1 Task 1

1.1 a)

1. Location of the new station

The new SHEPSHED station is located in eastern suburbs of the town, an area with sparse residential development, which circumvents the high demolition costs typically associated with urban station constructions. Crucially, its position ensures that the vast majority of the town is accessible within a 2000-metre radius, making it an optimal site for the station.

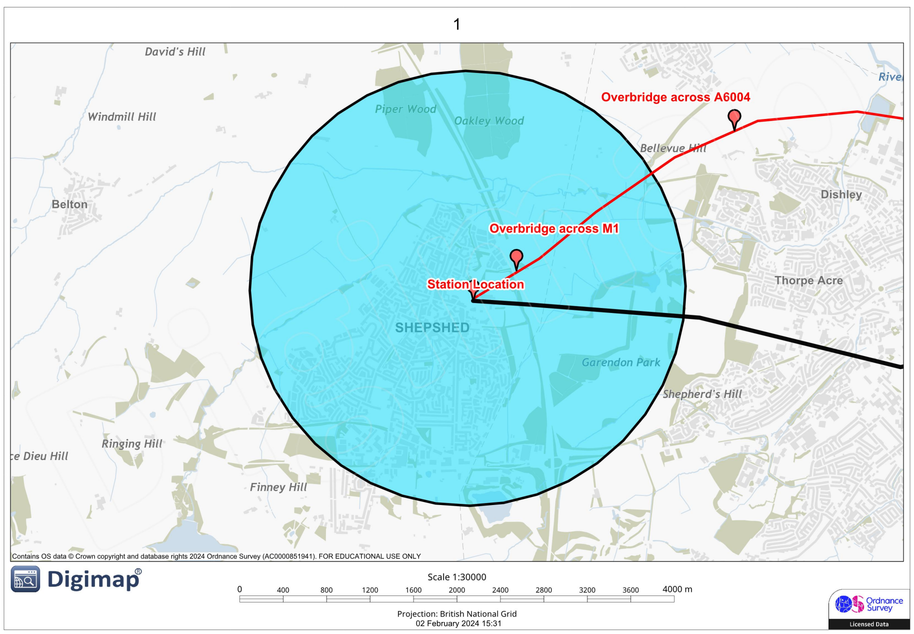


FIGURE 1. Location of the new station

2. Route direction

The proposed route outlined in red in Fig 2, bypassed Loughborough to the north. The detour, while lengthening the journey and navigating challenging elevations in the northwest, significantly increases construction costs with respect to excavation and filling works. However, this route minimizes disruptions to the urban road network, meeting key stakeholder expectations. Importantly, it enhances operational efficiency by eliminating the need for speed reductions at Loughborough Central Station, a critical advantage for maintaining optimal transit times. This alignment represents a deliberate trade-off, prioritizing operational and community benefits over the increased direct costs and construction complexities.

