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CLIMATE CHANGE AND RESILIENT RAIL FREIGHT TRANSPORT

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ABSTRACT

Rail freight transport is a key economic activity; many businesses and people rely on it. It should be available when needed and efficient in use. There are however factors that may reduce the availability and quality of a rail freight service offering. A distinction can be made between what may be called systemic factors, like congestion, accidents and technical failures, and external factors like weather conditions and natural disasters. Rail infrastructure managers and users of rail services have learned from experience to anticipate or adapt to systemic factors. They are, to some extent, also able to cope with certain weather conditions. A rather different situation occurs when the weather becomes more extreme and less predictable. Water management systems are usually not developed for excess amounts of rain and hence will fail. Terrestrial water can turn into a devastating flood that may (temporarily) incapacitate railway infrastructure. With this (partially) out of service, freight trains have to be rerouted. This may lead to severe delays, additional costs and externalities, in particular more emissions. This paper deals with the question: What are options for governments to make rail freight transport more resilient to disruptions triggered by climate change, while limiting the externalities caused by rerouting? The paper is an extension of earlier research on this topic. Methods used in the research were a case study, the data of which were fed into a simulation model, which was used to estimate route length, fuel consumption and emissions. The main outcome of the study is that there are interesting options to make rail freight transport networks more resilient. In order to reap their benefits, interoperability should be improved considerably.

Keywords: climate change, resilience, transport operations, modelling.

1 INTRODUCTION

1.1 Climate change and the weather

Climate change has a profound, structural, impact on the weather. Extremes will become even more extreme. Rising temperatures lead to a higher humidity and evaporation in non-arid areas. In a similar vein, arid areas will become dryer [1]. The focus in this paper is on areas with a moderately humid climate. People living there experience less predictable weather throughout the year. Some regions or locations will be more affected than others. This paper will look mainly into the impact on physical infrastructure.

1.2 A recent disaster

Humans are affected by the changing weather patterns (or lack of). A recent example of this is what happened in the Netherlands, Belgium, Germany and Switzerland in July 2021. Formations of large clouds caused extreme local rainfall, because due to a lack of wind, clouds were stalled [2] for days above certain (geographically elevated) regions. Land and rivers could not cope with massive amounts of water. The large water masses, containing things normally not present in waterways, damaged, dislocated and washed away physical structures like roads, railway tracks and stations, bridges and locks. In this part of Europe, many people live in close proximity and there are important road, rail and water infrastructure



networks. Damage to these infrastructures may disrupt the passenger and freight rail services using them. It was historically the second most damaging disaster behind Hurricane Katrina, with a damage of 43 billion euro [3].

1.3 Scope: Rail freight transport

This paper will focus on rail infrastructure and freight services in the European Union (EU). The reasons for this are as follows. First, rail transport is an alternative to road transport. Second, its board, the European Commission (EC), has expressed the need for a major modal shift from road to rail as part of its climate change mitigation policy [4]. Earlier modal shift policies were not effective, though. Road transport is growing over time, while rail is losing market share in most EU countries [5].

1.4 Earlier research

Rail freight service disruptions have been addressed earlier [6]. Its authors dealt with the impact of extreme winter conditions on rail freight services in Norway, Sweden, Switzerland and Poland in 2010. They concluded that “railway operators were totally unprepared”. Ad hoc measures were taken instead of contingency plans. As a consequence, important sections of the railways were not available. This had severe logistics implications and led to (further) loss of market share to road operators.

1.5 Research aim, scope and questions

This paper explores options to mitigate the impact of nature-related, non-systemic disruptions on rail freight services. These services are part of complex supply chains, whose disruption would have important negative consequences for business and via them for final consumers. Impact mitigation could be part of a strategy to make rail freight services more resilient [7].

This leads to the main research question: What are options for governments to make rail freight transport more resilient to disruptions triggered by climate change, while limiting the externalities caused by rerouting? The main research question will be addressed by answering the following sub questions:

1. What makes railways more prone to service disruptions than road transport?
2. How could the weather influence the use of railway infrastructure?
3. What is an interesting node in the railway network whose non-availability would cause a major disruption of railway services?
4. What are options to mitigate this impact?

