Rail network resilience and operational responsiveness during unplanned disruption: A rail freight case study

Woodburn, A.G.

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Abstract

This paper focuses on the resilience of rail freight operations when affected by extreme weather events. Such events, most likely linked to climate change, are becoming more common and it is vital to mitigate their effects on freight transport activity. Based on a British case study of rail network disruption resulting from a key line closure in early-2016, the analysis considers the impacts on rail freight service provision and the wider supply chains.

Following a review of the relevant literature, the case study is analysed using data from a combination of sources including an annual rail freight database, open access real-time train running data, observation surveys and stakeholder interviews. This reveals widespread consequences of the disruption, with fewer freight trains operated than normal, and longer and less punctual journeys for those which ran. However, despite the considerable disruption during the period of the line closure itself, there has been no discernible long-term impact on the rail freight flows which were impacted by the closure. The insight provided by the analysis is used to make a series of recommendations to the rail industry and policy makers.

Keywords: rail freight; weather-related disruption; transport network resilience; disruption impact analysis

1. Introduction

Transport infrastructure plays a fundamental role in facilitating the movement of people and goods but routes and nodes can suffer from planned or unplanned unavailability, disrupting transport flows and causing economic and social problems. Extreme weather events, most likely linked to climate change, are becoming more prevalent across Europe (and elsewhere) (IPCC, 2013), with consequent disruption to transport activity. Despite this, transport network resilience is insufficiently understood. Jaroszweski et al. (2010) found that surprisingly little research had been conducted, in the United Kingdom (UK) at least, investigating transport vulnerabilities to climate change.

This paper is based on a case study from 2016 of the lengthy unplanned closure of a key rail freight route in Britain. The aim of the paper is to analyse the rail industry's collective responsiveness and to assess the impacts that the closure had on the rail freight flows that were affected. Rail has a 9% share of the freight market in Britain (DfT, 2018) and it is estimated that goods valued at more than £30 billion per annum are moved by rail, including considerable volumes of time-sensitive and/or high-value traffics such as automotive products and consumer goods which require high levels of service performance (RDG, 2018). Despite being focused on a single British case study, the findings offer insight more generally since the impacts of rail network vulnerabilities on freight (and wider supply chain) activity are inadequately understood. A global survey by BCI (2018) found that adverse weather, supply chain disruption and transport network disruption were all ranked in the top 10 of 30 specified organisational threats. The case study (set out in Section 4) combines these three factors, with the specific research questions (RQs) addressed in this paper being:

- RQ1: To determine the impacts of the line closure on rail freight traffic levels and capability
- RQ2: To assess the wider supply chain implications of the line closure

- RQ3: To make recommendations for improving the resilience of rail freight operations, on the basis of the evidence from the case study

The paper is structured as follows. Section 2 reviews the relevant literature, highlighting the importance of the topic and the need for further empirical research such as that presented in this paper. Section 3 provides details of the research methods adopted to satisfy the research aim, followed in Section 4 by contextual information regarding the case study upon which the paper is focused. Section 5 presents the relevant data for RQ1, then Section 6 addresses each of the three research questions in turn. Section 7 concludes the paper with a discussion of the wider implications of the research findings.

2. Literature review

This review of the relevant literature starts by contextualising the topic of freight transport resilience (Section 2.1). Section 2.2 then concentrates on transport network resilience for rail freight operations, followed in Section 2.3 by an assessment of the growing body of literature demonstrating the vulnerability of transport infrastructure and operations to extreme weather events, the specific focus of this paper's subsequent original analysis.

2.1 What is freight transport resilience?

In broad terms, resilience is defined as 'the capacity to recover quickly from difficulties' (Oxford Dictionaries, n.d.). In the transport literature, the investigation of resilience is typically related to network (or system) vulnerabilities and the manner in which consequent unplanned disruption is handled (see, for example, Fikar et al., 2016; Mattsson and Jenelius, 2015; Tamvakis and Xenidis, 2012). In this context, the British government has defined resilience as ’the ability of the transport network to withstand the impacts of extreme weather, to operate in the face of such weather and to recover promptly from its effects’ (DfT, 2014a, 8).

Freight transport resilience is a prime consideration for well-functioning supply chains and, by extension, the economy of a country or region. Low resilience inhibits those providing freight services from satisfying customer requirements (Chen and Miller-Hooks, 2012), with potentially far-reaching economic consequences. McKinnon (2006) predicted rapid disruption to economic activity in the UK should there be a week-long cessation of road haulage activity. Waters (2011) stated that, while there is understandable concern about terrorist attacks, ‘the flow of materials is much more likely to be disrupted by an unreliable supplier or difficulty with transport’ and argued that the availability of parallel transport links can help to add operational resilience and mitigate freight transport disruption. A distinction can be made between frequent, but typically low-level, disruption leading to variability in everyday operating practices and major, but generally rare, events which cause widespread disruption (Li et al., 2016).

2.2 Network resilience for rail freight operations

Rail is commonly perceived as being less resilient than road haulage (Directorate-General for Internal Policies, 2015) so, to meet the European policy objective of shifting freight from road to rail (European Commission, 2011), it is important to make improvements. To achieve a considerable increase in freight mode share, rail needs to attract more flows of consumer goods and other time-sensitive freight but there are concerns over rail’s capabilities in dealing with the requirements of such traffic (AECOM, Arup and SNC Lavalin, 2016). Based on a review of the academic literature, Reis (2014) found that the attributes consistently identified as being key for freight mode choice decision making are reliability, transit time, flexibility and price. Patterson et al. (2007) found that freight customers tend to trust rail less than road haulage, with service performance being a critical factor, a view reinforced by the Freight

Transport Association (FTA, 2014) which advocated better service flexibility and availability for rail. Rich et al. (2011) argued that rail freight faces greater challenges than road haulage, its main competitor, since the former mode tends to have a much less dense network and fewer alternative routes than the latter, so is generally less resilient. Specifically, there is a perception that rail needs to be better at coping with unplanned issues such as route blockages (RSSB, 2012), extreme weather events being a major cause. In the 2012 Freight Customer Survey (ORR, 2012), the (lack of) flexible service/recovery strategy was cited as the second biggest barrier to using rail in Britain. When considering rail's performance, 'flexible service/recovery strategy' was highly ranked for importance but was the worst ranked attribute for performance. This suggests that resilience is important for customers, but that rail falls short on delivery during periods of disruption. Uncertainty over the extent and duration of disruption is a particular concern for customers. A high-profile media example affecting the UK was the Channel Tunnel disruption at Calais caused by migrants and strike blockades (FTA, 2015) which led to the cessation of some rail flows.

