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China's Iron Silk Road

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Abstract

The development of an East-West rail route from China to Western Europe provides an intermediate level of energy cost, fiscal cost and time of transit for shipping goods between these continents with the relevant performance parameters sitting between those for shipping and air freight. Metrics are presented to support this statement and now transit times are sufficiently reduced to permit certain time sensitive goods to be carried. These metrics have been developed further to give initial guidance on decarbonisation and magnitude of other combustion emissions.

There are rail gauge changes on the route and these can present difficulties/obstacles as do border crossings, exacerbated if there is conflict between the nation states.

Keywords: carbon dioxide, decarbonisation, diesel, emissions, greening, rail, Silk Road

1 Introduction

1.1 Background

The original Silk Roads were a network of trade routes between East and West, known for the transport of high value goods such as silks and spices. One route went south to Isfahan, Persia. Started during the Han dynasty in China (130 BCE), it ceased operation in 1453 CE when the Ottoman empire closed it down – see Rodrigue, Comtois and Slack [01]. Now it extends some 6,400 km across wild landscapes including the Gobi Desert and the Taklimakan Desert – see Frankopan [02] and today, the routes and destinations are different. The camel has been replaced by rail allowing efficient, low cost, transit for Chinese goods to the west and western goods into China and is contributing to the "Belt of Steel" concept. Rail use has expanded over the past ten years and is seen as a complement as well as competition to existing sea and air transport modes. Nearly 2,000 transits in three months of 2021 occurred but not all travelled the complete route. The Europe-China totals for 2021 were 1.46 million TEU and 15,000 trains – see Van Leijen [03]. The number in 2020 was 1.135 million TEU. Energy efficiency is important as China imports some 70 % of its oil. Diesel fuel's price in China to the rail operators is subsidised hence it is a preferred source of energy supply. Maximising range on the engine's integral tanks is important as is the quality of fuel used.

Metrics for energy efficiency in the freight sector are presented in Table 1 as published in years 1974 (UK based statistics) - Hendry [04] and 2020 see CSX R-1 report [05]. The metrics compare payload (tonnes) and distance (km) travelled per litre of fuel, per unit of energy (MJ) and per kilo (kg) of carbon dioxide produced. Shipping is most efficient. Speed can be critical and freight specific, as for most sea vessel designs the fuel consumption increases dramatically above 14 knots and the vessels travel long distances. Influence on future numbers will include IMO efforts to increase ship efficiency and reduce emissions. The parameters for shorter distances and bulk liquids are presented in references – see Lloyd and Atteridge [06, 07].

Table 1 Efficiency (η)					(η) Te*km/l			(η) Te*km/MJ	(η) Te*km/kg(CO_2)
Year		1974		2018	---->	2020			
Shipping		2160	ULCC =	2280	VLCC=	1660 (Int); 965 (Suez)		41.6	534.8
			Container = 740 - 1845						
Pipelines	Size		10"		12"		14"	12"	12"
(η)		1080	625		1110		1470	30.1	403.2
Diesel Trucks		72	135		(205 on test track)			3.66	49.0
Diesel Freight Trains		150	140		-->		205	4.67	62.7
Planes		15	10		(Most efficient Celera 500L = 120)			0.27	3.9

1.2 The Route

Table 2 shows the relative costs of shipping containers - DSV Global [08]. Difficulties to be addressed on the land route include the different rail track gauges between Russia plus its former satellites(1520 mm) and European countries(1435 mm). These railways have several different electrical systems. With containers, changing between flat-bed cars to suit rail gauge is an option as is changing their bogies, but with traffic density increasing, a more flexible, timely solution must be used. The capital investment will be high.

Table 2 [08]

Method	Cost (US$/container)+++	Transit Time (days)
Ship	4,000	30-45**
Train	8,000	15-18
Plane	32,000	2-5

**Reducing with faster container ships

+++ 40 ft containers

2 Ships' and Trains' Fuel Needs

A container ship using the Suez Canal with 24,000 TEU would consume 280,000 litres of marine fuel per day for a 20 to 25 days transit within a speed range of 20 to 25 knots.

Table 3 Typical Routes

	Start	Destination	Route	Distance (km)
Train	London	Hong Kong	Overland	11,775
Ship	Felixstowe	Hong Kong	via Suez Canal	17, 925
Ship	Felixstowe	Hong Kong	Cape of Good Hope	24,061
Train	Yiwu/Shanghai	London, UK	Overland	12,000
Ship	Shanghai	London, UK	Suez Canal	19,364

Train routes must be optimised for both their length and geographic elevation. Trains carrying 100 to 200 TEU are used here for comparison. For a rail route length of 12,000 km and an average speed of 95 km/hr the journey will take 5 to 6 days leaving a maximum potential 10 days to be saved from an average transit time of 15 days. For an average speed of 65 km/hr, journey time will be approx. 8 days. There will be refuelling stops, engine and gauge change stops and integration between other track users, so even with efficient design and route planning there are not many days available to be shaved off the schedule. However, in 2020 a new express route between Germany and China was inaugurated. For this 9,400 km route, journey transit time was 10 to 12 days whereas previously it was 17 days – see Jialu Zhang [09].

3 Integrating the Various Sections

The fuel energy for an outward rail freight journey from Yiwu to London is equivalent to 95,000 litres of diesel. This number will increase with the recent substantial increase in freight traffic hence train length and container weight. The return journey has been somewhat less, though in 2021 more TEU travelled west to east than east to west for the first time [03].

