and equally simple public transport services in the future." Elsewhere (UTM, 2022), it was noted that, while

> *only a slight shift from car to public transport [was detected,] the success of the 9-Euro Ticket is also measurable on the roads: according to analyses by the traffic data specialist Tomtom for the news agency dpa, a reduction in congestion levels could be demonstrated in 23 of 26 cities studied.*

As the Austrian and German schemes demonstrate, simplicity and affordability are key elements in the promotion of public transport use. Such promotions are likely to encourage at least some modal shift, but may mostly stimulate the making of additional, 'new' trips. The environmental benefits of such promotions are maximised when users switch from other, more polluting modes (i.e. road and air), and would ideally be accompanied by the introduction and implementation of road user and carbon charges for road and air travel respectively, complementing the 'carrot' of reduced-price rail and other public transport with the 'sticks' of increased costs for using the other modes, while also providing a source of funding to compensate for reduced fare income. (As road transport becomes electrified and government revenue from road fuel tax declines, the introduction of road user charging as a substitute becomes increasingly attractive, as well as encouraging more efficient use of the highway network.) Fares revenue impact aside, such promotions are again relatively cheap and easy to introduce, since they require no investment in additional 'hardware' (i.e. infrastructure and rolling stock), at least initially, and increased travel demand may be met by the reinstatement to service of underutilised (since Covid) rolling stock and network capacity. In the longer run, if continuing modal shift is to be encouraged and enabled, significant improvements and investment in capacity and quality will be needed. As noted on Austria's KlimaTicket (2022) website,

> *public transport is being bolstered by many other measures: modernisation and continuous expansion to ensure climate-friendly public transport.*

5.4. Prospects and objectives for rail

Looking forward, UIC has collaborated with Roland Berger and McKinsey in the preparation of two reports on the post-Covid prospects for rail: *Mobility post-Covid: An opportunity for railways* (Roland Berger GMBH, 2021), a UIC (2022) summary of which is quoted above; and *Boosting passenger preference for rail* (UIC and McKinsey, 2022).

The Roland Berger GMBH (2021) report identifies five 'megatrends' relating to railways that have been accelerated by Covid:

1. *Mobility behaviour will continue to evolve after the shock of remote working* – leisure travel is expected to recover quickly (as has happened in Britain and elsewhere), but recovery of work-related travel will be slower, and is unlikely to reach pre-Covid levels – a 'new normal' will take time to emerge.

2. *Secured during the crisis, public financing of rail can be expected to be maintained after Covid-19* – rail's environmental credentials mean that recent levels of subsidy and government support are likely to be continued (this is perhaps less clearly the case in Britain, amid ongoing uncertainty about government spending and railway investment).
3. *Passenger's environmental concerns are conducive to a central role for rail in mobility* – increasing environmental and social awareness and concern is likely to increase demand for rail travel, including increased provision of high-speed and night train services to replace air travel.
4. *Liberalisation of the EU rail market has slowed down but is not going to stop* – reduced traffic volumes with Covid have made the market less attractive to new entrants, but long-term increases in traffic volumes are likely to reverse that – there appears to be considerable interest in the introduction of new night train services, for example (Britain is no longer a member of the EU rail market, and the role of the private sector in Britain's railways seems likely to be reduced, in favour of greater integration and coordination, but this is a matter of considerable uncertainty, as noted above).
5. *Development of high-speed infrastructure will benefit from a change in perception, with air travel appealing less and less to passengers* – the development of high-speed rail systems is likely to continue, despite their high costs (and embedded carbon impacts).

The report also notes the financial and environmental challenges that have been faced by the aviation sector (although it didn't appear to anticipate the organisational challenges that have emerged at airports as air passenger numbers have recovered), and observes that road transport is undergoing a major transition away from the internal combustion engine, but cautions that this "window of opportunity for rail is … relatively short." It recommends that rail should secure its existing "modal share by capitalising on its main benefits – reliability and comfort" – and then enlarge its share by addressing its "main weaknesses, e.g. perception of high prices, limited connections with other modes, etc." The report sets out "three key objectives" for the industry:

1. *Improve the customer experience* – capitalise on rail's inherent advantages, and adapt to changing patterns of mobility and consumption.
2. *Improve the economic equation of rail* – optimise cross-industry costs to reduce fares, ensure profitability for operators and enable investment for the future.
3. *Improve environmental performance* – ensure that rail continues to maintain its favourable position in this regard relative to competing modes.