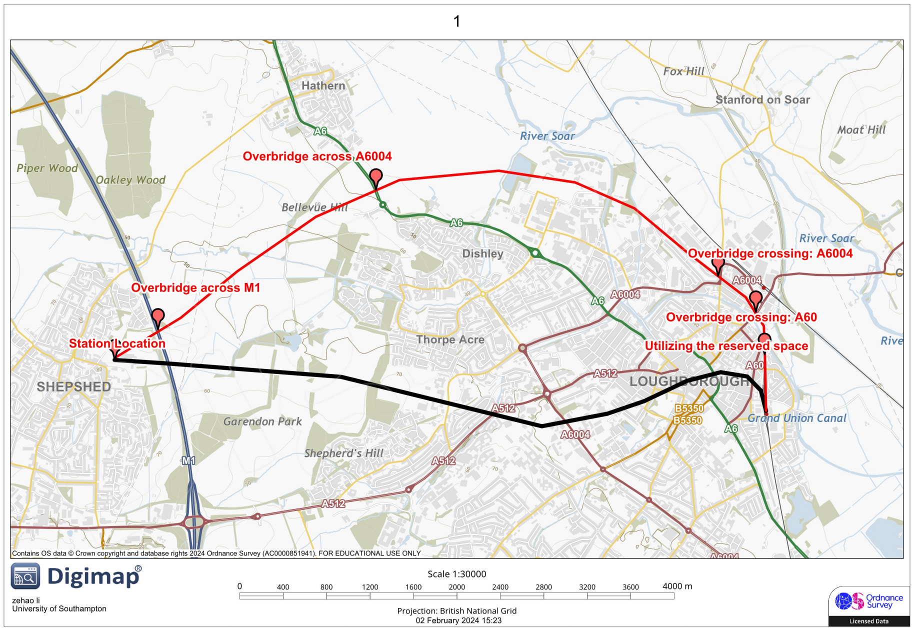


FIGURE 2. the outline of the new route

3. key control points

The design incorporates two types of control points to seamlessly integrate with existing infrastructure:

At Road Intersections: To maintain traffic flow on major roads, the design replaces level crossings at intersections with bridges over the M1, A6004(west and east sides), and A60. This choice, although increasing construction costs, is justified by the bridges' minimal disruption to existing traffic patterns. By prioritizing bridges, the design significantly mitigates interference with the traffic infrastructure, demonstrating a balanced approach to cost and community impact.

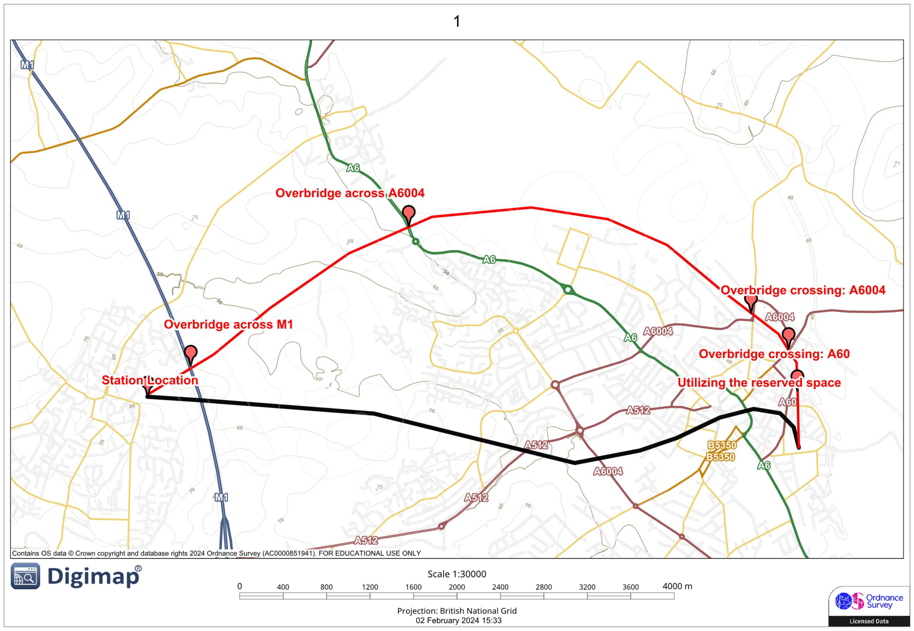


FIGURE 3. Key Control Points at Road Intersections

Near the Rail Connection: Strategically, the design leverages the reserved rail line on the north side of Loughborough Central Station, which is possibly prepared for future connection with the northern Loughborough Station. This integration significantly reduces costs by utilizing the reserved space and improves operational efficiency through a smoother line shape.

