A Railway from Saltney to Mold

CENV 3065: Railways

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0.0 - Introduction

The task was to design a railway to connect Saltney on the border between Cheshire and Flintshire on the England Wales border, to Mold in Flintshire, about 15km west. Mold historically had a railway station and line connecting to Saltney, however this was closed in 1962 and subsequently dismantled, leaving nothing behind aside from earthworks and a few bridges. Although this predates slightly the Beeching report in 1963, the line closure followed the trend at the time of closing branch lines due to decreasing demand caused by increasing popularity of road traffic.

Currently rail demand is seeing something of a resurgence caused by a range of factors. Recently the Scottish Borders Railway has been laid on the old Waverly Route, reinstating a Beeching cut line. The proposed Mold route is similar in nature, though much shorter. If the Mold route were to be built it would pave the way for further sections of line to be laid into northern wales; this would bring public transport to a large area of the country which is currently very inaccessible.

It was decided not connect the proposed line at Saltney, but rather Shotton, for a number of reasons, including reducing the length of new track to be laid and passing closer to population centres. To enable this a new linking section of track must be built between Shotton High Level and Shotton Low Level station, although only the High Level is scheduled for stopping (the line to Wrexham has less traffic hence has more capacity for trains stopping there).

Calculations on for design were based on base year statistics given in a data sheet shown in the annex. This shows a base year demand for the town of Mold. Although this has been used for track design, the route in reality would see much more than this, hence unit design has been done for a much larger demand.

Ultimately it becomes apparent that the route is unlikely to be ever built as the capital cost would be very high for low returns and ridership.

The project brief has been included in the annex for convenience.

1.0 - Route

Lots of different existing and dismantled railways exist in the area surrounding Mold, providing lots of options for the alignment.

Initially the dismantled alignment was considered, this is approximately 15km in length and some of the bridges and much of the earthworks remain. The fact that much of the earthworks remain is useful as this would reduce construction costs, however the stability of the earthworks is unknown, and being built in 1861 it is likely they are not safe according to modern standards. The alignment also passes over a significant number of roads and through the Airbus factory at Broughton, this would require significant changes to the route, negating the benefits from reduced earthworks costs. Critically the route does not pass close to the population centres on the way to Mold, reducing the usefulness of intermediate stations. As a result it was decided that despite the reduced construction costs due to remaining earthworks, an entirely new route would be devised passing closer to current population centres.

The proposed route remains with the mainline from Saltney to Shotton. A new station at Saltney would be built and the station at Queensferrry reinstated. At Shotton a new section of gauntlet track on a viaduct is created to connect with the north-south line from Wrexham. This is not only useful for the proposed route but enables trains to run from Wrexham to Chester. The route continues on the Wrexham line for another kilometre before splitting off on new tack and running directly to a new station at Ewloe. After Ewloe new track is created at a constant gradient passing over A55 and into a short 500m tunnel before a new station at Buckley. The track continues uphill to Mynydd Isa, then downhill to a station north of Mold. The terminus is designed such that continuation of the line in the future is easy. Unlike the dismantled route, this passes many more significant population centres. In addition the route is almost always at grade to the surrounding roads, this makes bridge construction substantially easier. Although in many ways this is a better route, it suffers from very steep gradients. The dismantled route has a very shallow grade and lots of curves, this suits slow not very powerful steam trains. In contrast the new alignment is designed for modern trains which are significantly more powerful hence can cope with steeper gradients and go much faster, requiring straighter track. In addition the new alignment requires significantly less track to be laid and avoids existing buildings.

Figure 0 – Route Map. At this scale the map and annotations are not clear, hence the full A0 version has been appended in the annex.

1.1 - Demand Forecast

An elasticity based model has been used to estimate the 2030 demand on the route from the current base year demand. 45% of passengers are assumed to be traveling for leisure, 40% are commuters and 15% for business.

Variable		Base Year	2030 Forecast
Journey Time	(mins)	44	44
Service Interval	(mins)	60	30
Time Penalty	(mins)	31	23
Generalised Journey Time	(mins)	75	67
Fare	(£)	11.00	12.10
Population	(people)	10,058	11,566
Demand	(trips/year)	110638	d_{y1}

Table 1 - Variables for elasticity model.

Variable	Elasticity
Generalised Journey Time	-1.2
Population	1.0
Leisure Fare	-1.3
Commuter Fare	-0.6
Business Fare	-0.7

Table 2 - Elasticity's with respect to variables.

$$\frac{d_{y1}}{110638} = \left(\frac{11566}{10058}\right)^{1}\left(\frac{67}{75}\right)^{-1.2}\left(0.45\left(\frac{12.10}{11.00}\right)^{-1.3} + 0.40\left(\frac{12.10}{11.00}\right)^{-0.6} + 0.15\left(\frac{12.10}{11.00}\right)^{-0.7}\right)$$
$$\Rightarrow d_{y1} = 110638\,(1.4993 \times 1.1459 \times 0.9156) = 174039\ trips/year$$

Equation 1 - 2030 demand forecast calculation using elasticity model.

2.0 - Trackbed Design

Good trackbed design ensures long term stability of the track, reducing maintenance and the likelihood of failures. Design is influenced by a number of factors including superficial geology and line usage.

2.1 - Annual Tonnage

The annual tonnage is a measure of the line usage and an important value in deciding how strong the trackbed must be. To calculate this, the number of carriage passes each year has been calculated, by assuming a capacity of 50 people per coach and fill rate of 50%. The annual tonnage is then calculated by assuming and axel load of 15tonnes and four axels per carriage. The line to be designed is single track hence all passengers will pass over the same line. Data for Southampton has been included for comparison. There is dual track just outside Southampton Central; it assumed that one track carries half of the total passengers and that there are no freight trains. The calculation for Southampton

Central is likely an underestimate, as a large number of freight trains pass through every day, which have much higher axel loading.

	Annual Trips	Carriage Passes	Annual Tonnage (tonne/year)
Base Demand	110,638	4426	265,560
2030 Demand	174,039	6962	417,720
Southampton Central 2016/17	6,361,000 (Office of Rail and Road, 2017)	127,220	7,633,200

Table 3 - Summary of Annual Tonnage.

Comparing the data to that with Southampton Central, a busy commuter route, the proposed line has a forecasted annual tonnage 18 times smaller. This is a significant difference suggesting an overall very lightly loaded line, meaning maintenance costs would be expected to be comparatively low.

2.2 - Ballast Design

Two key types of failures are common in clay type soils, specifically 'subgrade progressive shear failure' and 'excessive subgrade plastic deformation' (D. Li, 1998). The first from repetitive loading of passing trains causes the subgrade soil to get progressively squeezed outwards and upwards. The heaved sides and depression in the remoulded clay trap water and further aggravate the failure. The second happens as repeated loading leads to soil consolidation with ballast pockets forming underneath each rail, the location of highest loading, leading to segments of track significantly misaligned with others. In reality they are not entirely independent and often occur simultaneously.

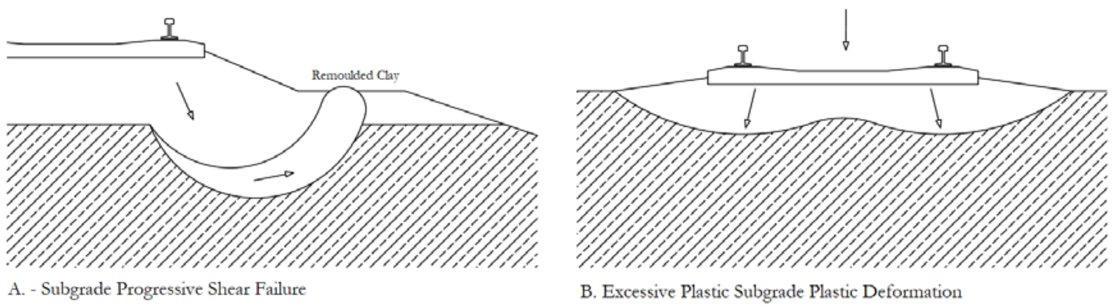

Figure 1 - Diagram of the two different common failure types, based on D. Li (1998).

The trackbed thickness has been designed in accordance to D. Li (1998), designing against the first failure type, 'subgrade progressive shear'. A maximum design strain of 3% was used for 10 million load cycles. The first step is to determine the stress-strength ratio in each soil for the given value of strain. This was done by plotting a graph of the strain against the stress-strength ration, and reading off the graph. All values are precisely detailed for each of the soil types in Table 4. The four soil types designed against are: CH - fat clay, CL - lean clay, MH - elastic silt, ML - silt.

$$\varepsilon_p = a\left(\frac{\sigma_d}{\sigma_s}\right)^m N^b$$

Equation 2 - Relationship between the design strain ε_p and Stress Strength Ration σ_d/σ_s, with a, b and m various parameters, N the number of load cycles, σ_d the deviator stress and σ_s the soil compressive strength.