The report then makes a series of more detailed recommendations for operators, infrastructure and station managers, transport authorities and suppliers, with customer service and the environment as recurring themes. Services and stations should be provided to meet customer needs and expectations, including appropriate levels of convenience, comfort and information provision, attractive fare options, and ease of interchange. New and improved infrastructure should be provided to optimise capacity and reliability and provide resilience to the effects of climate change, while financing and regulation should be provided and applied to deliver optimal outcomes.

The report by UIC and McKinsey (2022) reiterates rail's strengths in terms of capacity, speed, (potential) comfort and environmental performance, and its weaknesses in terms of pricing ("especially for group travellers or families, when compared to car travel"), reliability, density (i.e. network coverage) and end-to-end journey (in)convenience. It notes that rates of recovery of rail passenger traffic have varied around the world, that convenience is a major factor in the choice of whether or not to use rail, and also that "there have been fundamental shifts in travel behaviours" since the pandemic, echoing the findings above. Reflecting the Southeastern timetable changes described above, the report also observes that there are opportunities for operators

> *to make the whole system more sustainable and efficient as the typical morning and evening peaks may become less important in the future.*

The research described in the report found that the main priorities for rail users are "price, safety and the core product offering [i.e. total journey time, frequency of service, and station accessibility]", with environmental issues being (so far) a relatively low priority. The report identifies three "horizons" over which to recover and increase demand for passenger rail travel, and 10 corresponding "levers" to deliver the restoration and growth in demand, as summarised below:

1. *Restore rail to pre-Covid-19 levels*
   - *Re-establish the rail service* – this has largely been done, despite industrial relations issues in Britain
   - *Adapt the offering to cater to new behaviours* – update timetables and fare options to reflect changing user needs – this has been done to a limited extent in Britain, with more dramatic interventions taking place elsewhere (see above)
   - *Communicate with customers* – marketing initiatives are important for highlighting what rail can offer to 'lapsed' and new users
2. *Grow passenger rail by better operations*

- *Tap into new passenger segments with new offerings and differentiated pricing* – the 'low cost operator' model has been used in Britain (Lumo) and France (OuiGo), and fares can be adjusted to stimulate demand, as seen above (too much differentiation may run the risk of excessive complexity for users, though)
- *Enhance train and station passenger experience* – trains and stations should be comfortable, easy to use and navigate, and meet users' changing needs (perhaps especially those of new users)
- *Develop a leading position in end-to-end journeys* – improved convenience and integration of information, ticketing and transport modes, moving towards 'Mobility as a Service' (MaaS) – as noted above, part of the UK government's vision is that the railway should provide the "backbone of a cleaner, greener, integrated public transport system" (DfT, 2021)
- *Promote trains as an alternative, green and efficient means of transportation* – railways should do more to promote their 'green' credentials, as awareness of and concern about the environment grows

3. *Grow passenger rail by structural measures*
   - *Ramp up service, creating more capacity through rolling stock and digitalisation of the network* – improve services with new and upgraded rolling stock (while not sacrificing comfort for capacity, especially in the context of more discretionary post-Covid travel) and the use of technology to maximise available infrastructure capacity (again without sacrificing performance for capacity)
   - *Invest in high density, high speed and high frequency* – increase service coverage, speed and frequency to enable and encourage modal shift
   - *Regain an integrated perspective on the business models for rail* – draw upon rail's strengths and address its weaknesses (actual and as perceived by users) and improve integration between operators and infrastructure managers (and across borders where applicable) – these needs and concerns are reflected in the recent moves by the UK government towards increased integration of Britain's railways

These two reports confirm that, despite the challenges presented during Covid (which railways generally met, albeit with substantial government financial support) and since, the railway industry's future is encouraging, particularly in the context of ever-growing environmental concerns. Adaptation to provide improved infrastructural and operational resilience in the face of extreme weather will be necessary, if the industry is to provide the level and standard of service necessary to fulfil its potential role in helping to mitigate the effects of climate change. The call for increased differentiation of service provision and fares will also need to be balanced against the benefits and attractiveness to users of simplicity, as highlighted by recent European discounted ticketing initiatives.