Questions 1 and 2 will be answered by means of relevant literature (Section 2). Questions 3 and 4 will be answered by means of a quantitative study involving the earlier mentioned countries – Benelux, France and Germany (Section 4). The paper builds on an earlier paper about the impacts of rail freight service rerouting [8]. The main focus will be on the aftermath of a hypothetical disaster. It will not deal with prevention neither in the railway sector nor by means of (preventive) water management, such as discussed in Bal and Vleugel [9].



2 THE SYSTEM AND THE PROBLEM

2.1 Rail as complex system

Railway services, in particular those covering large distances, are in general more prone to disruptions than road transport, because of interrelated factors [10]. The rail network is less dense than the road network. The railway network is technically much more complex and expensive to build and maintain, than the road network. Rail freight services share the rails with passenger services, which may have local priority, hence there is a lack of capacity. Only part of the railway network is suitable for heavy freight trains. Rail freight services also have a more complex organization than services by road. Finally, rail almost always uses trucking for the first and the last mile of a logistic service. The same factors make recovery from disruptions also more complex and time consuming. This answers sub question 1.

2.2 Disruptions due to natural events

The events in July 2021 were not the first of its kind in this part of Europe. In 2013, an avalanche split a hill with tracks near Kestert on the Rhine Valley railway between the German cities of Wiesbaden and Koblenz. This is a section of the busiest rail freight corridor in Europe, connecting Rotterdam port in the Netherlands and Genua port in Italy. It took 6–8 weeks to restore both tracks on the right embankment of the Rhine River. Most freight trains were rerouted via the left embankment [11], which is normally used for (fast) passenger trains. Freight trains have lower top speeds and accelerate and decelerate slower than passenger trains, which makes it evident that mixing a large number of heavy freight trains with high density passenger services will lead to service delays of both.

Fortunately, a parallel route was available in close vicinity. This is not common. Even in a high density railway network not all tracks are suitable for freight trains, because of technical (axle loads) or organisational reasons (available train paths). Then (international) trains are forced to make a large detour, possibly even using tracks outside the region or country where the disruptive event happened.

2.3 The city of Koblenz

This ancient city is an important railway and waterway node (Fig. 1). The Rhine and Moselle rivers meet each other in its vicinity (Fig. 2). Water in these canalized rivers comes from various sources. They start in mountain areas (melting snow). Smaller rivers (branches) are another source. Rain is an important source, too. Finally, there are other sources like sewage systems and industry. River water levels are usually higher in summer than in winter. Very high water levels may cause overflow of these rivers, threatening cities and villages on their path. Both rivers and in particular the Rhine, are also important corridors for ships carrying bulk goods and containers.

2.4 A potential disaster zone

High river water levels frequently lead to service disruption in transport by water, because barges cannot pass bridges or locks anymore, or debris makes it too dangerous to navigate. With water management given the highest priority, ships are either queuing on the water or lying in ports along a river.





Figure 1: Railway network in and around Koblenz [12].

Customer contracts ask for speedy delivery, hence shippers need an alternative. Rail and waterway transport are serving the same markets. Replacing barges by trains could be a “synchro modal” [13] solution, at least in theory, but there are important caveats:

- It takes many trains to replace one single barge. It may then be technically impossible to arrange sufficient capacity at the required moment. It is likely that goods have to be stored (temporarily) at an inland terminal;
- Railway capacity should also be ad hoc available in the out-of-service period. This is again very unlikely, as railway contracts and train scheduling are arranged well in advance;

- Railway services should be able to run normally. But what would happen if massive rainfall would occur in and around Koblenz? Railway tracks on both embankments could be destroyed in case of extremely high water. This is not farfetched, as over 600 km of railway track and 80 stations were affected in Germany in July 2021 [14]. Rail freight transport was “paralyzed” as shunting and other cargo facilities were also unusable. Trains had to be parked or rerouted, with serious delays and many more km driven [15].



Figure 2: The Rhine river [16].

A detour of freight trains over a larger area is the core of the case study in Section 4.