There are few studies in the academic literature specifically considering the resilience (or otherwise) of rail networks and the impacts on freight activity. Focusing on the Brenner Pass rail route, a critical link in the European rail network, Fikar et al. (2016) substantiated a decision support system to understand the impacts of an unexpected closure of the route. Disruption scenarios lasting 24 and 72 hours were simulated, with diversion of flows to other rail routes or to road. Delay time was calculated at a strategic level, providing guidance on how to manage unplanned disruption but not taking into account detailed operational characteristics. In practice, the European Court of Auditors (2016) identified that, at times of network disruption, priority is given to passenger services, exacerbating the delays to freight trains. If this leads to a transfer of traffic from rail to road, either temporarily or permanently, improvements in freight transport sustainability may be jeopardised (RSSB, 2016a). As RSSB (2016b) notes, there is currently no recognised method for calculating the overall economic impacts of the disruption to rail freight services. In particular, Feo-Valero et al. (2011)

highlighted the limited extent of understanding of the value of time for freight flows, unlike their passenger counterparts. They found that the wide range of different flow characteristics and requirements, together with a lack of consistency over who is responsible for freight mode choice decisions, make establishing a standardised freight value of time almost impossible.

In a rare study focused specifically on actual disruption to rail freight operations caused by weather-related damage to the infrastructure, Ludvigsen and Klæboe (2014) modelled the effects of key weather elements on aggregate rail freight delays in five European countries, finding that severe weather events severely impacted on infrastructure availability and accounted for considerable delays and a loss of business. There can be significant economic impacts resulting from unplanned rail freight disruption, although it is rare for calculations to be made public. One recent example was that of the closure of the Rhine-Alpine rail freight corridor at Rastatt (Germany) for almost two months in 2017 following the collapse of a tunnel being constructed beneath the existing alignment (Railway Gazette, 2017). This caused major disruption to rail freight flows: just one third of scheduled freight trains operated during the closure, with major disruption to those that did run. A subsequent analysis estimated economic losses of just over €2 billion to the rail industry and wider supply chain activities (HTC, 2018).

It is evident from the literature that the challenges associated with resilient rail freight service provision are recognised, but there is limited understanding of the detailed impacts of unplanned disruption either directly on rail freight operations or more widely on supply chain activity. There is some commonality in the identification of concerns about the extent to which it is possible to run the planned rail freight services during times of disruption, together with service performance issues for those services which are able to operate. This paper therefore makes an original contribution to the topic.

2.3 Vulnerability of rail infrastructure and operations to extreme weather events

While there are many other reasons for unplanned rail network disruption, such as that at Rastatt identified in Section 2.2, there is a growing body of evidence demonstrating that transport infrastructure is increasingly vulnerable to the effects of extreme weather, with consequent risks across supply chains and to economic activity in general. Recent high-profile weather-related examples in the UK of sustained rail disruption include at Dawlish (Devon) in 2014 (BBC, 2014), the Dover to Folkestone line (Kent) for nine months from late-2015 (Network Rail, 2016a), the West Coast Main Line (WCML) in southern Scotland in early-2016 (Network Rail, 2016b) and the closure for more than a year of the Settle and Carlisle line in Cumbria (Network Rail, 2017a). Similar disruption has been experienced in other European countries, such as in Germany on the Hannover to Berlin high speed line in 2013 (Briginshaw, 2013).

More broadly, several policy-focused reports have emerged recently (e.g. European Commission, 2012; EWENT, 2012; RAIN Project, 2015) and common disruption causes which emerge include temperature changes, changes in rainfall and flooding, and sea level rises and sea surges. Disruption which is severe and of a long duration, sometimes including a considerable period of uncertainty as to the extent and duration of the disruption, is especially problematic (Mattsson and Jenelius, 2015). Assessments of the impact of climate change and associated weather impacts on freight transport operations vary in their outcomes. A common theme which emerges is that, without a determined effort, more frequent disruption is expected, even if there is no general agreement on the estimated extent of impact. Researchers and policy makers have been increasingly active in developing strategies both proactively to reduce the likelihood of weather events impacting on transport operations and to better react to events which do have operational impacts (see, for example, EEA, 2014; MOWE-IT, 2014). As such, actions to improve transport resilience broadly fall in to two categories: reducing the vulnerability of infrastructure to disruptive events, and mitigation of the effects of unplanned infrastructure disruption. The former is less disruptive to transport activity, but is often impractical or not cost-effective, so growing attention is focusing on the ways in which the effects of disruption can be minimised. The potential for disruption is considerable: focusing on the Dawlish example mentioned above, Dawson et al. (2016) found that the number of days where the train service would be disrupted could increase by up to 1170% by 2100 in the worst-case scenario.

In the UK, concerns have been expressed about the growing number of severe weather events. Major disruption during winter 2013/14 led the government to instigate the independent Transport Resilience Review (DfT, 2014a), to which it provided a response (DfT, 2014b). The most relevant recommendations were that a critical network of routes of national economic significance be designated to be maintained to a higher level of resilience and for contingency rail timetables to be produced to allow alternatives to be quickly implemented when disruption occurs. The latter recommendation seemed only to apply to passenger operations, however. Rail network vulnerability, and the need for greater resilience, had already been recognised (Network Rail, 2013). A Weather Resilience and Climate Change programme has been implemented and regional weather resilience and climate change adaptation plans have been produced (Network Rail, 2015a). There are no freight-specific actions, but infrastructure maintenance, contingency planning and timetabling flexibility all form a part of the programme and should benefit passenger and freight users alike. RSSB (2016b) emphasised the increasing likelihood of extreme weather events resulting from climate change and set out a range of recommendations on how to deal with their impacts on the rail network. Their research identified that there is currently a limited understanding of the nature of infrastructure damage caused by such events and, particularly, little insight into the operational impacts on rail flows.

As a result of these growing weather-related vulnerabilities, and the limited attention thus far devoted to rail freight when key routes are unexpectedly blocked, it is necessary to better understand how unplanned network disruption affects freight activity in order that negative impacts can be minimised.

3. Research methods

This is an empirical study using a mix of quantitative and qualitative methods to analyse a specific case study of an unplanned 53-day closure of a strategic railway line; the characteristics of the case study are set out in Section 4. As the literature review established, there is a dearth of detailed evidence regarding the effects on rail freight activity of unplanned network disruption. Specifically, the analysis is based on the range of methods and source material summarised in Table 1 and justified in the following text.

Insert Table 1 here (see end of document, due to landscape formatting)

The major part of the data collection related to freight train service provision during the case study disruption period. Given its online availability at an individual train level from an open access data source (Method 1 in Table 1), information was collected for the entire population of diverted freight trains. This allowed the total number of trains operated to be identified, together with the planned schedule, routing and actual timings of each train. Direct observation surveys of train composition and loadings (Method 2a) took place on five of the 53 days, supplemented by online train composition data from throughout the time period (Method 2b). In combination, train composition details were obtained for 21% of all services during the closure period; in itself, this coverage is not sufficiently representative to allow robust analysis but has proved useful in combination with other information.

To assess the level of disruption to service provision, it was necessary to establish the baseline (i.e. that expected in normal, non-disrupted, circumstances), with which the case study could be compared. The author's annual rail freight database (Method 3) provided this baseline. The database uses a consistent data collection method each year, with information from a range of published and online rail industry and rail enthusiast sources. Its construction is a bottom-up exercise leading to a comprehensive record of regular freight train service provision, with a set of characteristics relating to each service as set out in Table 1. Databases for subsequent years were used to assess any longer-term impacts arising from the line closure. More detailed information about the database can be found in Woodburn (2006). Since that time, the database coverage has expanded to cover all commodities (i.e. including the previously excluded mail and coal services) and additional data sources, most notably open access data (Method 1), have been used to corroborate the information from the long-established sources. For the period relating to this case study, there were no changes to either database coverage or sources, so there are no data consistency issues. The database covers 100% of regular freight train services using the case study route, though service frequency for some is on an 'as required' basis depending on customer demand. This last aspect is discussed further in Section 5.1.