Perhaps blurring the distinction made above between 'government by steering' and 'government by rowing', the achievement of this potentially positive outcome will require government to "have a sufficient hand on the tiller to steer towards positive social outcomes" (Marsden and Reardon, 2018). This would entail a shift from traditional, comparatively passive and incremental 'predict and provide' approaches to the provision of transport capacity and facilities, towards a more activist 'decide and provide' approach (International Transport Forum, 2021), whereby desired positive social and environmental outcomes are identified, and transport policy and provision are geared towards meeting them.

5.5. Helping Britain's railways to meet the challenges posed by Covid and Carbon

In his 2022 Beesley Lecture (GBRTT 2022b), Andrew Haines, the Chief Executive of Network Rail and the leader of the Great British Railways Transition Team, noted the uncertainty surrounding future passenger and freight demand. He also observed that Britain's railways, in their current form, are "structurally incapable of efficiently delivering an agile response to shifting patterns of usage and demand that is anything other than incremental."

Translating and converting qualitative objectives and strategies into detailed, quantified plans for implementation therefore presents a significant further challenge, as does striking the right balance between stimulated demand and modal shift and the available capacity of railways to accommodate it, as witnessed by some of the experiences in Germany described above. With these and other objectives in mind, the railway sector in the UK is developing a network of research centres, addressing the range of challenges facing the industry. The UK Rail Research and Innovation Network (UKRRIN, 2018) has already established four collaborative Centres of Excellence (CoEs) for academic research in cooperation with industry:

- Digital Systems – Universities of Birmingham, Lancaster, Imperial College, Swansea and Hull
- Rolling Stock – Universities of Huddersfield, Newcastle, Loughborough, Bristol, Cambridge, Brunel and Nottingham
- Infrastructure – Universities of Southampton, Loughborough, Nottingham, Sheffield, Heriot-Watt
- Testing – an industry-led collaboration between Network Rail, Transport for London and Porterbrook

Two further CoEs are currently in development, which will address many of the service provision issues facing the railways in the post-Covid environment:

- Centre of Inclusive Passenger Experience – Universities of Birmingham, Cambridge, Nottingham, Southampton and University College London

- Centre of Excellence in Railway Economics, Planning and Operations (CEREPO) – Universities of Leeds, Southampton and Birmingham

The Centre of Inclusive Passenger Experience will help to ensure that the evolving needs of current, 'lapsed' and new railway users are identified and met, enabling the full restoration and growth of railway passenger traffic, and helping to provide the 'carrot' needed to encourage modal shift. CEREPO intends to address the post-Covid railway travel demand and revenue challenges described above, among others, moving beyond qualitative objectives towards quantifying the trade-offs involved, and identifying the solutions that provide optimal outcomes, socially, economically and/or environmentally. Its main areas of interest and proposed activities include:

- Demand forecasting (and stimulation)
- Cost modelling
- Pricing
- Regulatory policy and competition
- Investment appraisal and evaluation
- Operations Research

The demand forecasting (and stimulation) element of CEREPO aims to develop balanced solutions to the stimulation of demand within current and anticipated capacity (and funding) constraints; these will include the appropriate allocation of capacity between passenger and freight services, with the potential for re-allocation towards freight in cases where this improves economic, social and/or environmental outcomes. The use of low-cost initiatives to improve and encourage rail use is likely to be particularly important in the near-term, given the current state of the UK economy and likely restrictions on public spending in the foreseeable future. The cost modelling, pricing, regulatory policy and competition, and investment appraisal and evaluation workstreams are reasonably self-explanatory. The Operations Research workstream is intended to operate on two levels: (i) detailed, 'micro-level' research on specific aspects of railway planning and operations; and (ii) 'macro-level', overarching research on the optimisation of policy, economic, social and environmental outcomes, reflecting the national and international future priorities for railways outlined above.