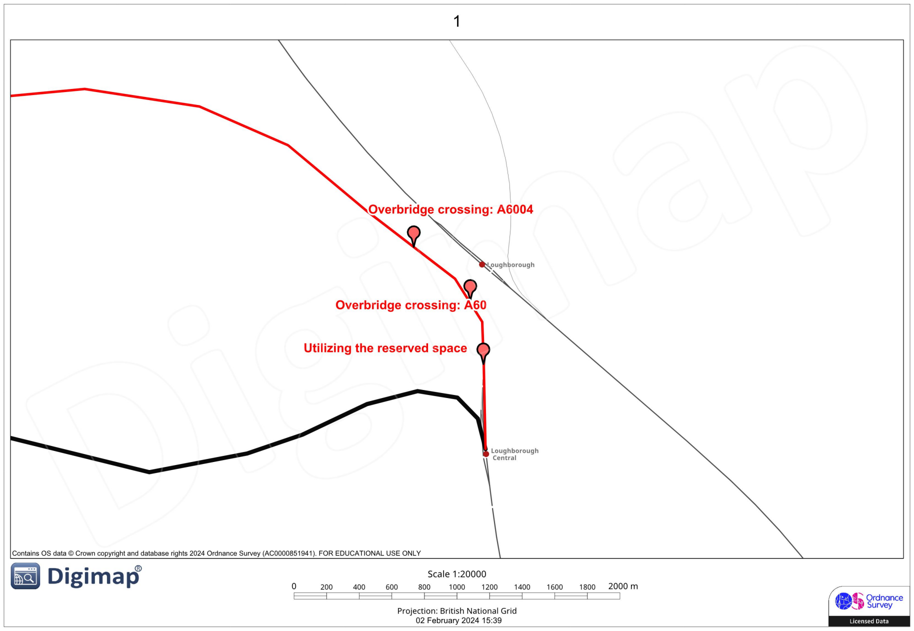


FIGURE 4. Key Control Points near the Rail Connection

1.2 b)

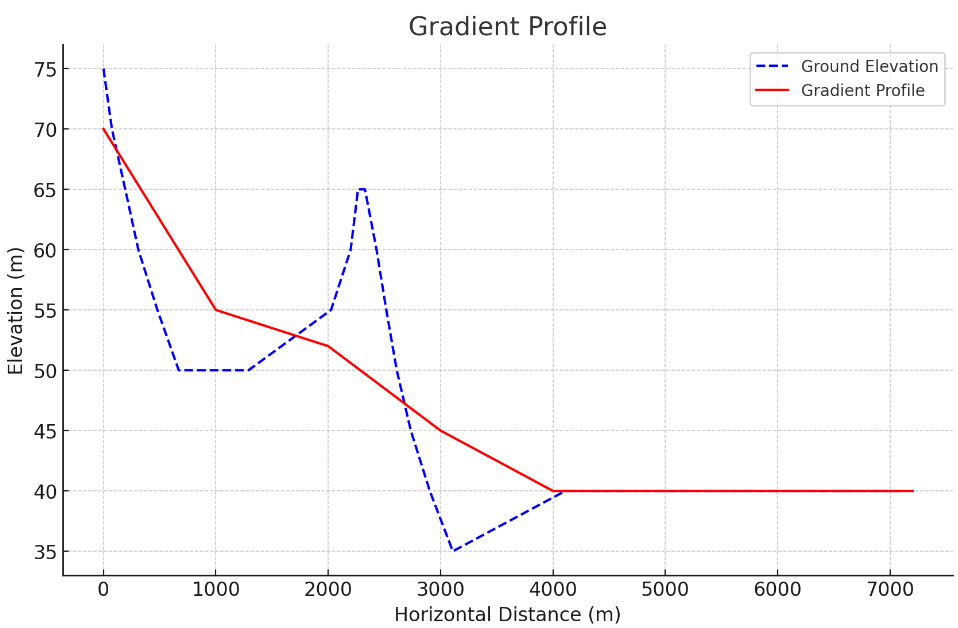


FIGURE 5. The Gradient Profile

Based on the obtained contour data, a gradient profile shown in Fig X is recommended, adhering to a maximum ratio of 1:50(for sections up to 3km). The profile reveals significant gradient changes, necessitating extensive earthwork. Such work increases costs and adversely affects the environment.