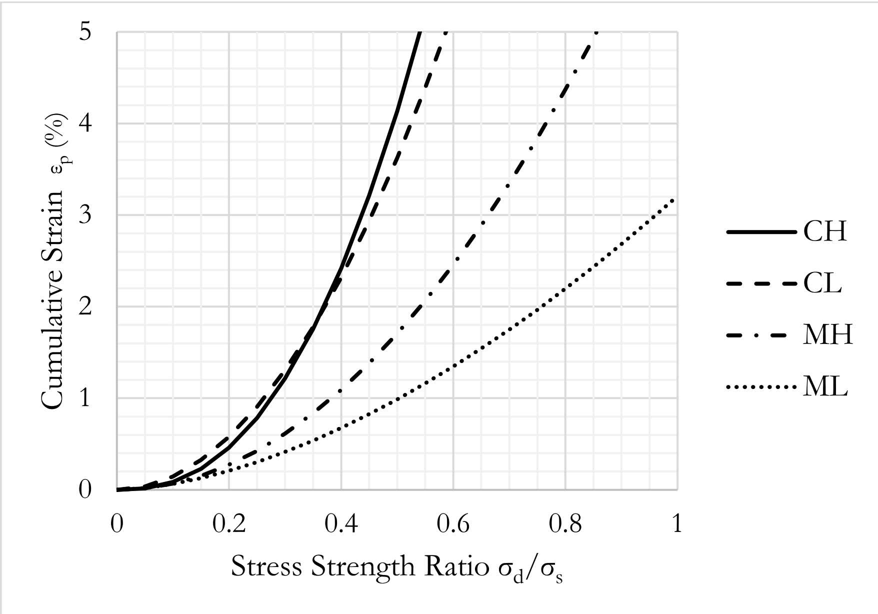

Figure 2 - design chart created to plot cumulative strain against stress strength ratio. Stress strength ratio read off for each curve at a cumulative strain of 3%.

The values of soil compressive strength are known, hence using the ratio determined from Figure 2, the deviator stress was calculated. The strain influence factor was then calculated using Equation 3.

$$I_\varepsilon = \frac{\sigma_d A}{P_d}$$

Equation 3 - Strain Influence factor, I_ε, calculated using σ_d the deviator stress, $A = 0.645m^2$ an arbitrary factor and P_d the wheel design dynamic load.

The wheel dynamic load is calculated using a dynamic load amplification factor involving the design speed of the track, which is a given 160kph which is equal to $44.44ms^{-1}$.

$$DAF = 1 + \frac{0.0052v}{D} = 1 + \frac{0.0052 \times 44.44}{1.0} = 1.231 \quad \Rightarrow \quad P_d = 75 \times 1.231 = 92.33kN$$

Equation 4 - Determination of P_d, with v the track design speed, D the wheel diameter and 75kN being the given design wheel load.

The strain influence factor was used to read off H/L from Figure 3, which is a design chart directly used from D. Li, 1998.

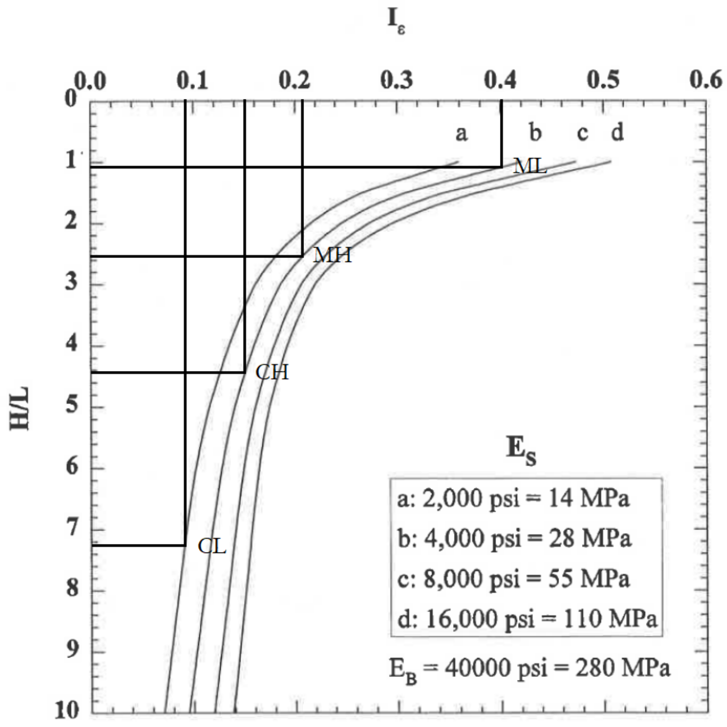

Figure 3 - Design chart (D. Li, 1998), plotting I_ε against H/L, with H being the trackbed ballast depth and L being an arbitrary scaling factor included in the original paper so that imperial units could be used.

Taking L as 0.152m, the design trackbed thickness was then calculated for each of the given soil types. The trackbed was thickness was calculated as 0.671m for type CH, 1.100m for type CL, 0.387m for type MH and 0.193m for type ML.

Soil Classification	CH - fat clay	CL - lean clay	MH - elastic silt	ML - silt
σ_s - Soil Compressive Strength (kPa)	50	30	45	60
a	1.20	1.10	0.84	0.64
b	0.18	0.16	0.13	0.10
m	2.40	2.00	2.00	1.70
N - Number of Cycles	10^7	10^7	10^7	10^7
ε_p - Cumulative Strain (%)	0.43	0.45	0.66	0.96
σ_d - Deviator Stress (kPa)	21.5	13.5	29.7	57.6
I_ε - Strain Influence Factor	0.150	0.094	0.207	0.402
Curve for Fig 3 - Given	b	a	b	b
H/L	4.42	7.24	2.55	1.27
H - Trackbed Thickness (m)	0.671	1.100	0.387	0.193

Table 4 - Calculated and given values used to determine the trackbed thickness for each of the given soils.

Given that the trackbed design was calculated for 10 million cycles before reaching the 3% strain, using the predicted number of carriage passes, the number of years before ballast renewal can be calculated. It is assumed that each carriage has 4 pairs of wheels, hence one carriage represents 4 sets of repeated loading.

$$Years\ Between\ Renewal = \frac{Design\ Cycles}{No.Carriges\ Per\ Year \times Load\ Cycles\ Per\ Carriage}$$
$$= \frac{10^7}{6962 \times 4} = 359\ years$$

Equation 5 - Calculating interval between trackbed renewals if designed to 10 million cycles. Note that the number of carriages per year is the 2030 forecast, this is because the renewal interval would bring the design much further into the future than 2030.

In reality the design renewal life of 359 years is unrealistic, it is likely that other failures would precede this, such as ballast crushing, silting and fouling.

2.3 - Soil Types Along Route

A map of the superficial deposits was used to determine soil types along the route (British Geological Survey, 2017). The terminus in Mold is built in a river valley on alluvial deposits of Clay Silt and Sand, Moving up the hill to Buckley the region is dominated by Glacial Till. At Buckley where the tunnel is, the bedrock of mudstone and sandstone rises to the surface. Moving down the hill towards Shotton, the superficial deposits remain Till, then become Secondary Till alternatively described as Glacialfluvial deposits. Finally the linking loop of track beyond Shotton will be built over tidal deposits.

The route is dominated primarily by Glacial Till superficial deposits. Till is very heterogeneous, consisting of boulders and pebbles combined with clays and sands, this is confirmed by the very wide range within borehole logs (BGS, Various, Various). Consequently it is challenging to define this within the scope of the paper (D. Li, 1998), however due to the contained boulders and pebbles, at a local scale it is more likely to act as a granular soil rather than a cohesive one. In addition from borehole logs it is clear that for much of the route the bedrock is very shallow (BGS, Various, Various), especially where cuttings are located, this is good as cuttings in rock are significantly more stable. The tunnel will be bored through rock rather than soil, this will make construction of the tunnel much easier. The final segment of the track is located over tidal mudflats, however being on a viaduct, this is not an issue, as the viaduct pillars can simply be placed on bored piles.