In combination, these CoEs could help to address the challenges facing Britain's railways, addressing their vulnerabilities and improving the quantity and quality of service provided to meet the social, economic and environmental needs of the mid- and late-21st century, while drawing upon research, practice, experience and lessons learned in continental Europe and elsewhere.

6. Conclusions

Railways, having recovered from various challenges in the 20th century and re-established themselves as providers of generally high-speed, high-capacity and high-quality passenger and freight transport with a low environmental impact, were severely affected by the Covid-19 pandemic. This was particularly true for the passenger railway sector, with almost all but essential workers ceasing to travel by rail during Covid lockdowns. However, railways continued to provide vital passenger and freight transport throughout the pandemic.

As life and society have returned to a new, with-/post-Covid normal, passenger traffic has returned to the railways in Britain and elsewhere, but work-related (i.e. commuting and business) traffic has not returned to its pre-Covid levels, and seems unlikely to do so in the near future, reducing railway revenue but also reducing capacity pressures and requirements in the weekday peak periods, potentially enabling the introduction of more consistent and reliable service patterns. Efforts have been made to encourage the increased use of rail, but these have been more dramatic and comprehensive elsewhere in Europe than in Britain, with reduced fare offers being used to address environmental and cost-of-living concerns, as well as to stimulate railway passenger traffic.

As the reality and implications of climate change become increasingly apparent, so does rail's potential expanded role in the provision of low-carbon passenger and freight transport, particularly if it includes modal shift from road and air (although the vulnerability of railway infrastructure and systems to the effects of climate change will also have to be addressed). Recent European experience, supported by work undertaken by the railway industry to develop a post-Covid strategy, indicates that, if railways are to succeed in providing the transport systems and facilities needed in a post-Covid, Net Zero Carbon world, they will need to improve the quality, coverage, integration, simplicity and value for money of their services, making them more attractive and easy to use for existing and new users, especially those shifting from other modes. Some railway systems have already made significant progress in these directions, while others have strategies in place that need considerable work to enable their realisation and delivery.

References

ACHILLES, 2022. Welcome to ACHILLES [online]. Available from https://www.achilles-grant.org.uk/ [Accessed 4 November 2022]

BEIS, 2021. Net Zero Strategy: Build Back Greener [online]. Available from net-zero-strategy-beis.pdf (publishing.service.gov.uk) [Accessed 4 November 2022]

Brunel, J., 2022. The recovery of long-distance mobility after COVID-19: What can we expect?. In: Zhang, J. and Hayashi, Y. (Ed.), "Transportation Amid Pandemics: Lessons Learned from COVID-19", Elsevier, Amsterdam, pp. 331-338

DfT, 2021. Great British Railways: Williams-Shapps plan for rail [online]. Available from https://www.gov.uk/government/publications/great-british-railways-williams-shapps-plan-for-rail [Accessed 1 November 2022]

DfT, 2022a. TSGB01010: Passenger Transport by mode from 1952 [online]. Available from https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1041061/tsgb0101.ods [Accessed 19 October 2022]

DfT, 2022b. TSGB0401: Domestic freight transport by mode [online]. Available from https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1041072/tsgb0401.ods [Accessed 19 October 2022]

DfT, 2022c. ENV0201: Greenhouse gas emissions by transport mode: United Kingdom [online]. Available from https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1112228/env0201.ods [Accessed 21 November 2022]

Euronews, 2022. Spain has just extended its free train travel scheme until December 2023 [online]. Available from https://www.euronews.com/travel/2022/10/04/spain-short-and-medium-distance-trains-will-be-free-this-autumn-thanks-to-a-windfall-tax [Accessed 7 November 2022]