To mitigate these impacts, it is suggested to construct a tunnel approximately 800 metres long at the most challenging mountain segment, located between 2000 and 2500 meters along the route.

1.3 c)

By using the online tool Station Demand Forecasting Tool, it is predicted that the number of passengers using the new station in its year of opening year is 905215. The follow figures show the station location and the road access point.

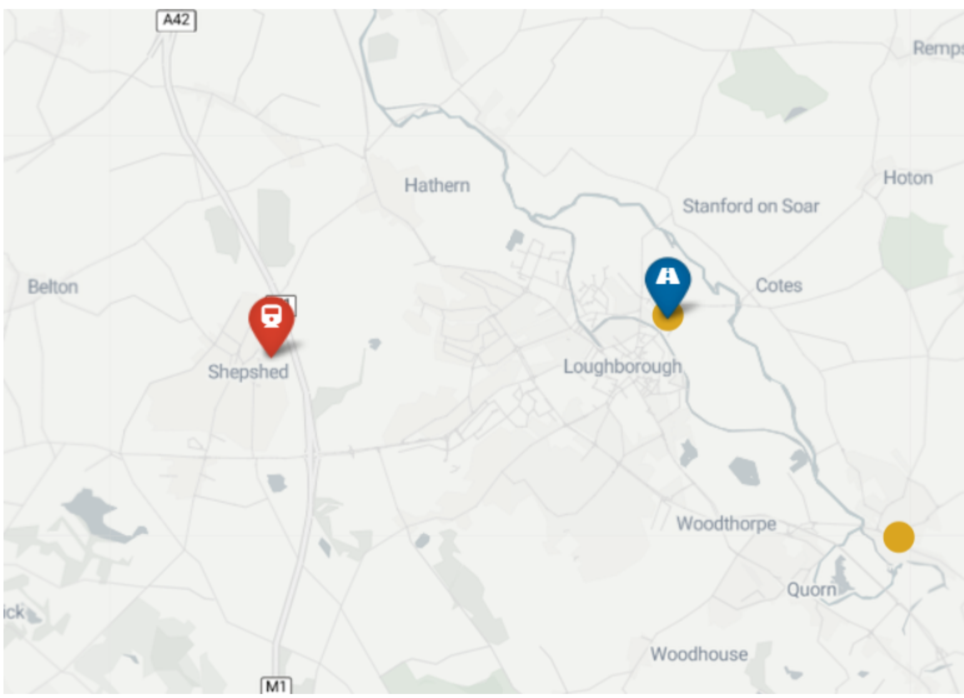


FIGURE 6. the Station Location(in Red) and Road Access Point(in Blue)

The input values are shown in Table 1 and it should be noted that the Frequency is calculated using the following formula:

$$\text{Frequency} = 2 \times \left(\frac{\text{total\_run\_time\_minutes}}{\text{interval\_minutes}} + 1 \right)$$

$$= 2 \times \left(\frac{18 \times 60}{40} + 1 \right)$$
$$= 56$$

TABLE 1. The Input Values

Field	**Value**
id	3812
name	SHEPSHED
region	East Midlands
station_easting	448381
station_northing	319786
access_easting	454346
access_northing	319361
frequency	56
frequency_group	NA
parking_spaces	100
ticket_machine	TRUE
bus_interchange	TRUE
cctv	TRUE
terminal_station	TRUE
travelcard_boundary	FALSE
category	E

1.4 d)

For commuters:

$$\text{Commuter Ratio} = \left(\frac{8.7}{8.25}\right)^{-0.6} \times \left(\frac{26+23}{26+27}\right)^{-0.6}$$
$$\text{Commuters in base year} = 0.40 \times 905215$$
$$\text{Commuters in 2035} = \text{Commuters in base year} \times \text{Commuter Ratio} = 367638$$

For business:

$$\text{Business Ratio} = \left(\frac{8.7}{8.25}\right)^{-0.7} \times \left(\frac{26+23}{26+27}\right)^{-0.6}$$