Finally, these data sources were supplemented by in-depth semi-structured interviews (Method 4) with key individuals from four organisations, representing both the rail industry and its customers, involved in the disruption; the interviews took place between one and three months after the line reopened. The interviews each had a duration of between 30 and 90 minutes, with tailored discussions relating to the nature and extent of the disruption and the measures taken in response.

In combination, the research methods set out in Table 1 offer considerable scope to conduct an in-depth analysis of the case study and compare the disrupted period with the normal situation. The analytical framework recognises that different flow types can have specific characteristics and requirements. Reflecting the flows affected in the case study, the rail freight market has been divided for analysis as follows:

- Intermodal (with sub-divisions for domestic intermodal and port intermodal)
- Trainload bulk (with sub-divisions for cement, china clay, metals, nuclear waste and petroleum)
- Wagonload (i.e. shared-user services)
- Mail

The analysis is structured around three key measures which allow quantification of the impacts of the disruption when compared with the baseline, in line with the service performance issues raised in the literature review. The measures are freight train service provision, scheduled journey times (and associated diversionary routings) and train punctuality. The train composition data and interview discussions provide additional information to enrich the analysis. To assess any longer-term impacts on rail freight activity (i.e. beyond the disruption period itself), the information gathered from the interviews has been supplemented by data from the rail freight database relating to service provision in January 2017 and January 2018, respectively one and two years on from the unplanned line closure.

4. Case study: unplanned closure of Lamington Viaduct

While the effects of rail network disruption on freight flows exhibit similarities no matter where they occur, some aspects of a specific event are influenced by the characteristics of the rail system and associated policy environment. This section therefore briefly sets out the salient features of the British rail system and its links to disruption management, then explains the specific context for the case study that forms the focus of this research.

4.1 The structure of the British rail system and responsibility for disruption

Britain’s rail network has been vertically separated since rail privatisation in the mid-1990s, exceeding the European Union (EU) requirement that ‘a distinction should be made between the provision of transport services and the operation of infrastructure’ to encourage liberalisation and competition (Council Directive 2012/34/EU, 1). Network Rail is the state-owned national infrastructure manager (IM) with responsibility for maintaining the rail network and generally making it available for traffic; it also coordinates the timetabling process. In formal terms, Network Rail is in charge of the Network Code, covering the rules, procedures and contractual relationships governing network access (ORR, 2016a). The train services themselves are provided by (passenger) train operating companies (TOCs) and freight operating companies (FOCs). While the overwhelming majority of passenger services are franchised by the government, with limited direct competition ‘on the rails’, rail freight activities were sold off and the market is openly competitive with six active FOCs (Woodburn, 2014).

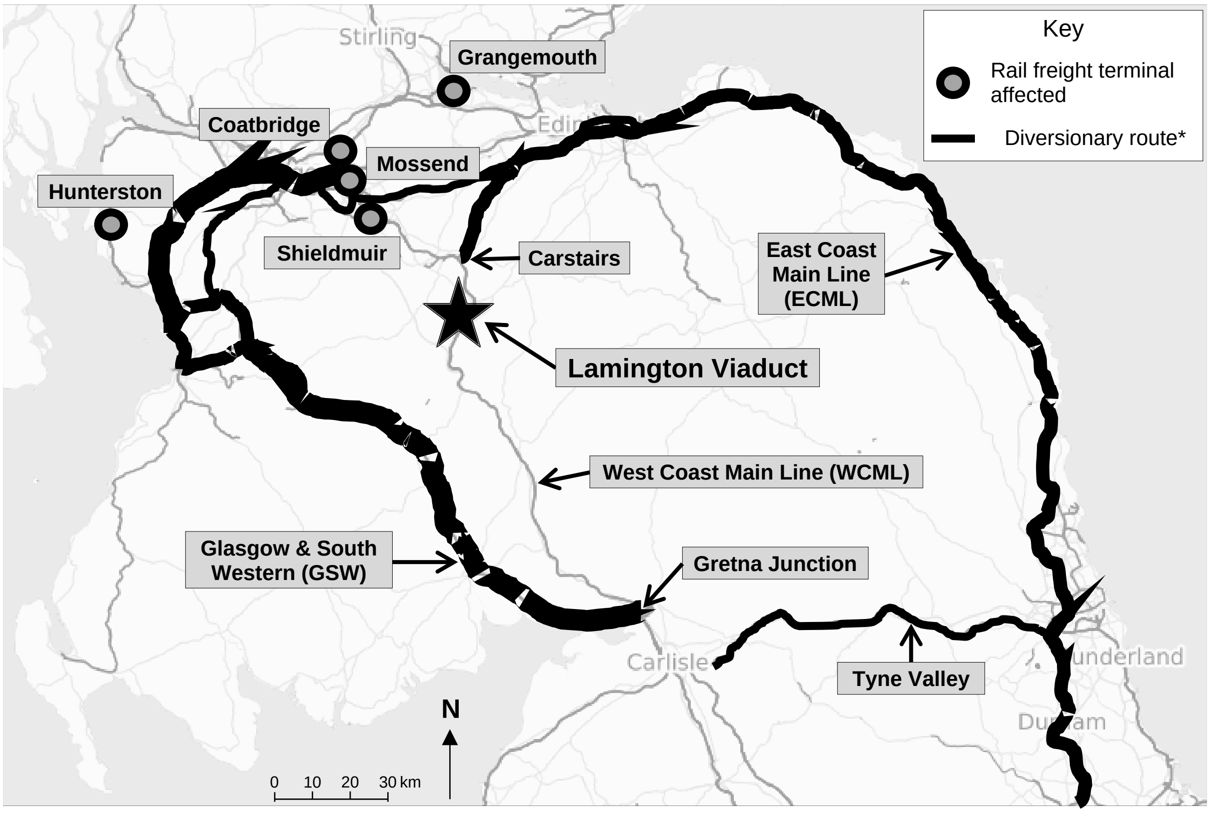
The Delay Attribution Guide forms a part of the Network Code, with the vision ‘for all parties to work together to achieve the core objective of delay attribution – to accurately identify the prime cause of delay to train services for improvement purposes’ (Delay Attribution Board, 2016, 3). Delays on the national rail infrastructure caused by severe weather are the responsibility of Network Rail, regardless of whether it could have been expected to prevent the delays through its maintenance programme, and it pays compensation to the FOCs based on the contractual arrangements in place. There is a specific delay code (X2) for ‘severe flooding beyond that which could be mitigated on Network Rail infrastructure’.