GBRTT, 2022a. Whole Industry Strategic Plan [online]. Available from https://gbrtt.co.uk/what-we-do/wisp/ [Accessed 2 November 2022]

GBRTT, 2022b. The Beesley Lecture: A Speech by Andrew Haines, Transition Team Lead [online]. Available from https://gbrtt.co.uk/blogs/beesley-lecture/ [Accessed 28 November 2022]

Guardian, 2022a. Spain announces free rail journeys from September until the end of the year [online]. Available from https://www.theguardian.com/money/2022/jul/15/spain-announces-free-rail-journeys-from-september-until-the-end-of-the-year [Accessed 7 November 2022]

Guardian, 2022b. It's just not worth it': why employers still can't get staff back to the office [online]. Available from https://www.theguardian.com/business/2022/oct/01/back-to-office-say-bosses-staff-prefer-working-from-home [Accessed 7 November 2022]

Independent, 2022. Huge leap in price for experimental public transport ticket sparks angry backlash in Germany [online]. Available from https://www.independent.co.uk/news/world/europe/germany-public-transport-ticket-price-increase-b2217545.html [Accessed 7 November 2022]

International Transport Forum, 2021. Travel Transitions: How Transport Planners and Policy Makers Can Respond to Shifting Mobility Trends [online]. Available from https://www.itf-oecd.org/travel-transitions-policy-makers-respond-mobility-trends [Accessed 28 November 2022]

IRJ, 2022. Germany's 9-euro ticket "as impactful as Covid" on passenger numbers [online], available from https://www.railjournal.com/passenger/main-line/germanys-9-euro-ticket-as-impactful-as-covid-on-passenger-numbers/ [Accessed 7 November 2022]

Kanoshima, H., Hasegwa, Y., Oguchi, T. and Suda, Y., 2022. A proposal of recommendations for post-Corona mobility. In: Zhang, J. and Hayashi, Y. (Ed.), "Transportation Amid Pandemics: Lessons Learned from COVID-19", Elsevier, Amsterdam, pp. 409-420

Khadem Sameni, M., 2022. The Impact of the Covid-19 Pandemic on Rail Transport in the Middle East. Presented in World Conference on Transport Research Society (WCTRS) Rail Webinar, 28 July 2022

KlimaTicket, 2022. Welcome to the mobility of the future [online]. Available from https://www.klimaticket.at/en/ [Accessed 7 November 2022]

Lai, R., 2022. How Covid-19 has affected Railway Transportation in the East Asia Region. Presented in World Conference on Transport Research Society (WCTRS) Rail Webinar, 28 July 2022

Marsden, G, Docherty, I., Anable, J. and Brown, L., 2022. The transport policy response to the COVID-19 pandemic in the UK. In: Zhang, J. and Hayashi, Y. (Ed.), "Transportation Amid Pandemics: Lessons Learned from COVID-19", Elsevier, Amsterdam, pp. 421-428

Marsden, G. and Reardon, L., 2018. Introduction. In: Marsden, G. and Reardon, L. (Ed.), "Governance of the Smart Mobility Transition", Emerald Publishing Limited, Bingley, pp. 1-15. https://doi.org/10.1108/978-1-78754-317-120181001

Modern Railways, 2020a. Franchises move to emergency measures. Modern Railways: Vol. 77, No. 860, p8

Modern Railways, 2020b. Europe in lock down. Modern Railways: Vol. 77, No. 860, pp74-75

Modern Railways, 2020c. Railtalk. Modern Railways: Vol. 77, No. 867, pp6-7

Modern Railways, 2020d. Better, happier, more productive. Modern Railways: Vol. 77, No. 867, pp20-21

Modern Railways, 2021. LNER aims to build back better. Modern Railways: Vol. 78, No. 870, pp50-55

Modern Railways, 2022a. Railtalk. Modern Railways: Vol. 79, No. 885, pp6-7

Modern Railways, 2022b. Railtalk. Modern Railways: Vol. 79, No. 886, pp6-7

Modern Railways, 2022c. Railtalk. Modern Railways: Vol. 79, No. 890, pp6-7

Modern Railways, 2022d. Six more months for Avanti. Modern Railways: Vol. 79, No. 890, p10