Business Travelers in base year = 0.15×905215

$$\text{Business Travelers in 2035} = \text{Business Travelers in base year} \times \text{Business Ratio} = 137134$$

For leisure:

$$\text{Leisure Ratio} = \left(\frac{8.7}{8.25}\right)^{-1.3} \times \left(\frac{26+23}{26+27}\right)^{-0.6}$$

Leisure Travelers in base year = 0.45×905215

$$\text{Leisure Travelers in 2035} = \text{Leisure Travelers in base year} \times \text{Leisure Ratio} = 398499$$

Therefore, the number of travelers in 2035 is 903271.

2 Task 2

2.1 a)

Based on Task 1, the frequency of trains passing through this route has been calculated. If we consider only one direction (for example, from Shepshed to Loughborough), there are 28 train services per day. Therefore, we can calculate the annual number of vehicle passes from Shepshed to Loughborough as follows:

$$the\ annual\ number\ of\ vehicles\ passes = 3 \times 365 \times 28 = 30660$$

According to the results found on the official website[1], there are 41 train services from Southampton Airport Parkway to London Waterloo per day, resulting in an annual number of vehicle passes of 44,895. Comparing this with the new route design, we can observe two main differences in the train service from Southampton to London.

[1]https://ojp.nationalrail.co.uk/service/pockettimetable

First, the frequency of trains increases during peak hours in the morning and evening. Second, at certain times within these peak periods, the service operates two trains simultaneously—one fast and one slow. This design is flexible, tailoring the frequency and intervals of departures to meet varying travel demands at different times. It's an approach worth learning from and applying elsewhere.

National Rail Enquiries

Your personal journey from Southampton Airport Parkway to London Waterloo
Valid from Wednesday 14 February 2024 to Monday 19 February 2024

Monday to Friday always runs
Outward

		SW	SW	SW	SW	SW	SW	SW	SW	SW	SW	SW	SW
Southampton Airport Parkway	dep.	12:08	12:38	13:08	13:38	14:10	14:38	15:08	15:38	16:08	16:38	17:08	17:38
London Waterloo	arr.	13:21	13:49	14:21	14:49	15:20	15:49	16:21	16:49	17:24	17:51	18:20	18:49
Duration		1:13	1:11	1:13	1:11	1:10	1:11	1:13	1:11	1:16	1:13	1:12	1:11
Changes		0	0	0	0	0	0	0	0	0	0	0	0
Seating Class		1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st
Catering													

		SW	SW	SW	SW	SW	SW	SW	SW	SW	SW	SW
				1	**2** OT		**3**	**4** OT	**5**	**6** OT	**7** OT	
Southampton Airport Parkway	dep.	18:08	18:38	19:08	19:08	19:38	20:08	20:08	20:38	20:38	20:38	21:07
London Waterloo	arr.	19:20	19:51	20:20	20:24	20:49	21:29	21:30	21:49	21:51	21:52	22:22
Duration		1:12	1:13	1:12	1:16	1:11	1:21	1:22	1:11	1:13	1:14	1:15
Changes		0	0	0	0	0	0	0	0	0	0	0
Seating Class		1st	1st	1st	1st	1st	1st	1st	1st	1st	1st	1st
Catering												

Monday to Friday always runs
Outward Continued

		SW	SW
Southampton Airport Parkway	dep.	21:38	22:08
London Waterloo	arr.	22:44	23:31
Duration		1:06	1:23
Changes		0	0
Seating Class		1st	1st
Catering			

FIGURE 7. The timetable of the journey from Southampton Airport Parkway to London Waterloo

source: https://ojp.nationalrail.co.uk/service/pockettimetable

2.1.1. b)

According to the paper of Li and Selig (1998), there are two types of soil failure the methodology is designed to prevent, Subgrade Progressive Sheer Failure and Excessive Subgrade Plastic Deformation, which can be represented by the following figure.