4.2 Case study: Lamington Viaduct

The case study analysed in this paper relates to an unplanned closure for 53 days of part of the West Coast Main Line (WCML). The WCML is the most important rail freight artery in the UK, with 40% of all freight trains using at least some of its length at some point in their journey (DfT, 2015). A bridge (known as Lamington Viaduct) over the River Clyde between Carlisle and Glasgow/Edinburgh sustained considerable damage to its structural supports as a result of exceptionally high water levels and fast flow caused by Storm Frank on 29/30 December 2015 (Network Rail, 2016b; RAIB, 2016). The line was closed to traffic from 08:53 on Thursday 31 December 2015 after maintenance staff witnessed unusual track movement during the passage of a passenger train and spotted a large crack in the viaduct structure (RAIB, 2016). There had been unusually high rainfall in the weeks leading up to the closure, with winter 2015/16 being the wettest on record for Scotland (Met Office, 2016). Short-term line closures as a result of flooding had occurred elsewhere on the northern part of the WCML during December (Network Rail, 2015b, 2015c). The subsequent accident investigation found that previously agreed Flood Action procedures for monitoring at-risk structures such as Lamington Viaduct were no longer being implemented within Scotland, resulting in ineffective management of the effects of high river flow (RAIB, 2016).

As a consequence of the failure of Lamington Viaduct, the section of line from Gretna Junction (north of Carlisle, near the England/Scotland border) to Carstairs, a distance of 104 kilometres, was closed to freight traffic. This necessitated lengthy diversions via a range of alternative routes. Figure 1 shows the location of the affected section of line, along with the diversionary routes used by freight trains to serve the terminals affected.

Figure 1: Location map showing Lamington Viaduct and diversionary routes



Source: adaptation of base map from openstreetmap.org (© OpenStreetMap contributors); * line thickness is representative of the number of diverted trains by that route (see Section 5.2)

Despite the section of line affected being located at the quieter end of the WCML, in southern Scotland, it caters for considerable rail freight activity. According to the author's annual rail freight database, at the time of the disruption this section would normally have handled an average of 146.5 freight trains in a typical week. This accounts for more than three-quarters of rail freight services between England and Scotland, including almost all intermodal traffic since at the time of the disruption the East Coast Main Line (ECML) had not yet been gauge-enhanced to allow the carriage of 9' 6" height containers on standard height wagons (Network Rail, 2016c).

There was considerable uncertainty over the anticipated duration of the line closure and the estimated date for reopening was revised several times. The timeline of updated estimates from the IM, Network Rail, is shown in Table 2, demonstrating how it initially lengthened but then contracted. The line eventually reopened in the early hours of Monday 22 February

(Network Rail, 2016g). Network Rail spent £4 million on renewing Lamington Viaduct and paid out around £10 million in Schedule 4 payments to train operators to compensate them for the disruption (ORR, 2016b), though the distribution between passenger and freight operators has not been published.

Table 2: Timeline of reopening estimates from Network Rail

Date	**Estimated timescale for reopening**
3 January 2016	Work 'likely to continue until end of January', with reopening expected on 1 February 2016
18 January 2016	'Further damage delays opening until first week in March 2016'
12 February 2016	'Works…are progressing ahead of schedule'; new date for reopening to be confirmed
15 February 2016	Confirmed reopening date of Monday 22 February 2016

Source: Network Rail (2016b, 2016d, 2016e, 2016f)

The duration of the closure of such a vital rail freight route, together with the uncertainty over just how long the closure would last, provide the circumstances for an interesting and insightful case study into how the disruption was managed for rail freight customers and to identify lessons to be learned for future disruptive events given the likely increase in the frequency of their occurrence.

4.3 Limitations of the case study

As is often the case with the analysis of 'real world' situations, the conditions for investigation were not ideal. Three specific study limitations have been identified:

1. The damage to Lamington Viaduct occurred during a holiday period, so caution is needed when interpreting the early response to the line closure. Some traffic, notably domestic intermodal, tends to be little affected by holiday periods, while other flows generally would

not be expected to operate. Friday 1 January was a UK-wide holiday and Monday 4 January was a Scottish holiday. It was therefore Tuesday 5 January at the earliest before some flows would have been expected to operate in normal circumstances. Also, the Tyne Valley route, one of the possible diversionary routes (see Figure 1) was itself closed from 6 January until 8 February. Its loading gauge restrictions and detour length meant that it is unlikely it would have been used much in any case, which was confirmed in discussions with interviewees and was borne out by the very few trains diverted that way during the times it was open. These issues are discussed as appropriate throughout the following analysis.

2. Most freight service provision on the affected line operates with a high degree of predictability, but certain smaller flows are more erratic in nature and cannot be recorded reliably in the database. The effects of this are discussed in the results presented in Section 5.1.
3. Changes in diversionary capabilities during the closure period meant that the train composition survey data (see stages 2a and 2b in Table 1) were not sufficiently representative to allow rigorous analysis of the different phases that became apparent in the analysis supporting RQ1 (see Section 6.1). However, in combination with material gathered from the interviews, some pertinent findings did emerge, albeit of a more general nature than anticipated.

5. Rail freight traffic levels and service performance during the line closure

In this section, the data relating to freight train service provision (Section 5.1), diversionary routings and associated schedules (Section 5.2) and train punctuality (Section 5.3) are presented. These key measures are key to the subsequent analysis of the impacts of the line closure, which follows in Section 6.

5.1 Freight train service provision

Table 3 reveals that just over 80% of the number of trains that would have been expected to run had the line not been closed actually did so. The expected number of trains was calculated on the basis of a seven week closure, given the holiday weekend at the start of the period (see Section 4).

Table 3: Expected and actual number of freight trains (full closure period), by commodity/train type

Commodity/train type	**Expected no. (baseline)**	**Actual no. (WCML closure period)**	**Actual as % of expected**
Intermodal, of which:	630	529	84
Domestic intermodal	*420*	*399*	*95*
Port intermodal	*210*	*130*	*62*
Trainload bulk, of which:	150.5	137	91
Petroleum	*77*	*69*	*90*
Cement	*49*	*34*	*69*
Nuclear waste	*14*	*16*	*114*
Metals	*7*	*9*	*129*
China clay	*3.5*	*9*	*257*
Mail	140	71	51
Wagonload	105	99	94
Total	**1,025.5**	**836**	**82**

Source: based on data from realtimetrains.co.uk and author’s annual rail freight database; n = 836

While it may seem odd that there were more services than expected for three of the five trainload bulk commodities in the table, this is largely a function of the fact that they operate infrequently on an ‘as required’ basis. In calculating the expected level of service, the default position in the database analysis is that a train which operates on, for example, a Thursday as required will operate on 50% of the possible occasions (i.e. every second Thursday); the reality may be that such a train will actually operate on, say, three Thursdays out of four, thus appearing to be over-represented. This may have been the case with nuclear waste and metals. It may also be true to some extent of china clay, but the dramatic over-representation largely reflects the changed nature of provision during the line closure. In the main, during the line closure the empty china clay services generally ran direct to Carlisle as dedicated trains;

under normal circumstances, the empty wagons would be combined at Mossend with other flows and thus be categorised as wagonload. An additional two northbound wagonload trains were terminated at Carlisle with no onward schedule over a diverted route. It is likely that any Scottish traffic on these trains was added to other services in order to complete its journey.