Although much of the route is on Till which will act locally in a granular manner, the paper does not cover this. This is largely because granular material is very strong, drains well, and does not suffer from the same kinds of shear failure, consequently when designing on granular material the constraint becomes the minimum ballast depth to use the automatic ballast refreshing machines at.

3.0 - Loading Gauge

Standard track gauge will be used for compatibility with the national rail network. The loading gauge used will be W8, this is used from Crewe to Shotton (Network Rail, 2016) and south from Shotton to Wrexham (Network Rail, 2017). Using a loading gauge greater than W8 is unnecessary as it is unlikely in the near future that the whole north wales line will be upgraded. Although a smaller gauge would present cheaper construction costs especially given the tunnel, it would restrict the size of stock to be used on the line. W8 accommodates almost all current UK rolling stock allowing for standard units to be used on the line from elsewhere in the UK rather than requiring custom built units.

The route will not be designed to accommodate overhead lines as although there have been plans in place to electrify the north wales line in the near future (Osborne, 2015), a battery operated train would be more cost effective than electrifying the proposed route.

Although in reality the W8 gauge is designed for intermodal container freight, which is unlikely to ever run on the line, it does provide slightly more space at the top corners, allowing for potentially wider stock. Though if the line were extended up the valley, several quarries operate with potential to use intermodal rail freight.

As the route is built on an entirely new alignment concerns with existing structures is not an issue.

3.1 - Geotechnical Design

Almost all of the cuttings pass through strong bedrock with only a few meters of topsoil, hence slope stability is not much of an issue. However embankments will have to be designed to ensure slope stability, as these are of made ground. The section to be designed is a 4m high embankment south of Shotton made from the underlying Glacial Till, in order to pass over a minor road. The embankment will be designed according to Whitlow's method (2001). Till has an effective stress friction angle, Φ, of 30°, an effective cohesion, C', of 5kPa and a unit weight γ of 20kNm^{-3}. The slope has been designed for a safety factor of 1.25. The first step is to determine which design chart to use (Whitlow, 2001).

$$\frac{C'}{\gamma H} = \frac{5}{20 \times 4} = 0.0625$$

Equation 6 - Determination of design chart to use.

From this the design chart for a value of 0.050 was chosen as this is more conservative than that for 0.075.

$c'/\gamma H = 0.050$													
Slope cot β:		0.5:1		1:1		2:1		3:1		4:1		5:1	
D	φ′	m	n	m	n	m	n	m	n	m	n	m	n
1.25	20	1.16	0.98	1.24	1.07	1.50	1.26	1.82	1.48	2.22	1.79	2.63	2.10
	25	1.40	1.23	1.50	1.35	1.81	1.59	2.21	1.89	2.70	2.28	3.19	2.67
	30	1.65	1.51	1.77	1.66	2.14	1.94	2.63	2.33	3.20	2.81	3.81	3.30
	35	1.93	1.82	2.08	2.00	2.53	2.33	3.10	2.84	3.78	3.39	4.48	4.01
	40	2.24	2.16	2.42	2.38	2.94	2.78	3.63	3.38	4.41	4.07	5.22	4.78
1.50	20	1.48	1.28	1.55	1.33	1.74	1.49	2.00	1.69	2.33	1.98	2.68	2.27
	25	1.82	1.63	1.90	1.70	2.13	1.89	2.46	2.17	2.85	2.52	3.28	2.88
	30	2.18	2.01	2.28	2.09	2.56	2.33	2.95	2.69	3.42	3.10	3.95	3.56
	35	2.57	2.42	2.68	2.52	3.02	2.82	3.50	3.25	4.05	3.75	4.69	4.31
	40	3.02	2.91	3.16	3.02	3.55	3.37	4.11	3.90	4.77	4.48	5.50	5.12

Figure 4 - Design Chart from (Whitlow 2001).

Once the design chart was chosen the following equation was applied to determine a suitable slope, iterating through the values of m and n. The largest value of D has been selected, 1.50. As the embankment is made of a clayey material, r_u is 0.40.

$$F = m - n \cdot r_u \;\;\Rightarrow\;\; m - 0.4n > 1.25$$

Equation 7 - Calculation for factor of safety F, given m, n and r_u.

The least conservative slope of 0.5:1 was the first to be checked, using values of m = 2.18 and n = 2.01.

$$2.18 - 0.4 \times 2.01 = 1.376 > 1.25$$

The least conservative slope was deemed acceptable, hence the slope width must only be 2m wide for a 4m height. In reality this is unlikely to be a safe design, the calculation assumes a very high value of cohesion that is only likely in consolidated conditions, i.e. in situ. As the embankment is made ground it is likely to have a far lower cohesion, hence require a far shallower slope.

Many of the earthworks in the proposed route should be relatively straight forward to create, as most of the cuttings and the tunnel pass through bedrock. However there are numerous subsurface coal mines in the area, especially near the tunnel. Great care would need to be taken to avoid these potentially unstable structures, or serious collapses/sinkholes could occur from overloading.

4.0 - Rolling Stock

To design appropriate rolling stock the expected capacity of the trains must be determined. A peak time usage has been estimated by assuming that all commuters and business travellers make a journey evenly spread over a 2 hour period. This is assumed to be travel in one direction hence half of the total commuter/business journeys made. PJ stands for peak journeys

$$PJ\ per\ year = Base\ Demand\ \times Proportion\ Commuters\ and\ Business = 110638 \times 0.55$$
$$= 60851\ \text{Journeys}\ per\ year$$

$$PJ\ per\ day = \frac{PJ\ per\ year}{Working\ days\ per\ year} = \frac{60851}{52 \times 5} = 234\ per\ day$$

It is assumed that half of these journeys are evenly split between a morning rush hour in one direction and an evening in the other, hence the factor of two in the following equation.

$$Req\ Capacity = \frac{PJ\ per\ day}{No.trains\ in\ rush\ hour\ \times 2} = \frac{234}{2 \times 2} = 59\ people\ per\ train$$

The calculation was repeated for the 2030 demand of 174039 trips per year and 2 trains per hour giving 46 people per train. Consequently the design capacity would be 59 people per train. This figure would suggest that all that is required is simply a railcar, a one carriage train. In reality this figure is an underestimate as the route services a much greater area having exclusive stops at Mynydd Isa (5873 people), Buckley (21502 people, approximately half serviced) and Ewloe (4862 people). This represents a threefold increase in population hence passengers at peak, which requires a peak capacity of approximately 180 passengers. This figure is to be used as the design capacity.

Figure 5 – Carriage layout diagram, a blown up version is provided in the annex.

The units were designed to be very versatile. The proposed route is likely to take a wide variety of passengers: commuters in the rush hour towards regional cities such as Liverpool and Manchester requiring high capacity, and tourists out to the north wales country side requiring luggage and bicycle space. In addition a large number of leisure journeys are likely to be made to regional cities, demanding a higher standard of comfort than a commuter line.

A two carriage unit could have catered for a capacity of 180, but this would have required very dense seating, which would be unacceptable for leisure and business travel. Consequently a 3 carriage unit was created, this allows ample space for extra amenities. Two first class sections have been placed at the ends of the train, next to luggage racks to cater for long distance travellers. A total of four bicycle zones have been put on the train to encourage commuters to use bicycles as part of their journey, these are distinct from the accessible zone, which is placed next to the accessible toilet, to ensure that there is always space for both wheel chair users and bikes. A large number of priority seats have been placed next to the doors to ensure easy access for people with restricted mobility. All seating is double width and multiple tables have been included to increase passenger comfort for the mixed use service. Two toilets are included ensuring no one has to travel more than one carriage to reach a toilet, this also increases reliability.

The unit has been designed with open gangways, this increases capacity above the calculated and increases accessibility within the train. The cab units are not designed as walkthrough, though this reduces the utility of connecting units part way through the journey, the aerodynamic efficiency is increased substantially; in reality as these are local low use services not having walkthrough cabs is a minor issue.

4.1 - Powertrain

The mainline to Crewe is currently not electrified, this precludes using electric or electro-diesel trains, as the electrification of the proposed route would require electrification of a large portion of the north wales line; a major task. In addition the units are to be running on very steep gradients over long distances, with stations midway on the hills, if a standard DMU was used the energy from going downhill could not be recuperated to go uphill, greatly reducing efficiency.

Instead a relatively new approach is to be used, a Hybrid DEMU (Mynavi Corporation, 2013) (Barrow, 2017). Using a multiple unit increases the traction over a locomotive as 100% of wheels would in this instance be powered. The hybrid approach means that the energy expended going uphill or accelerating can be partially recovered when going downhill or braking, storing this for later. In addition being able to draw on battery power and diesel power simultaneously would create a very powerful train capable of rapidly accelerating even out of stations going uphill.