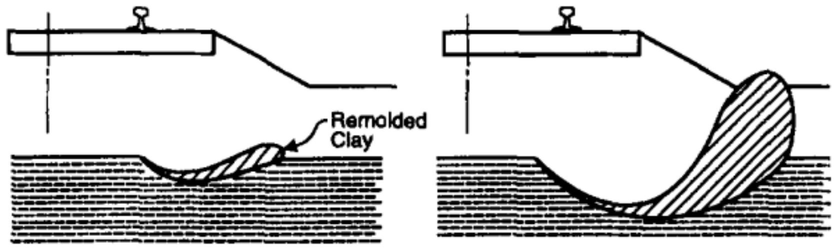


FIG. 2. Subgrade Progressive Shear Failure

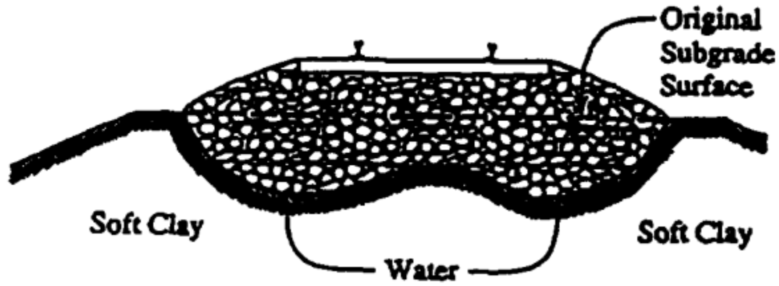
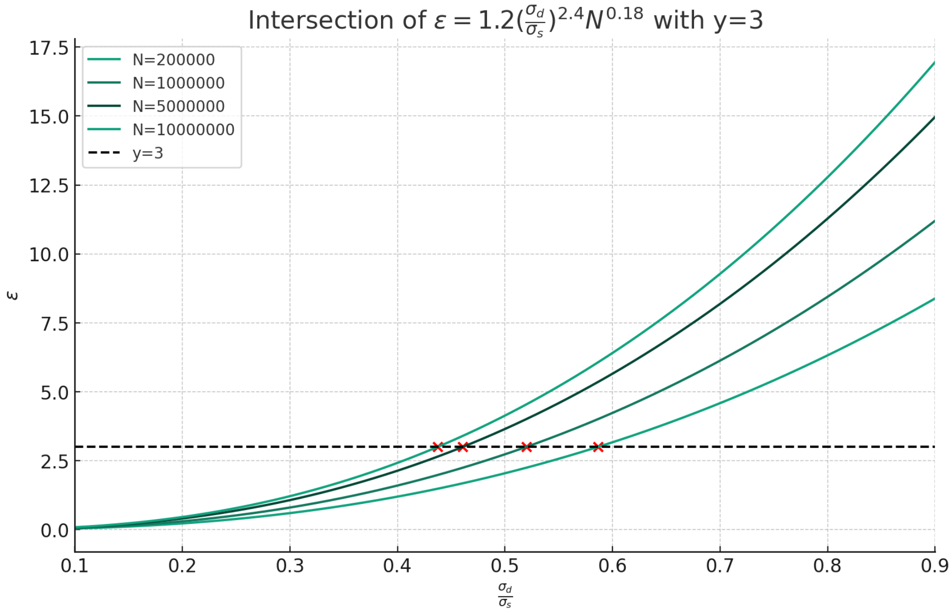


FIG. 3. Excessive Subgrade Plastic Deformation (Ballast Pocket)

FIGURE 8. Two kinds of soil failure
source: Li and Selig (1998)