The typical fuel tank capacity for a large diesel engine will demand intermediate stops. Capacity range is 7,500 to 15,000 litres and it is possible to use dedicated containers to give extended range, but usually intermediate refuelling stops are employed. For this journey there will be several engines possibly using different power sources or employing multi-fuel hybrids. Changing engines at borders may be necessary and refuelling of the stops must be addressed . Differential fuel costs along the route are another consideration.

Power assisted, semi-automatic variable track bogies can possibly eliminate the need to change wagons and is one option for tackling varying gauges. The Spanish engine manufacturer, Talgo, has announced that funding for fuel cells and traction batteries for the Travca L9202 "Virgen del Buen Camino" has been received. This will be a variable gauge locomotive prototype – see Railway Gazette [10]. They first announced their work on "Gauge Change Capability" in year 2005 though here we have large freight engines. A realistic compromise on using these bogies would be to equip the flat cars with variable gauge equipment and have engine change outs only. Engine changes are needed for other reasons along the route.

Loading 150 trains with the same number of containers as one large ship, the trains' fuel quantity consumed (150 trains) will be 14,250 cubic meters. This compares with 6,160 cubic metres (280 cubic metres per day for 22 days) per trip for a ship. The comparison is the value of fuel with the value of journey times between the two options. There are also sunk costs and security issues to be considered. The faster trains offer the opportunity to handle semi-perishable goods. Other benefits of this include greater container loading density and reduction of HVAC utilities if they are distributed along the length of the train. Self contained HVAC containers exist but still need utilities and are expensive.

4 Outcome

4.1 Decarbonisation.

The methods available for decarbonisation of trains are well known. Electrification of the route is ideal as long as the remote generation of electricity does not produce carbon dioxide. Route electrification is expensive, and costs are known in various countries from other projects. Difficulties arise from the magnitude of the project and the superficially incompatible nature of the various countries' trains but with variable gauge rolling stock one problem is removed. Some other issues are:

(i) Optimisation of the route , including terrain must be addressed. Most of the track exists but local improvements will help.

(ii) Selection of the most appropriate drive units is necessary as oversized units operating away from their design point often have poor efficiency.

(iii) Hydrogen fuel must be delivered to the intermediate fuelling stations - it can be made elsewhere. Another option is to use locally sourced water, treat it and generate green hydrogen. The significant supply then is electricity, again ideally green, but water supply also will be critical in barren locations.

(iv) Alternative fuels such as ammonia can be considered especially if the stations are in remote/low population density areas. Ammonia is a hazard to humans and when combusted can make NOx.

(v) Trees can be planted. To offset 95,000 litres of diesel (79.8 te), approximately 65 acres (26 ha) of land would be needed for each journey, but once the trees are mature, subsequent journeys would be covered. Several sources suggest that this number is low. The number of trees, hence land area will depend on environment, location (arid land for example) and train frequency per day, Optimising tree species used is necessary as deciduous trees will have different carbon removal rates between winter and summer and day/night for example. The averaging rate throughout the year is important but a mixture of suitable tree species will help here.

4.2 Motive Power

The present engines are diesel though in certain locations, electric engines are used. Assuming that diesel power is used throughout, the predicted emissions' quantities are given in Table 4.

Table 4 Emissions

Fuel used = 95,000 litres diesel
Carbon Dioxide = 253 Te
NOx = 2.5 Te
Particulates = 0.016 Te
SOx = 0.008 Te

The SOx values depend on the sulphur content of the fuel and all emissions are influenced by engine design. The standards of several countries are high on permitted exhaust pollution levels.

With 15,000 trains per year and assuming only 90% of outward fuel consumption is needed for the return journey, then with decarbonisation, production of some 7.45 million tonnes of carbon dioxide is avoided. With increasing traffic to China, this quantity will increase further. However, the carbon dioxide quantity will adjust in the electrical power section of the route according to the electrical generation source used.

Local passenger trains using hydrogen fuel cells are entering service in Europe with the fuel carried in pressure vessels above the passengers. Here any larger quantities needed would be carried on purpose-built wagons which when depleted would be exchanged for full ones at pre-determined pit stops. However, this is not an ideal application for hydrogen – see Atteridge and Lloyd [11].

Battery powered trains need development. The industrial scale batteries would be mounted on wagons behind the engine and several would be required depending on the range and distances between stops. The depleted battery wagons would be exchanged at pit stops, recharging there using solar power or other renewable generated electricity. In remote locations an array of large wind turbines is perhaps ideal as such an array using larger units would have minimum interconnections.

Freight trains need substantial engine power and tractive effort. A medium sized diesel engine driver would be 3,200 HP (2.4 MW) and a frequently used larger one 6,000 HP (4.5 MW). Swapping these for battery drives would demand high current applications. Physically large batteries would be needed to give a reasonable range before needing charging and low winter temperatures will affect the charge capacity. HVAC can be used for temperature control but would involve penalties. For well used sections of the route, overhead electrical supply becomes attractive as a local renewables charging source is complex. Battery units would be suitable for low traffic density areas. Research in decarbonising heavy freight trains is being undertaken in several countries. As the trains are so heavy (150 TEU containers), regenerative braking becomes acceptable.

To give an indication of scale, 16 MW-h of capacity would currently occupy some eight TEU containers, but new systems are being developed. Advances in both hydrogen systems and batteries will continue to be made. They will be lighter, cheaper, smaller, more powerful and will promote decarbonisation efforts

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