Using the Hybrid approach also leaves potential for replacing the diesel engine with a pantograph if the mainline becomes electrified, by simply running on battery power on the proposed branch line to Mold.

However as no hybrid trains currently exist for the UK market, an off the shelf unit could not be purchased, making this substantially more expensive.

5.0 - Noise

Keeping noise to a minimum is important to prevent hearing damage and increase comfort levels of residents near to the station.

5.1 - Speed Profile

The first step in determining noise contours is to create the arriving and leaving speed profiles. As no trains in the UK are hybrid DEMUs, data had to be estimated. The train mass has been estimated to be 50 tons tare, 5 tons greater than similar DMUs, this is to account for the more complex drive train and batteries, which are notoriously heavy. The laden mass is hence assumed to be 55 tons laden per car. All axels have been specified to be powered to increase uphill traction. The traction coefficient is assumed to be 0.11, in line with similar modern DMUs and EMUs. Each axel has a specified 125kW motor, giving a total power per car of 500kW, this is very large and can only be mobilised briefly for uphill acceleration by utilising battery and diesel power. The available power proportion is assumed to be 90%, the same as an EMU over the period of acceleration as the train draws on battery power.

In addition as all axels have motors, regenerative breaking is expected to be much more powerful than an equivalent train, hence a breaking acceleration of 1.0ms^{-2} has been assumed.

The slope from the terminus at Mold to the station at Mynydd Isa is 1:50 uphill, or a gradient of 0.02.

The speed profile was plotted between Mold and Mynydd Isa for both uphill and downhill journeys. The trains are assumed to accelerate as hard as they can until reaching a peak speed before slowing down at their maximum deceleration, hence gbeing the loudest they possibly can. Trains never reach their maximum line speed over this segment of 160kph or 44.44ms^{-1}. The acceleration profiles and braking profiles were obtained using the provided spreadsheet (Thompson, 2018).

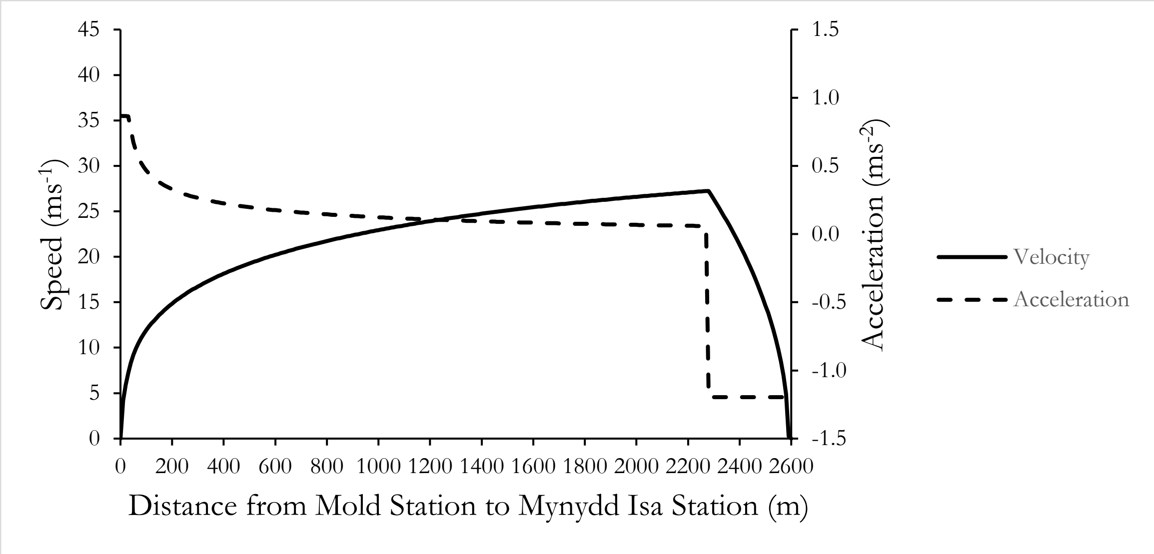

Figure 6 - Speed profile for trains running uphill from Mold to Mynydd Isa.

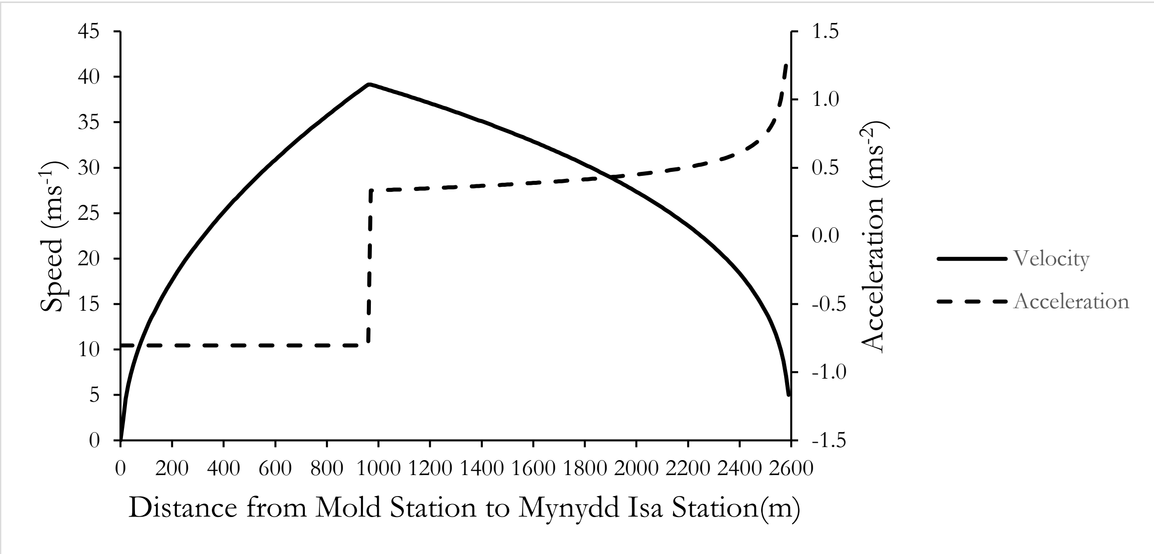

Figure 7 - Speed profile for trains running downhill from Mynydd Isa to Mold.

5.2 - Noise Contours

Noise contours are obtained from the combination of the different trains running over a given time period. The first step was to obtain each noise source level $L_{w'}$ over a normalised one carriage per hour. Subsequently L_p, the attenuation distance, is calculated over a normalised 25m

$$L_{w\prime} = 12.7 + A_{train} + A_{track} + 20\log(V)$$

Equation 8 - Noise source calculation, this was iterated over the uphill and downhill directions. A_{train} was taken as 8.0 for a DMU/EMU which the proposed unit will be similar. A_{track} at certain sections was 1.0 for concrete bridges and 0.0 elsewhere.

$$L_p = L_{w\prime} - 10\log(r) - 3$$

Equation 9 - Noise attenuation. Here r is taken as a normalised 25m.

After calculating L_p, the individual contribution is normalised to account for service frequency and the number of vehicles to find L_{eq}. Subsequently $L_{eq,tot}$ is found, summing the individual contributions from both the downhill and uphill journeys.

$$L_{eq} = L_p + 10\log(N_{veg} \cdot N_{train})$$

Equation 10 - Individual contributions. N_{veh} is set to 3 in this instance as each unit is 3 cars long, N_{train} is set to 1.0 as there are one trains per hour in each direction.

$$L_{eq,tot} = 10\log\left(10^{\frac{L_{eq,uphill}}{10}} + 10^{\frac{L_{eq,downhill}}{10}}\right)$$

Equation 11 - Calculation of the total source contributions towards overall noise level.

$$L_{eq,2030} = L_{eq,tot} + 10\log(2)$$

Equation 12 - Calculates the attenuation distance for the 2030 service interval of 30mins, by doubling the number of trains per hour. The 2030 interval gives the least conservative noise results.

$$r = 25 \cdot 10^{\frac{(L_{eq,2030} - \alpha)}{10}}$$

Equation 13 - Calculates r, the distance of the noise contour at given level α from the track.

Finally the distance from the track of the noise contours at given levels of 55, 60 and 65dB are calculated. These values were then plotted on a graph in Figure 8 and on the map in Figure 9.