5.2 Freight train diversionary routings and schedules

Analysis of the revised schedules for the 836 diverted trains revealed a diverse and complex set of routings to avoid Lamington Viaduct, though with two core diversionary routes. Figure 1 showed the revised routings in southern Scotland and part of northern England. The majority (77%) of trains used the WCML as normal to the south of Gretna Junction, with the GSW route being used north thereof. The other 23% of trains used the ECML, with diversionary routings generally extending much further south. Most ECML-routed trains ran cross-country to/from the Midlands via Yorkshire using a number of different routes, but mail trains between Shieldmuir and London remained on the ECML to/from London. A small number of trains used the Tyne Valley route but, as mentioned previously, it itself was closed by a landslip for much of the duration of the study period. In total, there were 32 diversionary routes, discounting some very short distance (i.e. 10 km or less) deviations on sections of route further south than shown in Figure 1. The GSW formed the core of 10 of the diversionary routes, with the remainder using the ECML. A small number of these diversionary routes accounted for the majority of trains: the two most common routes each accounted for 28% of the trains, the top six routes combined saw 91% of the trains, while the remaining 26 routes saw just 74 trains (9%) in total.

Table 4 summarises the difference between the schedules for the disruption period and the baseline for each of the commodity/train types and in total. As a consequence of the disruption, some schedules bore little resemblance to those in the normal operating period, for example with very different train reporting numbers and origin departure times. Where possible, schedules were matched based on train reporting number and/or on the closest origin-destination pair and commodity/train type. A small number of trains (4% of the total) were excluded because no equivalent service in the baseline could be identified, resulting in 800 train schedules being compared between the baseline and the disruption period. For information, Table 4 displays the number and percentage of trains excluded per commodity/train type.

Table 4: Impact on schedules: disruption period vs baseline, by commodity/train type

Commodity/train type	**Revised scheduled journey time per train as % of baseline**	**Trains excluded**	
		No.	**As % of type**
Intermodal, of which:	130	21	4
Domestic intermodal	*133*	*18*	*5*
Port intermodal	*124*	*3*	*2*
Trainload bulk, of which:	111	9	7
Petroleum	*109*	*1*	*1*
Cement	*121*	*2*	*6*
Nuclear waste	*105*	*0*	*0*
Metals	*123*	*0*	*0*
China clay	*70*	*6*	*67*
Mail	99	0	0
Wagonload	121	6	6
Total	**124**	**36**	**4**

Source: based on data from realtimetrains.co.uk; n = 800

It is evident that scheduled journey times for comparable services were extended considerably during the disruption. The average revised schedule was 24% longer than normal, though china clay trains had much faster schedules than normal, owing to the revised method of working outlined in Section 5.1, and mail trains had schedules which were little changed from normal: however, as discussed later (see Section 6.1), these services were unable to serve their key intermediate terminal en route to/from London so the capability was much reduced. The schedules for intermodal services, particularly domestic intermodal ones, experienced the greatest journey time lengthening. For china clay, cement, wagonload and domestic intermodal, at least 5% of services were excluded from the analysis because of the inability to match them to an equivalent service in the baseline. Of these, china clay was once again the extreme example, for the aforementioned reason.

5.3 Freight train punctuality

An important measure of service performance which is quantifiable from the real-time data relates to train punctuality, specifically the extent to which trains arrive at the destination 'on time'. For this analysis, on-time arrivals are defined as trains arriving at their destination up to (but not including) 15 minutes after their scheduled arrival time. This matches the current industry standard, the Freight Delivery Metric (FDM), although this measures only delays caused by Network Rail (ORR, 2018). Table 5 reveals that 77% of trains arrived at their destination 'on time' during the line closure. At the national level, 94% of freight trains arrived on time in 2015/16 Q4 (ORR, 2018), this being the period within which the case study disruption occurred. This national performance was very considerably better than that shown in Table 5 for the case study, though the basis of the two calculations is too dissimilar to be regarded as particularly insightful.

Table 5: Train punctuality during disruption period, by commodity/train type

Commodity/train type	**'On-time' arrivals (%)**
Intermodal, of which:	77
Domestic intermodal	*74*
Port intermodal	*87*
Trainload bulk, of which:	80
Petroleum	*75*
Cement	*88*
Nuclear waste	*88*
Metals	*89*
China clay	*67*
Mail	68
Wagonload	83
Total	**77**

Source: based on data from realtimetrains.co.uk; n = 830

Of the four main train types, wagonload and trainload bulk displayed the best 'on-time' performance, at 80% or greater, with mail trains performing particularly poorly at just 68% on time. Within intermodal and trainload bulk, there was considerable variation between the sub-groups with, for example, port intermodal outperforming domestic intermodal by a margin. It should be remembered that all of these punctuality statistics relate to the revised scheduled arrival time. As Section 5.2 revealed, this was generally at the end of a far longer journey than would be the case under normal circumstances.

6. Analysis and key findings

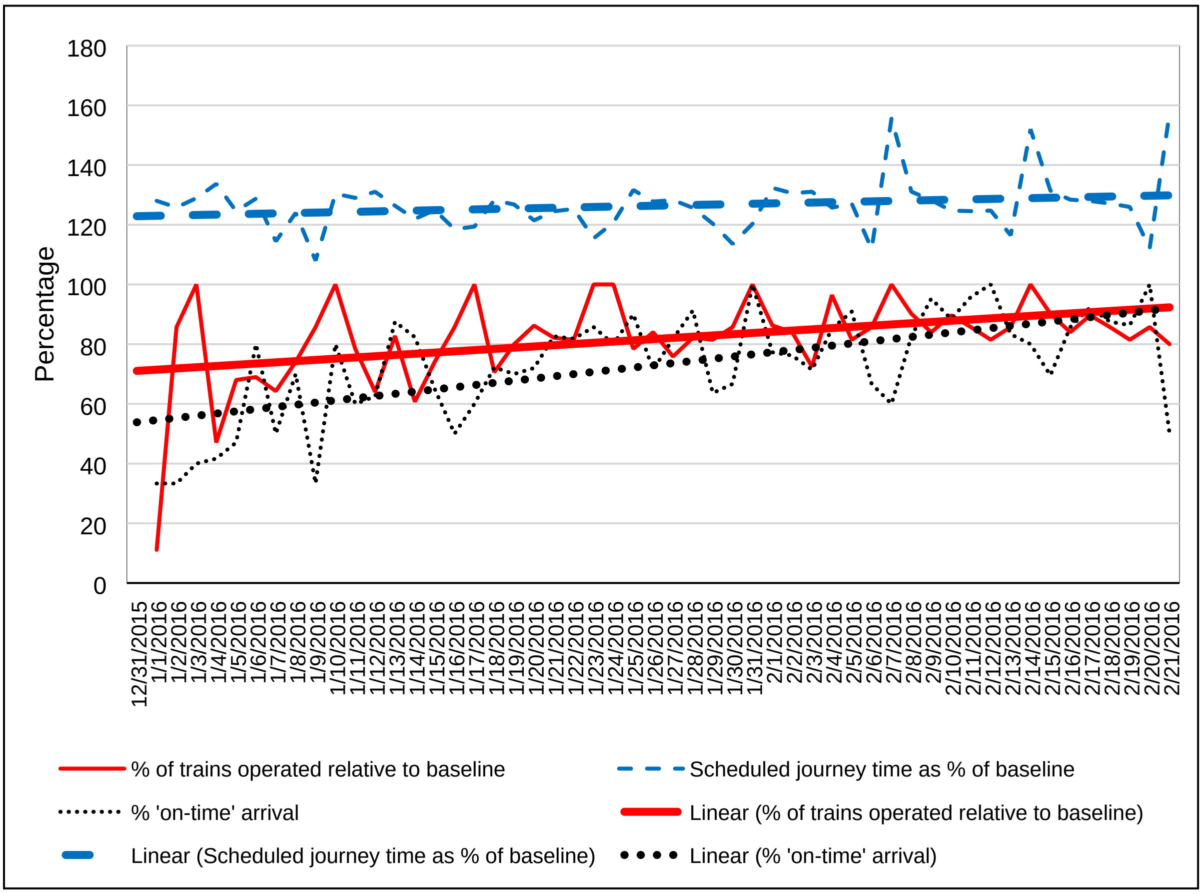
Building on the key measures presented in Section 5, this section focuses on the three inter-related research questions (RQs) which form the basis for the paper, allowing the overall research aim to be satisfied. Section 6.1 incorporates findings from the interviews to the data already presented, allowing the direct impacts of the line closure on rail freight service provision to be established. Section 6.2 then adopts a broader supply chain perspective as well as identifying any longer-term impacts. Finally, Section 6.3 takes the available evidence from this case study and makes recommendations for improving the resilience of rail freight. It should be remembered that the main focus of this analysis is on operational and policy issues. Attempts were made to examine in detail the cost implications of the line closure on both the rail industry and its customers, but insufficient information was forthcoming from the interviewees to allow this.