Since we're using the fat clay(CH), the parameters are as follows: a=1.2, b=0.18, and m=2.4. The formula given is:

$$\epsilon = 1.2(\frac{\sigma_d}{\sigma_s})^{2.4} * N^{0.18}$$



$$\frac{\sigma_d}{\sigma_s} \approx 0.586, 0.520, 0.461, 0.437,$$

$$\because \sigma_s = 65 \text{ kPa}(\textit{this val ue is given in the data sheet}),$$

$$\therefore \sigma_d \approx 38.09, 33.8, 29.965, 28.405 \text{ kPa},$$

$$DAF = 1 + 0.052 \times \frac{150}{3.6}/1 = 3.1667,$$

$$P_d = DAF \times 100 = 316.67 \text{ kN},$$

$$\therefore I = 0.645 \times \frac{\sigma_d}{P_d}.$$

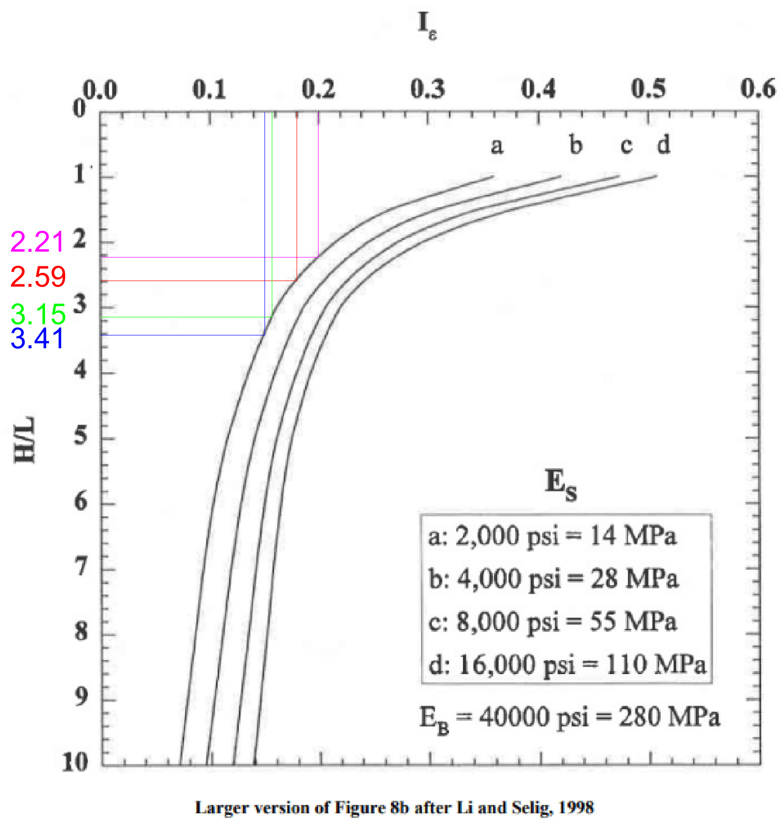


FIGURE 9. Larger version of Figure 8b after Li and Selig (1998)

The final thickness is derived from the figure and is shown in the table:

vehicle passes			I	H/L	H	Time(year)
200000	0.586	38.09	0.201928625	2.21	0.33592	6.523157208
1000000	0.52	33.8	0.17918581	2.59	**0.39368**	32.61578604
5000000	0.461	29.965	0.158855113	3.15	0.4788	163.0789302
10000000	0.437	28.405	0.150584998	3.41	0.51832	326.1578604

Assuming that ballast is replaced once every 30 years, I would suggest that a ballast thickness of 0.39m be used, a value that strikes a balance between engineering cost and durability.

2.2 c)

The majority of the bedrock geology along the entire route is Mudstone(with subordinate dolomitic siltstone and fine-grained sandstone). The surface layer consists of Till, a mixture made up of clay and large rocks.