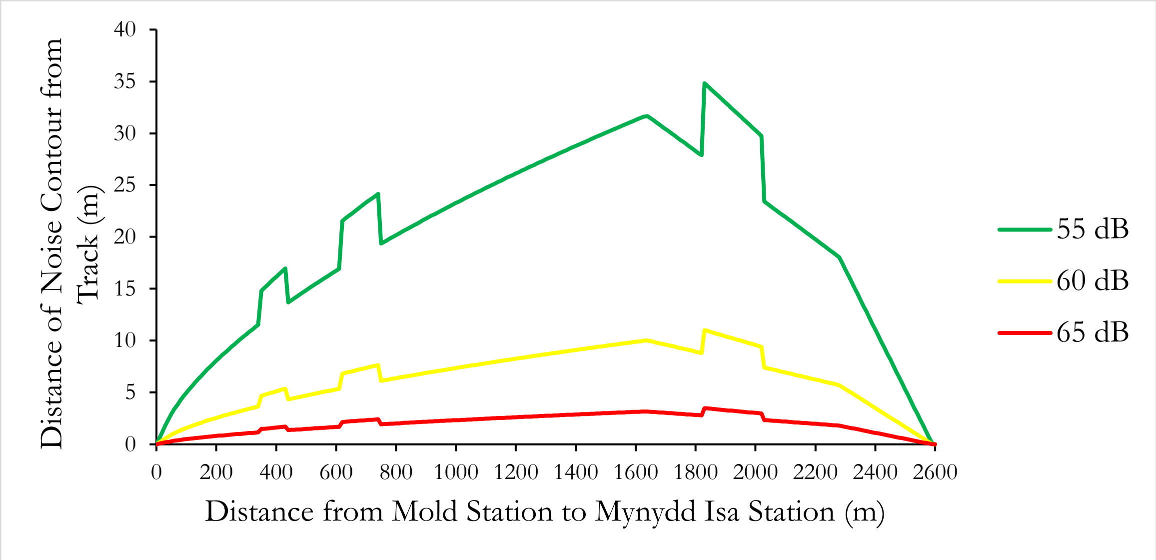

Figure 8 - Noise contours plotted on graph for clarity, note the discontinuities are caused by the bridges which are louder.

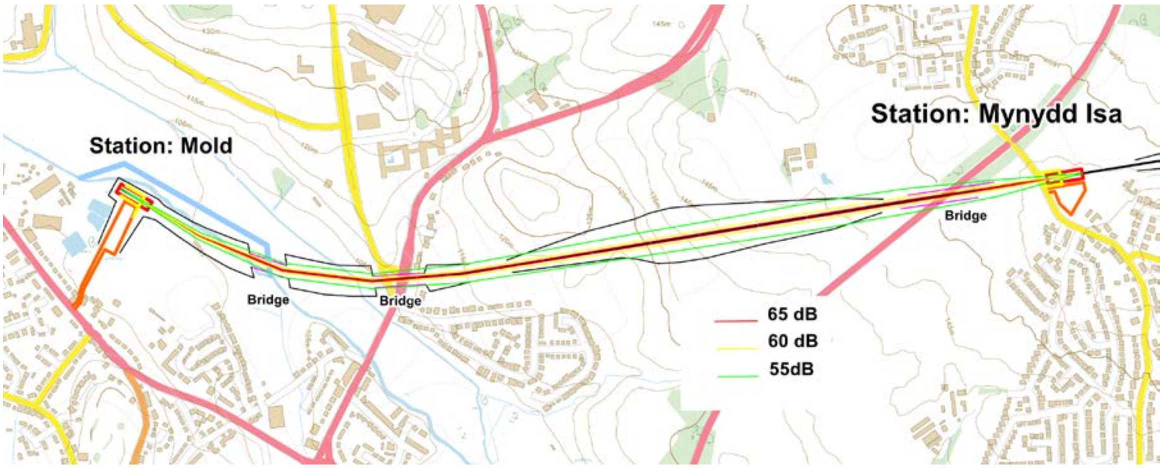

Figure 9 - Noise contours plotted on map of proposed route.

Distance	V_{uphill}	$V_{downhill}$	$L_{w,uphill}$	$L_{w,downhill}$	$L_{p,uphill}$	$L_{p,downhill}$	$L_{eq,uphill}$	$L_{eq,downhill}$	$L_{eq,total}$	$L_{eq,2030}$
0	0	0	0	0	0	0	0	0	0	0
200	14.9	18.4	55.3	57.1	38.3	40.1	43.1	44.9	47.1	50.1
400	18.1	23.6	58.0	60.3	41.0	43.3	45.8	48.1	50.1	53.1
600	20.2	27.4	57.9	60.6	41.0	43.6	45.7	48.4	50.3	53.3
800	21.7	30.3	58.6	61.5	41.6	44.5	46.4	49.3	51.1	54.1
1000	22.9	32.9	59.0	62.2	42.1	45.2	46.8	50.0	51.7	54.7
1200	23.9	35.1	59.4	62.7	42.4	45.8	47.2	50.5	52.2	55.2
1400	24.7	37.1	59.7	63.2	42.7	46.2	47.5	51.0	52.6	55.6
1600	25.4	38.9	59.9	63.6	43.0	46.6	47.7	51.4	53.0	56.0
1800	26.1	35.7	60.1	62.9	43.2	45.9	47.9	50.7	52.5	55.5
2000	26.6	30.9	61.3	62.6	44.3	45.6	49.1	50.4	52.8	55.8
2200	27.1	25.1	60.5	59.8	43.5	42.9	48.3	47.6	51.0	54.0
2400	21.3	17.6	58.4	56.7	41.4	39.8	46.2	44.5	48.5	51.5
2600	0	0	0	0	0	0	0	0	0	0

Table 5 - Selected Data for the various noise values calculated with intervals of 200m. A spreadsheet was used to calculated values at 10m intervals.

5.3 - Noise Mitigation

The route runs far enough away from most nearby buildings that they exist outside the 55dB contour. However a couple of houses lie just within this contour, lying next to the second bridge along. The noise level at these houses has been calculated exactly, assuming a distance of 25m from the track at 720m along the track from Mold station.

$$L_{eq} = L_{eq,2030} + 10\log\left(\frac{25}{r}\right) = 54.8 + 10\log\left(\frac{25}{25}\right) = 54.8$$

Equation 14 - Calculation of noise level at critical house. As the critical distance is 25, the calculation is trivial.

At this location the noise levels are well outside the 65dB limit, consequently no sound proofing would be needed in this section of track, in reality however the noise levels may be much louder from the elevated bridge, as the equation did not take into account the embankment. Noise due to the concrete bridge could be quickly reduced by running the tack on rubber pads.

Much of the remaining proposed new track does not pass close enough to residential areas to make noise a concern. Additionally a large proportion is in cuttings, further reducing noise levels. The connecting loop after Shotton may present problems, specifically wheel squeal from the 175m curve, which is relatively tight. Solutions could include noise barriers, or specifying the units with boogies employing shorter wheelbases.

6.0 - Signalling and Track.

Although the route map from the geographic route, this is not enough information, a precise diagrammatic layout was also be created to show the layout of signals, points and crossings on the route. The diagram also shows the layout of the dual and single tracks. It is important to note that as a connectivity graph, the diagram does not accurately represent scale, for instance the section of dual track before single track in junction B, in reality would be merged straight away. Signalling past Shotton Low level has not been included as this is to be determined according to the current mainline standards.

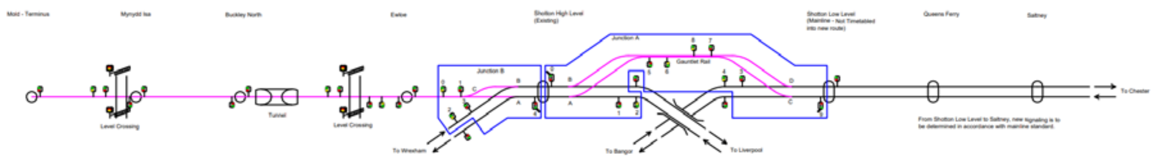

Figure 10 – Network Diagram, a blown up version is shown in the annex.

For the network Shotton Low Level has been included, as this is an important part of the interlocking matrix. With respect to the timetabling and the route, this has not been included as only one of the Shotton stations needs to be served, and the Higher Level sees less rail traffic, hence having more capacity.

The track runs on single line to Shotton, before connecting on the mainline at junction B. Two level crossings exist, both with caution and stop signals, this is in the unexpected event that a level crossing becomes blocked. As all stops are scheduled in the single track section and it is to be occupied by one train at a time, only start signals have been provided at stations, as trains will not be required to stop before stations; Instead speed limits will be used to slow down trains.