6.1 RQ1: Impacts of the line closure on rail freight traffic levels and capability

A common theme that emerged from the interviews was that the response to the closure improved over time, perhaps not unexpectedly. Building on the data presented in Section 5,

Figure 2 shows the three key service provision measures on a daily basis throughout the closure period, plus the smoothed (linear) trend for each measure. While there is considerable day-to-day variability, each trend line is evidently upward. For two of the three measures (i.e. % of trains operated and % on-train arrival), an upward trend is unambiguously positive. For the third, reflecting the change in scheduled journey times, a downward trend would be preferable, since that would show journey times converging with those in the baseline. The very slightly upward trend in this measure was influenced by the spikes on the three final Sundays where scheduled journey times were extended beyond that experienced at any other time during the closure.

Figure 2: Daily performance of key service provision measures



Source: based on data from Tables 3 to 5; ‘baseline’ refers to the non-disrupted period

Two of the four interviewed organisations made specific reference to the closure period being divided into three distinct phases, with the situation improving with the progression from one phase to another:

- Phase 1: from line closure (31 December 2015) until around 5/6 January 2016
- Phase 2: from 5/6 January 2016 until 17 January 2016
- Phase 3: from 18 January 2016 until line reopening (22 February 2016)

Post hoc analysis of the key service provision measures in line with these phases provides supporting evidence for this division, as Table 6 demonstrates. The comparison of revised and baseline journey schedules showed no noticeable difference between the phases, but Phase 2 showed considerable improvements over Phase 1 in both the proportion of services operated and the punctuality of those trains which ran. From Phase 2 to Phase 3, the changes were less marked but still showed improvements in these two measures. However, the difficulties of quantifying fully the effects of the disruption on the key measures in Phase 1 need to be borne in mind since the New Year holiday period would have resulted in a reduced level of service provision in any case. That said, punctuality of the relatively small proportion of trains which did run in Phase 1 was particularly poor and, according to one interviewee, the limited timetabling resource available in this phase meant that trains were running without workable schedules, compounding delays.

Table 6: Summary statistics for key service provision measures, by phase

Service provision measure	**Phase 1**	**Phase 2**	**Phase 3**
No. of freight trains operated (as % of baseline)	48	73	84
Revised scheduled journey time (as % of baseline)	128	125	127
Punctuality (% ‘on time’ arrival)	39	68	82

Source: based on data from Tables 3 to 5

In the interviews, concerns were raised about the limited number of train paths available on both the Glasgow and South Western (GSW) and East Coast Main Line (ECML) diversionary routes to cater for the displaced freight traffic, leading to sub-optimal schedules which were less customer-friendly. Pre-planned engineering work on the ECML meant that this route was not available at all over three of the weekends, while the additional freight traffic over the GSW route led to limited time available for infrastructure maintenance. The strict industry requirements for driver route knowledge presented challenges in resourcing the revised schedules, particularly for the ECML since few freight trains normally travel by that route. The fragmented and competitive nature of freight train service provision created extra resourcing challenges than would have been likely under a unified operational structure. From the observation surveys and industry interviews, several additional impacts were identified which particularly affected intermodal services:

- revised schedules for some of the domestic intermodal services did not allow for the usual 24-hour wagon rake rotations, so either additional wagon rakes were required or fewer services could operate
- additional diesel traction had to be found, as a consequence of the longer end-to-end journey times and the need to substitute the electric traction normally used on the majority of intermodal trains, since diversionary routes generally were not electrified
- loading gauge restrictions, particularly affecting the key GSW diversionary route: until Phase 3, there was a 9’ 2” height restriction which meant that around two thirds of the normal intermodal units could not be moved by rail on this route. The increased gauge clearance to allow 9’ 6” intermodal units to be carried on the GSW route at the start of Phase 3 resulted from urgent gauging checks carried out by Network Rail in the first two weeks of the disruption
- restrictions on train length due to diversionary route infrastructure constraints: the dedicated Tesco train was worst affected, with a 22% reduction in the maximum

number of units per train compared to normal, with other intermodal services impacted to a lesser extent
- challenges at intermodal terminals: extended journey times often led to less terminal time for train loading and unloading, plus most terminals handle several trains per day and the disrupted schedules led to problems in dealing with out-of-course arrivals

Two specific factors which led to the disruption being lower than it could have been were identified from the data analysis and confirmed in the interview phase:

- the timing of the line closure, during a relatively quiet period for intermodal traffic in particular; had it occurred in the September to December period, in the build up to the retailing peak, the impacts on supply chains (see Section 6.2) would have been more severe
- the reduction in coal traffic in the five years preceding the line closure, since this had freed up freight train paths on the key GSW route (see Figure 1)

Turning to possible longer-term impacts on the rail freight market, Table 7 compares the typical weekly rail freight service provision at the time of the disruption (i.e. January 2016) with that in the following two years. Small year-on-year reductions can be seen, but these changes are explained by factors unrelated to the line closure, such as amended flow requirements and the rationalisation of wagonload rail freight services.