Modern Railways, 2022e. Strike action continues. Modern Railways: Vol. 79, No. 890, p10

Modern Railways, 2022f. Passenger numbers continue to rise. Modern Railways: Vol. 79, No. 890, p14

Modern Railways, 2022g. Southeastern restructures timetable. Modern Railways: Vol. 79, No. 890, pp76-77

National Rail, 2022. Great British Rail Sale [online]. Available from https://greatbritishrailsale.nationalrail.co.uk/ [Accessed 7 November 2022]

NCE, 2021. MPs back Integrated Rail Plan cuts to HS2 and Northern Powerhouse Rail [online]. Available from https://www.newcivilengineer.com/latest/mps-back-integrate-rail-plan-cuts-to-hs2-and-northern-powerhouse-rail-09-12-2021/ [Accessed 4 November 2022]

NCE, 2022. Fury as government rows back on Northern Powerhouse Rail [online]. Available from https://www.newcivilengineer.com/latest/fury-as-government-rows-back-on-northern-powerhouse-rail-promise-03-11-2022/ [Accessed 4 November 2022]

Network Rail, 2018. Earthworks Technical Strategy [online]. Available from https://www.networkrail.co.uk/wp-content/uploads/2018/07/Earthworks-Technical-Strategy.pdf [Accessed on 21 November 2022]

Network Rail, 2022. Resilience of rail infrastructure [online]. Available from https://www.networkrail.co.uk/who-we-are/our-approach-to-safety/stonehaven [Accessed 4 November 2022]

ORR, 2022a. Table 1231 - Passenger kilometres by sector [online]. Available from https://dataportal.orr.gov.uk/media/2012/table-1231-passenger-kilometres-by-sector.ods [Accessed 28 October 2022]

ORR, 2022b. Table 1310 - Freight moved by commodity [online]. Available from https://dataportal.orr.gov.uk/media/1998/table-1310-freight-moved-by-commodity.ods [Accessed 28 October 2022]

ORR, 2022c. Table 6105 - Estimates of passenger energy consumption and carbon dioxide equivalent (CO2e) emissions [online]. Available from https://dataportal.orr.gov.uk/media/1526/table-6105-estimates-of-passenger-energy-consumption-and-carbon-dioxide-equivalent-emissions.ods [Accessed 28 October 2022]

ORR, 2022d. Table 6115 - Estimates of freight energy consumption and carbon dioxide equivalent (CO2e) emissions [online]. Available from https://dataportal.orr.gov.uk/media/2114/table-6115-estimates-of-freight-energy-consumption-and-carbon-dioxide-equivalent-emissions.ods [Accessed 28 October 2022]

ORR, 2022e. Table 1231 - Passenger kilometres by sector [online]. Available from https://dataportal.orr.gov.uk/media/2012/table-1231-passenger-kilometres-by-sector.ods [Accessed 21 November 2022]

ORR, 2022f. Table 1212 - Passenger revenue by ticket type [online]. Available from https://dataportal.orr.gov.uk/media/1484/table-1212-passenger-revenue-by-ticket-type.ods [Accessed 28 October 2022]

ORR, 2022g. Table 3133 - Train punctuality at recorded station stops by operator [online]. Available from https://dataportal.orr.gov.uk/media/1425/table-3133-train-punctuality-at-recorded-station-stops-by-operator.ods [Accessed 1 November 2022]

ORR, 2022h. Table 1333 - Freight train kilometres by operator [online]. Available from https://dataportal.orr.gov.uk/media/1825/table-1333-freight-train-kilometres-by-operator.ods [Accessed 1 November 2022]

ORR, 2022i. Table 1320 - Freight Delivery Metric [online]. Available from https://dataportal.orr.gov.uk/media/1824/table-1320-freight-delivery-metric.ods [Accessed 1 November 2022]