Junction B is situated just outside Shotton station, hence an intermediate block is not created. In addition divergent signals are used as the station starting signals. This simplifies signal layout.

Junction A is a new section of track used to connect Shotton high Level to Shotton Low Level. Initially a single track line was proposed as the segment is short and does not need the capacity for two trains at a time, however this introduces six sets of points. Another more unusual approach was instead taken, using gauntlet track. The gauntlet track has the benefit of being narrow like single track, requiring less supporting structure, yet requires two sets of points less. This reduction in the number of points will significantly reduce maintenance costs and increase reliability.

Junction A - Interlocking Table

Signal		0strt.	0divg.	9strt.	9divg.	1	2	3	4	5	6	7	8	B -> D	C -> A
		Conditions for Signal to be Clear												Conditions if Gauntlet Occupied	
0strt.	Signal Positions		stop							stop	stop				
0divg.		stop			stop					stop	stop				stop
9strt.					stop										
9divg.			stop	stop				stop				stop	stop	stop	
1							clear			stop	stop				
2										caut.	caut.				
3					stop				clear			stop	stop		
4					caut.							caut.	caut.		
5		stop	stop			stop	stop				clear	stop	stop		stop
6		caut.	caut.			caut.	caut.					caut.	caut.		caut.
7				stop	stop			stop.	stop.	stop	stop		clear	stop	
8				caut.	caut.			caut.	caut.	caut.	caut.			caut.	
a	Points positions					strt.	strt.			divg.	divg.				
b		strt.	divg.		strt.										strt.
c			strt.	strt.	divg.			strt.	strt.					strt.	
d								strt.	strt.			divg.	divg.		

Table 6 – Interlocking matrix for junction A in the network diagram.

7.0 - Timetabling

Timetabling must be carefully done to avoid conflicts and delays on a route. The timetable has only been done for the route through to the proposed Saltney station on the current North Wales mainline. Although the current timetable assumes a clear line over the Shotton mainline segment and Segment through to Saltney, in reality this is not the case and any new timetable would have to be integrated with current mainline services.

To determine the timetable the time taken between stops was calculated. An average speed was used, based on that determined from section 6.0. An uphill average speed of $22ms^{-1}$ or 80kph was used, an average downhill speed of $27ms^{-1}$ or 97kph and a flat speed of $35ms^{-1}$ or 126kph. The flat line speed is much greater as the distances between stations increase, allowing for a longer time for the train to accelerate and brake.

Station	Distance (m)	Assumed Avg. Speed (ms^{-1})	Travel Time (s)	Station Wait Time (s)	Cumulative Time (s)	Timetable Time (mm:ss)
Mold	Leaves Mold at a time of 00:00					00:00
Mynydd Isa	2.6	22	118	90	118	02:00
Buckley North	1.9	27	70	90	278	04:30
Ewloe	2.5	27	93	90	461	07:45
Shotton	2.6	27	96	90	647	10:45
Queens Ferry	4.5	35	128	90	865	14:30
Saltney	4.0	35	114		1069	18:00
Saltney	Leaves Saltney at a time of 00:00					00:00
Queens Ferry	4.0	35	114	90	114	02:00
Shotton	4.5	35	128	90	332	05:30
Ewloe	2.6	22	118	90	540	09:00
Buckley North	2.5	22	113	90	743	12:30
Mynydd Isa	1.9	22	86	90	919	15:15
Mold	2.6	27	96		1115	18:30

Table 7 - Train cumulative travel times used to create timetable chart.

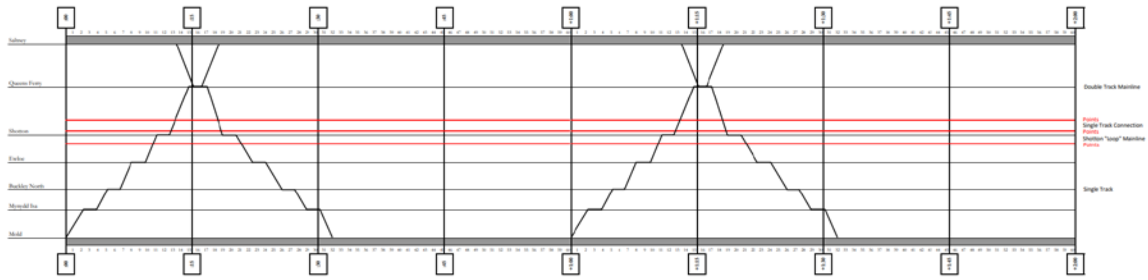

Figure 11 - Timetable for route past Saltney station. The Red lines represent the location of the points for switching to the mainline tracks. A blown up version is provided in the annex.

The outwards and return journeys for the trains were created using the data from Table 6. The timetable was designed in "clock face" style meaning that trains travel at the same point every hour. The journeys were then moved such that the clearance time between the last set of points relative to Mold, is 5 minutes, in line with regulation. This leads to the trains arriving at Mold at 32 minutes past the hour leaving on the hour, giving well above the 10 minute turnaround time.

In order to calculate the Capacity Utilisation Index, CUI, a compressed timetable was produced to determine the minimum return time. This ignores the timetable beyond the first set of points relative to Mold, as it assumed trains can wait at stations, then the most compressed possible timetable was produced. For the compressed timetable, a junction clearing time of 5 minutes was taken, and a turnaround time of 10 minutes. The platform has been assumed to reoccupy in this turnaround time.

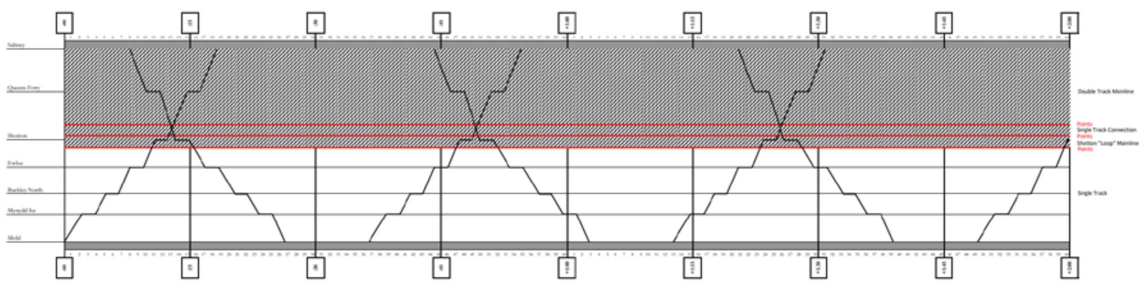

Figure 12- Compressed timetable, all information beyond the first set of points, in the hatched region, is ignored. A blown up version is provided in the annex.

Form Figure 12 the compressed timetable has a return time of 36 minutes equivalent to 1.67 trains per hour. The CUI is the inverse of this as the regular timetable runs on an hourly basis, giving a utilisation factor of 60%. This is well below the recommended 70% over a daily period for commuter lines.

The standard timetable has trains arriving at 32 minutes past the hour and leaving on the hour. This gives a spread out timetable, ensuring that waits to board the train at the terminus are short. Although under the current assumptions, two trains could not be run per hour, if the turnaround time of 10 minutes was substantially shortened, this would be possible.

8.0 - Wider Transport Infrastructure

Currently Mold is small town with only bus links. It is likely that a new rail link would lead to development within the town.

The proposed route could allow for direct trains to both Liverpool, running through the Mersey tunnel (the proposed stock using a hybrid system would be able to run through the underground section of Merseyrail by turning off their engines and running on battery power) and to Manchester via Chester. By allowing for a direct trip to Manchester (apprx 1 hour journey) and Liverpool (apprx 30 min journey), Mold is brought within reasonable commuter distances of these two major cities.

If a similar line was proposed in London considering the terminus for a transit orientated development, TOD, would be unquestionable due to the extreme pressure on housing in the capital. However Liverpool and to an extent, Manchester do not quite suffer from the same pressures. At the very least in the near future towns closer to these cities wold see development long before Mold does. This suggests TOD is not a suitable approach for Mold presently. In addition TOD, combining rapid development of commercial and housing properties with the construction of a new transit link, would be expected to receive substantial opposition in Mold which is presently a small town within greenbelt land.

8.1 - Terminus Interchange

The terminus is to be situated approximately 800m to the northwest of the town centre. Although this is much further than ideal, especially for people with restricted mobility, the primary reason was to avoid constructing the route over existing buildings. In addition the route was situated to allow for easy extension of the route further up the valley in the future if desired, specifically to Denbigh which is far from current rail.