Table 7: Weekly rail freight service provision in each January (2016, 2017 and 2018)

	Expected no. of trains per week in:		
Commodity/train type	**January 2016**	**January 2017**	**January 2018**
Domestic intermodal	60	60	60
Port intermodal	30	30	30
Mail	20	20	20
Wagonload	15	14	0
Petroleum	11	10	10
Cement	7	6	6
Nuclear waste	2	2	2
Metals	1	1	1
China clay	0.5	1	3
Automotive	0	0	10
Ministry of Defence (MoD)	0	0	0.5
Total	**146.5**	**144**	**142.5**

Source: author's annual rail freight database

The analysis has demonstrated that there were very considerable impacts on rail freight traffic levels and capability, albeit with evidence of improvements in service provision and train punctuality as the closure period progressed. There is no evidence that the closure has had any long-term impacts on rail freight service provision.

6.2 RQ2: Assessment of the wider supply chain implications

Information provided by the interviewees provided insight into wider supply chain implications resulting from the line closure. No such implications were identified for any of the trainload bulk commodity flows, for which the transport requirements tend not to be particularly demanding. On the other hand, there were considerable implications for the intermodal traffic.

The interview findings made clear that the extended journey schedules posed particular challenges for domestic intermodal traffic, since much of this is highly time-sensitive. Journey time extensions of several hours proved problematic, particularly where the arrival time at the destination rail terminal was later than normal. This was especially challenging for services delayed against their revised schedule but was also an issue where services arrived 'on-time' against the revised schedule though still hours later than would usually be the case. Under normal circumstances, the transfer of domestic intermodal loads from road to rail for onward movement takes place very rapidly. One example offered by the logistics service provider (LSP) interviewee was of a three-hour time window after the train's arrival where the loads would be taken from the rail terminal to local distribution centres for re-working/cross-docking and departure en route to retail outlets. The extended rail schedule during the line closure meant that this time window disappeared, so the consignments that were most time-sensitive and/or needed the most re-working at the local distribution centre had to switch to road. The fact that the domestic intermodal traffic is controlled by LSPs helped to limit the overall impact on the ultimate customers, generally retailers, since they had flexibility to divert the most critical traffic to their road haulage operations. Despite this, there was disruption to some Anglo-Scottish retail supply chain activity. Evidence from both the interviews and the train composition information showed that train lengths were shorter than normal because of infrastructure limitations on the diversionary routes, though this was not identified as a particular constraint given the transfer to road of the most critical consignments.

Port intermodal traffic was also badly affected, with just four of the six daily services operating for most of the period. Although port intermodal train lengths show some variability ordinarily, those services which did operate also had a reduced maximum train length compared to normal. Two interviewees believed it likely that the relatively quiet period for deep-sea container traffic had limited the impacts of the reduced capacity, though one of the two reported that some of the traffic had switched from rail to short-sea feeder services using the ports of Grangemouth and Greenock.

While the other flows were able to serve their usual rail freight terminals, albeit with disrupted schedules, the main diversionary route used for the mail trains meant that intermediate mail traffic between northern England and Scotland also reverted to road during the closure period because the Warrington terminal could not be served. These trains were diverted along the full length of the ECML to/from London, preserving end-to-end journey times between London and Scotland and vice versa (see Table 4) and allowing the specialist electric trains to continue to be used. The intermediate Warrington traffic was therefore sacrificed to road to allow the London traffic to continue with as little disruption as possible.

6.3 RQ3: Recommendations for improving the resilience of rail freight operations

Using the evidence base provided by the preceding analysis, a series of recommendations has been developed. These have been separated into managerial recommendations and policy recommendations, though this distinction is somewhat artificial given the considerable overlap between the two. Those that are managerial in nature are ones assumed to be able to be implemented by the rail (or wider logistics) industry, while the policy-related ones are aimed primarily at government. In the UK context, Network Rail (as the public sector infrastructure manager) essentially straddles the rail industry and government, accentuating the overlap. The discussion focuses on those recommendations supported by the evidence from the case study. Table 8 presents an overview of the recommendations, with the detailed discussion around the managerial aspects in Section 6.3.1 and for wider policy issues in Section 6.3.2. While the main focus of this research has been on the impacts on rail freight service provision during the line closure itself, the interview process also identified a number of wider issues relating to strategic rail network resilience. In line with the themes raised in the literature review, the recommendations based on this case study analysis are divided into two groups: strategic network resilience, to prevent or limit disruptive incidents, and operational response to incidents which cannot be prevented. This structure is in line with the recommendations set out in the Transport Resilience Review (DfT, 2014a) and, as can be seen in the following discussion, there is commonality between the recommendations arising from that review and from the analysis in this paper. That said, the Transport Resilience Review did not produce freight-specific recommendations (see Section 2.3), so the recommendations here are targeted at minimising the impacts on rail freight. Considering the overall list of recommendations, it is evident that the rail industry itself bears primary responsibility in almost all cases.

Table 8: Overview of recommendations

Nature of recommendation	Primary responsibility
A. Strategic network resilience	
A1. Preventative maintenance	Rail industry
A2. Understanding the needs of freight customers	Rail industry
A3. Improved freight resilience: network investment	Government/rail industry
A4. Contingency planning	Rail industry
A5. Rail industry coordination	Rail industry
B. Operational response to incidents	
B1. Contingency plan implementation	Rail industry
B2. Understanding the needs of freight customers	Rail industry
B3. Communication with freight customers	Rail industry
B4. Rail industry coordination	Rail industry

6.3.1 Managerial recommendations

Many of the managerial (i.e. rail industry) recommendations are aimed at Network Rail, as infrastructure manager, covering both strategic network resilience and the operational response to incidents. The number and impact severity of disruptive incidents is influenced by the extent to which preventative maintenance takes place across the rail network. Despite the high river flow, this particular line closure may well have been avoided had the agreed Flood Action procedures been implemented (RAIB, 2016). An interviewee raised other examples of situations where considerable disruption was caused by a lack of preventative maintenance such as vegetation clearance and embankment management, and this is something raised by the Transport Resilience Review (DfT, 2014a) as a particular issue. To reduce the chances of extreme weather events causing line closures, it is vital to have sound preventative maintenance procedures and for them to be implemented and monitored (Recommendation A1).

There is a need for better coordination and communication within the rail industry (i.e. between Network Rail and the FOCs) (Recommendations A5 and B4) and between the rail industry and its customers (Recommendations A2 and B2). Industry coordination is particularly important in a fragmented rail industry such as in the UK, where infrastructure and operations are separate and where there are multiple freight train operators, but other European rail networks also share some of these characteristics. To date, however, the freight perspective in relation to coordination and communication has not been adequately recognised in the literature from government or the rail industry.

Recommendations A2 and B2 relate to the level of understanding within the rail industry of the requirements of customers and their flows. On a mixed traffic rail network such as in the UK, as elsewhere in Europe, the requirements of the different freight flows are often poorly understood. Recognition of the demanding requirements of some of the freight flows, particularly domestic intermodal and mail, could be higher and both strategic and operational planning could better deal with these requirements. Network Rail's newly implemented devolved organisational structure is as yet unproved when it comes to the focus on freight requirements. Many freight services cross multiple routes, although there is a national 'route' tasked with the requirements of rail freight. This leads in to Recommendation A3, which relates to ensuring that the rail network is fit for purpose for the various freight flows using it, both now and in the future. This recommendation is focused primarily on policy makers (see Section 6.3.2), but there is a need for the rail industry to contribute to the planning process.