RAIB, 2022. Derailment of a passenger train at Carmont, Aberdeenshire 12 August 2020; [online]. Available from R022022_220310_Carmont.pdf (publishing.service.gov.uk) [Accessed 4 November 2022]

RailTech.com, 2021. After the flood: European rail repairs will cost billions [online]. Available from https://www.railtech.com/infrastructure/2021/07/21/after-the-flood-rail-repair-costs-amount-to-billions/ [Accessed 2 November 2022]

RDG, 2021. More than a journey [online]. Available from https://railtechnicalstrategy.co.uk/ [Accessed 2 November 2022]

Reuters, 2022. Germany to let commuters ride buses and trains for 49 euros a month [online]. Available from https://www.reuters.com/business/autos-transportation/germany-let-commuters-ride-buses-trains-49-euros-month-2022-11-02/ [Accessed 7 November 2022]

Rhodes, R.A.W., 1996. The New Governance: Governing without government. Political Studies, 44.4, 652-667. https://doi.org/10.1111/j.1467-9248.1996.tb01747.x

Roland Berger GMBH, 2021. Mobility post-Covid: an opportunity for rail transport [online]. Available from https://uic.org/IMG/pdf/mobility-post-covid-an-opportunity-for-railways.pdf [Accessed 8 November 2022]

Rothengatter, W., 2022. Impacts of COVID-19 on the economy and the transportation system in Germany. In: Zhang, J. and Hayashi, Y. (Ed.), "Transportation Amid Pandemics: Lessons Learned from COVID-19", Elsevier, Amsterdam, pp. 71-86

RSSB, 2014. Operational Philosophy for the GB Mainline Railway (T952 Report) [online]. Available from https://www.sparkrail.org/Lists/Records/DispForm.aspx?ID=20936 [Accessed 2 November 2022]

RTS, 2022. Rail Technical Strategy [online]. Available from https://railtechnicalstrategy.co.uk/ [Accessed 2 November 2022]

Soza-Parra, J, Circella, G. and Sperling, D., 2022. Changes in activity organization and travel behavior choices in the United States. In: Zhang, J. and Hayashi, Y. (Ed.), "Transportation Amid Pandemics: Lessons Learned from COVID-19", Elsevier, Amsterdam, pp. 191-199

TFI, 2022. The TFI Price Drop Is Here! [online]. Available from https://www.transportforireland.ie/fares-reductions/ [Accessed 7 November 2022]

UIC, 2022. Mobility post-Covid: an opportunity for rail transport [online]. Available from https://uic.org/com/enews/article/mobility-post-covid-an-opportunity-for-rail-transport [Accessed 8 November 2022]

UIC and McKinsey, 2022. Boosting passenger preference for rail [online]. Available from https://uic.org/IMG/pdf/20220728_-_uic_and_mckinsey_bossting_passenger_preference_for_rail_final_online.pdf [Accessed 8 November 2022]

UKKRIN, 2018. Centres of Excellence [online]. Available from http://www.ukrrin.org.uk/centres-of-excellence/ [accessed 1 December 2022]

UTM, 2022. Germany's 9-Euro Ticket – what's next? [online]. Available from https://www.urban-transport-magazine.com/en/germanys-9-euro-ticket-whats-next/ [Accessed 7 November 2022]

Veeneman, W., 2022. Governance, COVID responses, and lessons on decision-making in uncertainty. In: Zhang, J. and Hayashi, Y. (Ed.), "Transportation Amid Pandemics: Lessons Learned from COVID-19", Elsevier, Amsterdam, pp. 441-450

Zhang, J., 2022. Governance for post-COVID-19 carbon reduction: A case study of the transport sector. In: Zhang, J. and Hayashi, Y. (Ed.), "Transportation Amid Pandemics: Lessons Learned from COVID-19", Elsevier, Amsterdam, pp. 429-440

Zhang, J. and Hayashi, Y., 2022. Policy recommendations and future challenges. In: Zhang, J. and Hayashi, Y. (Ed.), "Transportation Amid Pandemics: Lessons Learned from COVID-19", Elsevier, Amsterdam, pp. 453-460