The line is very similar in operation and length to the line from Oxenholme to Windermere (Network Rail, 2016), which allows for commuting from the Lake District outwards and tourists inwards. The proposed line and terminus is expected to operate in a similar way.

The proposed station is well situated to become a terminus for the numerous local bus routes (Flintshire County Council, 2018), especially for routes extending into north Wales towards Denbigh and Ruthin. This allows interchange onto the rail network for extended transport onwards to regional cities and airports. This makes a large region of the north wales countryside accessible to tourists.

The new terminus is expected to be a significant interchange for tourist cycling for north wales. Cycling small distances, especially in urban areas can significantly reduce the desirability of cycling as a form of leisure. The new terminus unlike the existing station at Buckley (Buckley South), would drop tourists straight into the north wales countryside. A new cycle route could easily be built on the dismantled line running northwest from Mold, further enhancing cycle tourism. As a consequence of this desire to enhance cycle tourism the units were specified with four bicycle racks each.

The stations between Mold and Saltney are expected to primarily serve commuters and local residents who are expected to know their own journeys and turn up for the timetabled trains, rather than waiting. This means that these stations are not likely to require any facilities beyond automatic ticketing machines and shelters from the rain with a small number of seats. Hence these can be unstaffed.

In contrast the Terminus at Mold is expected to see a large proportion of tourists, who are unfamiliar with the area and routes. It is likely that these travellers will turn up to stations not in line with when trains arrive, requiring further facilities such as an accessible toilet and waiting area. As the station is likely to incorporate a bus station, staff would be present to assist passengers, especially unfamiliar tourists. Having staff present requires extra facilities at the station such as staff rooms and extra toilets.

The terminus could feasibly host a tourist office under a partnership between the rail operator and the local authorities. In addition accommodation for a privately run café should be given.

Automatic ticket barriers will not be included on the route as these require staff at every station to deal with faults in the equipment. In contrast running a scheme with conductors on board trains checking tickets reduces the number of staff over ticket barriers as there are lots of stations, but few trains. Although this is likely to lead to increased fare evasion, the low usage of the trains should enable conductors to check tickets regularly minimising the impact.

9.0 - Operational Safety

The combination of high speeds and large heavy units can make railways exceptionally dangerous unless risk is properly managed. Conflict points with roads, paths and other railway lines can lead to very serious head on collisions with other vehicles including trains. Ensuring this doesn't happen is of paramount importance and has led to the development of sophisticated signalling systems and even more recently complete automation that uses hard coded logical software to prevent conflicts (Transport For London, 2018).

9.1 - Review of Ladbrooke Grove Crash (1999)

On the 5th of October at 08:06 a Class 165 Turbo left Paddington station traveling northwards. At 08:08 the Turbo passed signal SN109, which at the time was set to red, known as a SPAD - signal passed at danger. This led it into conflict with a Class 125 HST coming down the line into Paddington station. Signal controllers manually switched signal SN120 to danger in attempt to warn the incoming HST of the conflicted route, however as the HST at the time was traveling at 130kph, the train did not have time to stop. 10 seconds later at 08:09 the HST collided head on with the Turbo. The collision resulted in 31 deaths and over 400 injuries, from both the crash and the ensuing fires compounded by spilt diesel, which burnt out several coaches. This is a summary of the work done by Lawton and Ward (2005).

The crash, as with most engineering failures was caused by a cascade of problems that compounded to defeat the in place safety mechanisms. Lawton and Ward (2005) propose that although ultimately caused by the driver of the Turbo passing signal SN109 at danger, there were numerous factors as to why this occurred. In addition they show that the signallers even after the SPAD had time to prevent a collision by either diverting the Turbo or sending a timelier emergency stop message. These factors are listed below.

Reasons the driver did notice a red signal

- The signal was part of a large gantry of signals obscured by a bridge, this means that it was difficult to work out exactly what signal was yours.
- Sunlight glare further obscured the signal.
- The network around Paddington was recently changed to optimise traffic flow, but created an unnecessarily complex system leading to drivers becoming lost and an over reliance on signallers.
- The driver was a relative novice and had previously passed this stretch with all yellows, it is feasible that the he did not check the signal and had assumed it was yellow.
- Having expected a yellow could have led to confirmation bias preventing him from noticing the red.
- Potentially being temporarily distracted focussing on the route ahead.

Reasons for passing through the AWS check. AWS audibly warns a driver of a signal being red or yellow on the route in the cab, and requires that the driver acknowledge this or else brakes are automatically applied.

- The AWS system did not differentiate between a red or yellow signal.
- Had the driver assumed the signal was yellow then he would not have been informed that it was in fact red, and hence proceeded to "acknowledge" and pass anyway.
- The AWS gives only 3 seconds for the confirmation to be given, this can lead to rushed confirmation and double checking not being done.

Training and management errors.

- Instructors teaching drivers were unclear of their precise role, leading to inadequate route training, despite the Turbo drive reputably being an excellent student.
- The signal had had numerous SPAD incidents which drivers were not told about.
- Despite the signal having numerous SPAD incidents, nothing was done to solve this.

An inquiry into the crash was performed which took a systems analysis approach and demanded sweeping safety improvements at all levels within the rail network and operators, including infrastructure and management. Specifically significant work was done to locate and remedy signals with multiple SPAD incidents.

9.2 - Operational Saftey on Proposed Route

The proposed route has a relatively complex network structure, especially in the Shotton North Level - South Level link, which comprises a section of short gauntlet track, leading to numerous conflicts. In addition two level crossings exist (RLXs), which create even more risk (G. Ćirović, 2013).

The segment of gauntlet track is designed such that it can hold trains on the loop itself although in practice this would be rarely used, it allows trains to wait without conflicting either of the mainline sections.

Complete track side signalling is to be provided to prevent conflicts assuming driver compliance along with full in cab signalling installed in the new units. In order to mitigate SPADs the more modern European Train Control System, ETCS, is to be fully implemented (RSSB, 2010). ETCS automatically stops the train if a SPAD has occurred, or slows the train if it is going too fast.

The best form of safety is to remove hazards, hence almost all road crossings and pedestrian crossings have been designed at grade. Only two RLXs exist over the proposed new route. The first is situated adjacent to Mynydd Isa station, here it is impractical to build at grade as the preceding track has to cross over another road as a bridge. The RLX is relatively safe as the trains passing through slow substantially to stop at the station, reducing risk. To mitigate against trains running through the station, mandatory speed limits would be imposed here. The second RLX is midway between Buckley North and Ewloe, hence trains will be running fast here. This is a safety concern, however the road only serves a small number of houses, hence is unlikely to see much traffic. Both level crossings would be fitted with fully active systems including the standard three light warning and full width automated barriers, to improve safety by reducing accidental noncompliance.

At a passenger level, the usage of conductors on all trains will greatly increase safety levels, by helping with security and preventing accidents involving passengers becoming trapped in doors. In addition conductors will be first aid trained in the event of a passenger becoming unwell or a general emergency.

Because the line is not electrified, the danger from stepping on rails is not present.

In order to reduce trespassing, the line shall be entirely fenced off. CCTV will be installed at all stations and monitored at a centralised facility so that drivers can be warned in advance of trespassing, especially given that most of the stations will be unstaffed.

10.0 - Finance and Organisation

Very few new non-urban lines have been built in the UK recently which sets less precedent for the proposed line. Examples include the Scottish borders line and the Airdrie-Bathgate rail link, with respective costs per km of £5.2 million (BBC, 2015) and £12.5 million (BBC, 2010). Both lines were built on the old pre Beeching cut routes reusing and refurbishing much of the original infrastructure. The rail link is somewhat more expensive per km as this is dual track and electrified. In reality the proposed route would be more similar to the borders line, despite being on a new route hence more expensive. An estimated £7.5 million per km has been assumed leading to a total line cost of about £80 million over the 10.6km of new track.

In the past few decades private finance initiatives, PFIs have commonly been used to raise private capital for government schemes, however recently there has been a move away from using private capital for public projects (Independent Newspaper, 2017). Hence it is likely that the new route itself would be built under network rail using government funds.

Once constructed the line would be incorporated into the current franchise of 'Wales and Borders'. The current operator would then pay a portion of revenues back into network rail to pay for the line. Although routes and units have been specified here, in reality this is normally left up to the franchise operator to decide. The organisational structure is to be determined by the TOC, but is likely to be flat as is current business practice.