Next to excess water, there are also other conditions related with the weather that could influence track availability. Snow and ice are the culprits in winter (Section 1.4). High temperatures may also cause rail track damage. This answers sub question 2.

3 METHODOLOGY

3.1 Conditions and assumptions

Several assumptions were made because of practical concerns.

The focus is on freight services using rail infrastructure in Germany, France, Belgium and the Netherlands. The goods transported have their origin and destination in this part of

western Europe. Externalities considered are the contribution to climate change (by CO₂ emissions) and local air pollution (NO_x and PM₁₀), as far as the available public data allow. The time horizon is the year 2025. This allows changes in international railway timetables, which is a complex process. It is assumed that the selected routes are interoperable [18] by the trains used.

3.2 Research steps

The research for this paper was carried out as follows:

- Study literature. Select relevant rail corridors from a set of possible routes. Select services frequently mentioned in scientific and professional literature;
- Modify an existing scenario simulation model to include the studied routes/services;
- Collect additional data if needed and filter it. Fill gaps in data by assumptions;
- Run the model with the chosen routes and services to estimate fuel consumption, emissions and trip time;
- Evaluate the simulation results quantitatively;
- Write policy recommendations based on this evaluation.

A Microsoft® Excel® model, validated in previous studies, was calibrated to estimate the energy consumption and emissions of a specific rail service. Fuel consumption is an average based on the estimated kilometres driven via a specific one-way route. Emissions are based on this estimated fuel consumption and emission factors for each fuel. The model contains

- A data entry and calibration module allowing changes in user data, e.g. transport means, fuels and track (section) length;
- Matrices with energy consumption, emission factors (ef), tank-to-wheel (ttw) emissions;
- A choice box to estimate emissions of different source mixes to produce electricity;
- A solver module with policy scenarios as constraints to the linear programming.

4 CASE STUDY

4.1 Introduction

In this section, sub questions 3 and 4 will be answered. After the discussion in Section 2.4, it will be of no surprise that the chosen node is Koblenz. Sub question 4 refers to a choice of rail service combined with routing alternatives. To simplify the analysis, one service will be chosen, which will be executed via four alternative routes, all one-way:

- The base route scenario is modelled on the existing situation;
- Alternative scenario 1 is a detour via Belgium;
- Alternative scenario 2 is a detour via the north of France;
- Alternative scenario 3 is a variant of route alternative 2, with a detour via Paris.

4.2 Description of the rail service

Iron ore is a key input in steel manufacturing. Dillingen is a German town in the state of Saarland in the south-western part of Germany, close to the French and Luxembourg borders. It is the home base of a manufacturer of premium quality metals. Iron ore is not excavated in Europe, but in a South-American country. The largest vessel in the world is used to cover the sea leg between the two continents. Dillingen is an inland destination, which by definition



lacks a sea port. Only part of the inbound logistics is studied, namely the rail service connecting the largest port in Europe, the port of Rotterdam, in the Netherlands with the plant of Dillinger Hütte in Dillingen.

One train is headed by two electric locomotives type 189 running in tandem. They pull a train with around 33–37 wagons of 12 m each, equivalent with 6,000 metric ton train weight, fully loaded. Locomotive type 189 is gradually replaced by Siemens Vectron locomotives (type 193 in Germany). This may result in a lower energy use per tkm, as the newer locomotives have an average electricity consumption of about 0.015 kWh/tkm. The actual train composition and weight are decisive for the actual energy consumption of a trip, however. The return trip, which may be empty, is not considered in this paper. Its emissions should be added to the emission figures in Tables 1–3 to estimate the full impact of this transport service.

4.3 Base route scenario

Each (simulated) route should be fully available. This means that

- All technical systems function properly;
- There is no planned or unplanned maintenance of any track section;
- A scheduled train path is also available.

Table 1: Route 1 – via Koblenz. (Source: Own estimations.)

| Route: Rotterdam (NL) – Betuweroute – Zevenaar – Emmerich (G), Wesel, Dinslaken, Oberhausen, Duisburg-Wedau – Köln-Gremberg – Koblenz – Trier – Dillingen | | On way, fully loaded |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------|-------|----------------------|
| Distance in km | 620 | |
| Train weight in ton | 6,000 | |
| MWh (kWh/tkm = 0,02 [18]) Source: Green | | 74.3 |
| CO ₂ in ton | | 0.0 |
| NO _x in kg | | 0.0 |
| PM ₁₀ in kg | | 0.0 |

In July 2021, the Betuweroute was not accessible due to maintenance works. In the paper, which looks forward to the year 2025, we assume that it is available, though.