Of particular importance to the findings from this analysis, better contingency planning at both the strategic and operational levels is required (Recommendations A4 and B1). The UK government has recognised the importance of this (DfT, 2014b) and expects Network Rail to overcome the weaknesses of the prevailing situation. However, it is not evident that sufficient awareness of the particular characteristics of freight exists. Specifically, when developing contingency plans to cope with the unplanned closure of key rail freight arteries, it is important to holistically consider the capabilities of diversionary routes. In the case study examined in this paper, during Phases 1 and 2 the rail industry was very much exploring options owing to a lack of detailed contingency planning beforehand. The greater complexities of intermodal wagon and loading unit combinations meant that this took time to resolve for these flows. Contingency plans should be refreshed regularly, particularly for intermodal traffic, given the frequent changes in train operating characteristics. This creates a heavier planning workload, but should reduce the work needed to minimise disruption when unplanned line closures occur. As the rail network has got busier the effects of disruption are magnified, with less slack in the system and more secondary impacts, further strengthening the arguments for thorough contingency planning. Such contingency planning must take account of the varied characteristics of rail freight flows including, for example, train weights, loading gauge requirements and use of electric traction.

In addition to the lack of coordination within the rail industry (see Recommendations A5 and B4 above), concerns were raised about the lack of ‘real-time’ updating of customers about the number of freight trains that could be operated, together with their planned schedules and any restrictions on what could be carried. To date, attention has focused on the importance of keep rail passengers informed (DfT, 2014b) but, to retain freight customers’ trust in rail, it is vital to ensure good, pro-active communications with them too (Recommendation B3), so that they can better plan their businesses and implement their own contingency plans where necessary.

6.3.2 Policy recommendations

Most of the managerial recommendations set out in Section 6.3.1 will need government support to enable them to maximise their potential. In particular, the increased likelihood of disruptive weather events strengthens the argument for investment in key freight corridors, together with appropriate diversionary routes, to provide better network resilience (Recommendation A3). The government acknowledges the need for a 'critical network' (DfT, 2014b), though the case study came soon afterwards so there had as yet been no discernible change in investment appraisal. Despite this, the ongoing gauge enhancement works as part of the Strategic Freight Network investment programme are leading to a greater range of diversionary routes able to cater for intermodal traffic on standard wagons. Linking Recommendation A3 with others aimed primarily at the rail industry, the following policy-related aspects should be considered:

- when developing the strategic direction for the rail industry, through the regulatory process and the implementation of strategies (e.g. rail freight strategy, electrification strategy), government should be cognisant of the need for greater resilience to cope with disruption, both in planning and operational terms
- strengthen regulatory oversight, to mandate that Network Rail (as infrastructure manager) improves its asset register: linked with the managerial recommendation relating to contingency planning for diversionary routes, better awareness of infrastructure capability should allow a smoother transition to revised service provision when unplanned route closures take place

Finally, policy makers should ensure that their strategies and interventions take account of the growing importance of intermodal rail freight, much of which has more demanding customer requirements than does traditional rail freight. With 40% of the rail freight market, intermodal has grown to be by far the largest of the commodity groupings in the UK (ORR, 2018) and forms the backbone of growth forecasts (Network Rail, 2017b). In implementing the recommendations set out, government and the rail industry should work together to ensure resilient intermodal service provision.

7. Wider implications of the research findings

Despite being based on a single case study, this in-depth empirical investigation of the nature of rail freight disruption resulting from the unplanned closure of a key railway line has broader relevance, both in terms of the research methods adopted and in the ability to generalise from the case study findings to other geographical areas.

Methodologically, the application of disaggregated data relating to key rail freight operational measures to assess the rail freight impacts in this way is believed to be novel, and the findings provide considerable insight into the effects of the disruption. Specifically, the availability of open access train running data covering all individual freight trains operated in Britain allowed this detailed analysis to be conducted, and the annual rail freight database provided the opportunity to compare the service provision during the disruption with that expected in the baseline (non-disrupted) period. It would be beneficial to replicate the study's methodology to analyse similar cases of network disruption in other spatial settings, to identify common themes as well as areas of divergence. Access to the necessary disaggregated data would likely be challenging unless provided by the rail industry, however, since no other country is believed to provide comprehensive open access freight train running data at the present time.

Despite the lack of similar studies based on an equivalent methodological approach, and recognising that each rail network has its own structure and operational practices, the research findings are not limited to the UK context, since many of the issues and recommendations have relevance elsewhere. In particular, there is commonality with the (limited) rail freight literature identified earlier relating to experience elsewhere in Europe, where mixed traffic rail networks predominate and where weather patterns are broadly comparable. In the five countries analysed by Ludvigsen and Klæboe (2014), a similar lack of contingency planning led to widespread service disruption and a recognition of a need for greater preparedness if existing customers were to be retained and new ones attracted from road haulage. Despite being part of a strategic European rail freight corridor, the unplanned closure at Rastatt in 2017 (Railway Gazette, 2017; HTC, 2018) also revealed a lack of resilience and consequent widespread disruption. In general terms, it is important to recognise that freight flows are not homogenous, with different flows having varying network and scheduling requirements. Specifically, efforts must be made to support resilient intermodal rail freight service provision, a major existing and potential growth area across Europe (and beyond). The fact that severe, disruptive weather events are likely to become more frequent, and that it is impractical to prevent all instances of major network disruption from occurring, adds urgency to the implementation of recommendations to increase resilience and minimise the implications for rail freight and associated supply chain activity.

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Table 1: Overview of case study research methods

Method	Purpose	Details	Sampling coverage
1. Open access real-time information for freight train services (from realtimetrains.co.uk)	To collect route and schedule data for freight trains diverted as a result of the line closure	The following information was captured for each specific train: date/day of operation; train origin; scheduled and actual departure time; route; train destination; scheduled and actual arrival time; freight operating company (FOC)	n = 836 (100% of freight trains diverted during the period of the line closure)
2a. Observation surveys	To gather additional details about train composition and loadings	Direct observation of diverted trains, collecting details of train composition, on-train capacity, load factor, heights of unitised loads, etc. as appropriate	n = 38 (5% of freight trains diverted during the period of the line closure)
2b. Online information relating to train composition	To supplement the observation surveys	Using an approach adopted in previous research (see Woodburn, 2015), train composition information for additional trains was gathered from reliable online sources	n = 134 (16% of freight trains diverted during the period of the line closure)
3. Author's annual rail freight database	To determine the baseline 2016 service provision as a comparator for the disrupted period, and to identify changes in subsequent years (2017 and 2018)	Compiled from a range of sources, for each January since 1997 the database contains information about each service, including: days of operation; scheduled departure and arrival time; commodity; FOC	The database provides national (i.e. Great Britain) coverage of regular freight train services operating each January
4. Industry interviews	To augment methods 1, 2a and 2b and to provide qualitative information about the impacts of the disruption and how it was handled	In-depth, semi-structured interviews with key individuals from relevant organisations, representing the infrastructure manager, a FOC, a logistics service provider (LSP) and the rail freight users group	n = 4 organisations (5 individuals)