This method of financing and operation is proposed as it is in line with the current UK system, although in my opinion it is not a particularly good way. Part of the problem of franchising out whole regions of network is that passengers often have no choice as to which network operator to use. For instance someone traveling from Southampton to London Waterloo has to use South Western at some point in their journey. Although operators compete slightly with road transport, the situation leads to inelastic passenger demand. These features combine to give little incentive for operators to improve the passenger experience or to reduce ticket prices.

This is particularly compounded by commuters who have no option aside from rail. For example house prices and rent are too expensive in central London for many people to live, this forces people to commute to work in London. Additionally road transport is not an option as congestion and lack of parking makes this a prohibitively difficult option, forcing the use of rail. This leads a large number of people with no other option aside from rail. Evidence for this is that during the disputes with Southern Rail, many people simply could not get to work at all (The Guardian Newspaper, 2017). This has left peak time prices to London becoming incredibly inflated, for example a peak ticket from Southampton Central to London Waterloo costs £42.60 compared to Bath Spa, a non-commuter line which is further, costs £8.00 (National Rail, 2018).

In my opinion better options are to either renationalise which removes competition completely, force the state to bid on every franchise to provide a baseline of quality or to use an open access franchising system which makes TOCs compete directly against each other for passengers. The latter two introduce better competition, incentivising TOCs directly to improve passenger experience and reduce ticket prices.

11.0 - Conclusions

Although the line is entirely feasible, using innovative stock and reducing construction costs to a minimum by using single track not electrified, the project in reality would never be built. At an estimated construction cost of £100 million, not including stock, the line is a very expensive investment for little benefit and low ridership. The most similar project to this is that of the Scottish Borders line which ultimately had a 0.5:1 expected economic return from the £300million cost (Transport Scotland, 2012). This was later revised to 1.3:1 after other factors were considered (Transport Scotland, 2012). As the proposed route is on a new route, hence costing more than the borders railway, and serves less people, the economic return is expected to be even lower than the borders railway.

Much better options are to use regular bus services, although these are generally less popular, slower and normally don't carry bicycles, over the 10km of route they offer a much more cost effective solution. Busses do not require remotely the same capital investment as rail in addition to being much more flexible in routing.

As regular bus services currently run from Mold to key local locations, including many nearby railway stations, the present situation is adequate. Leading to the conclusion that nothing needs to be done to change the present situation, least of all building a new railway.

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13.0 - Annex List

The following lists the order of figures in the annex.

- Brief Document
- Figure 0 - Full scale route map
- Figure 5 - Carriage Layout
- Figure 10 - Network Diagram
- Figure 11 - Timetable
- Figure 12 - CUI Timetable

CENV3065 Coursework Data Sheet

Route ID number: 54

New station	Mold
County	Flintshire
Link to existing network	Saltney
Train service pattern	Mold-Crewe
Base year demand forecast	110638
Base year population	10058
Base year service interval (mins)	60 minutes
Base year mean fare (£)	£11.00
Base year journey time	44 minutes
Line speed (km/h)	160
2030 population	11566
2030 service interval	30 minutes
2030 mean fare (£)	£12.10

RailwayRoute

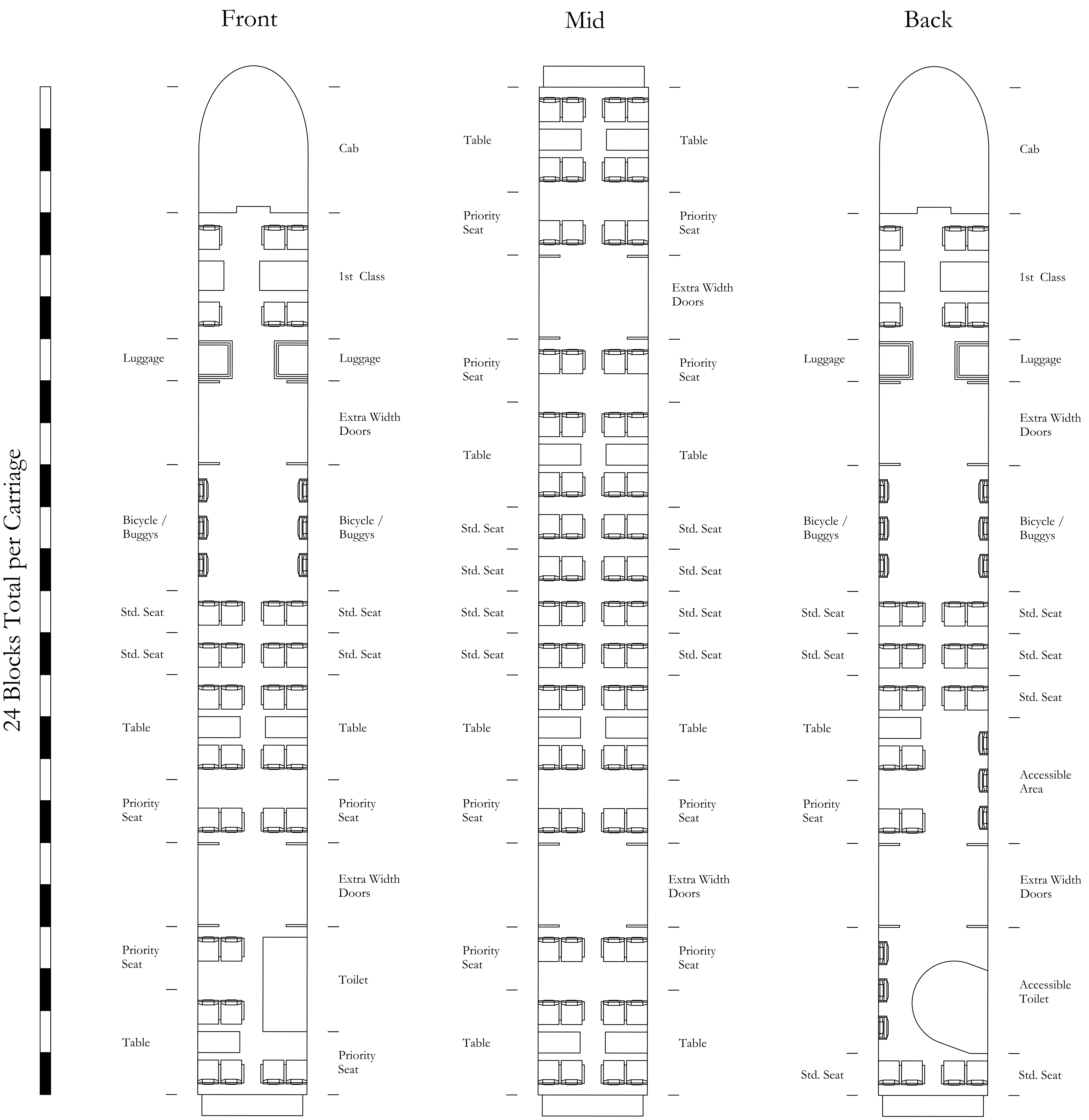
Digimap®
Ordnance Survey

Scale 1:20000

0 0.2 0.4 0.6 0.8 1 1.2 1.4 1.6 1.8 2 km

Projection: British National Grid

May 12, 2018 15:58
Michael Cooper
University of Southampton


24 Blocks Total per Carriage
Front
Mid
Back
Cab
1st Class
Luggage
Luggage
Extra Width Doors
Bicycle / Buggys
Bicycle / Buggys
Std. Seat
Std. Seat
Table
Priority Seat
Toilet
Table
Priority Seat
Table
Priority Seat
Extra Width Doors
Std. Seat
Accessible Area
Accessible Toilet
Std. Seat

Mold - Terminus
Mynydd Isa
Buckley North
Ewloe
Shotton High Level
(Existing)
Shotton Low Level
(Mainline - Not Timetabled
into new route)
Queens Ferry
Saltney
Junction A
Junction B
Gauntlet Rail
Level Crossing
Tunnel
Level Crossing
To Wrexham
To Bangor
To Liverpool
To Chester
From Shotton Low Level to Saltney, new signaling is to
be determined in accordance with mainline standard.


Saltney
Queens Ferry
Shotton
Ewloe
Buckley North
Mynydd Isa
Mold
:00
:15
:30
:45
+1:00
+1:15
+1:30
+1:45
+2:00
Double Track Mainline
Points
Single Track Connection
Points
Shotton "Loop" Mainline
Points
Single Track


:00
:15
:30
:45
+1:00
+1:15
+1:30
+1:45
+2:00
Saltney
Queens Ferry
Shotton
Ewloe
Buckley North
Mynydd Isa
Mold
Double Track Mainline
Points
Single Track Connection
Points
Shotton "Loop" Mainline
Points
Single Track