4.4 A detour via Belgium

The flooding in July 2021 caused a breakdown of 20 railway lines in the east of Belgium, including the Montzen route [19], part of three European Rail Freight Corridors and the main connection between the Belgian port of Antwerp and its German hinterland. A detour via the east of Belgium was there for impossible. Even if it would have been available, then the high weight of this train on the hilly terrain might cause traction problems, a higher electricity consumption and emissions.

4.5 A detour via northern France

In France there is an east–west railway line that connects ports such as Dunkirk with the German hinterland: the Artère Nord Est line. It could not be used in July 2021 due to an



accident in the beginning of June 2021. It reopened in the last week of July; almost 2 months later [20]. If it would be available, then Route 2 could be used, but with a detour of 152 km.

The estimated CO₂-emission is based on the overall grid mix of the additional countries crossed, viz., Belgium and France. The authors could not retrieve emission factors for NO_x and PM₁₀ for these countries.

Table 2: Route 2 – via Artère Nord Est. (Source: Own estimations.)

| | | |
|----------------------------------------------------------------------------------------------------|-------|-----------------------|
| Route: Rotterdam (NL) – Brussels (B) – Lille (F) – Thionville – Metz – Saarbrücken (G) – Dillingen | | One way, fully loaded |
| Distance in km | 772 | |
| Train weight in ton | 6,000 | |
| MWh (kWh/tkm = 0.02 [18]) Source: Partially green, partially fossil | | 86.6 |
| CO ₂ in ton | | 5.8 |
| NO _x in kg | – | – |
| PM ₁₀ in kg | – | – |

4.6 A detour via Paris

With the Artère Nord Est line out of service, a route via Paris is a logical alternative. In general this is not a favourable one. There are environmental considerations of the detour of 248 km.

Table 3: Route 3 – via Paris. (Source: Own estimations.)

| | | |
|-------------------------------------------------------------------------------------------------------|-------|-----------------------|
| Route: Rotterdam (NL) – Brussels (B) – Lille (F) – Paris – Reims – Metz – Saarbrücken (G) – Dillingen | | One way, fully loaded |
| Distance in km | 868 | |
| Train weight in ton | 6,000 | |
| MWh (kWh/tkm = 0.02 [18]) Source: Partially green, partially fossil | | 104 |
| CO ₂ in ton | | 6.6 |
| NO _x in kg | – | – |
| PM ₁₀ in kg | – | – |

Routes 2 and 3 are not available on demand. There are major operational hurdles to take. A detour via two additional countries means that train paths should be available on demand, which is hardly realistic in railways. Train drivers should be available, certified and experienced in driving a train through France. Else, French speaking train drivers should be hired. Locomotives should be technically approved by the French railway authority. This is frequently not the case. The approval process is very slow, as France tends to protect its own railway industry.

4.7 Evaluation

From these modest examples it becomes apparent that (international) railway transport may face serious problems if a main route would be closed due to weather conditions. Its problems



would be even larger if detours would be complicated due to maintenance works on alternative routes, next to the regular operational hurdles.

5 CONCLUSIONS

The paper started with the question: What are options for governments to make rail freight transport more resilient to disruptions triggered by climate change, while limiting the externalities caused by rerouting?

Railway infrastructure and rail freight services have shown to be vulnerable for disruptive events, in particular weather conditions. Once certain parts of the railway infrastructure are not available, detours are necessary, otherwise railway network managers have to halt trains. If they do, then rail customers, businesses in particular, face serious logistic problems, in particular in industries that rely on just-in-time delivery.

With policy demands on railways rising and climate change becoming a serious issue, it is apparent that governments have even more reason to invest in detour routes, preferably in the country or region where the disruption occurs, as this reduces the detour length, hence the electricity consumption and emissions of the train services.

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