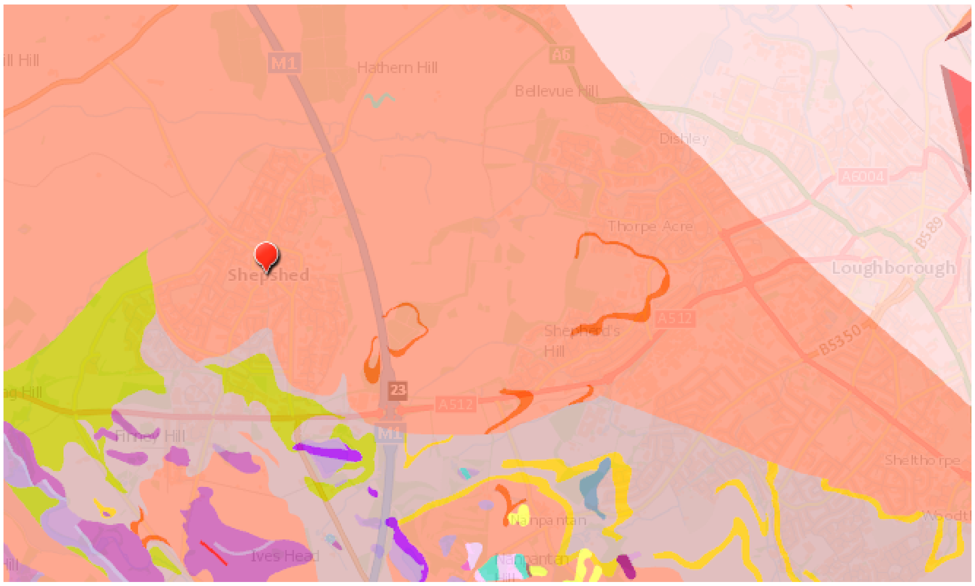


FIGURE 10. Bedrock Geology
source: https://mapapps2.bgs.ac.uk/geoindex/home.html

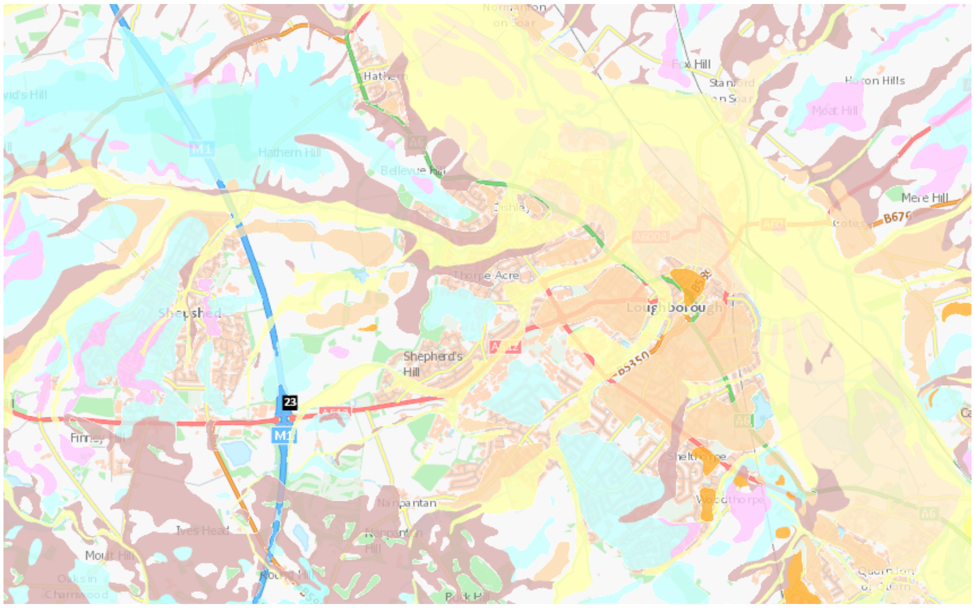


FIGURE 11. Superficial Deposits
source: https://mapapps2.bgs.ac.uk/geoindex/home.html

Due to the presence of clay at the surface, there's a higher likelihood of shear failure and excessive plastic deformation. This can be described using the Li and Selig method(This means that the shear strength Es is relatively small and can be taken as one of 14, 28, 55 or 110 MPa).

2.3 d)

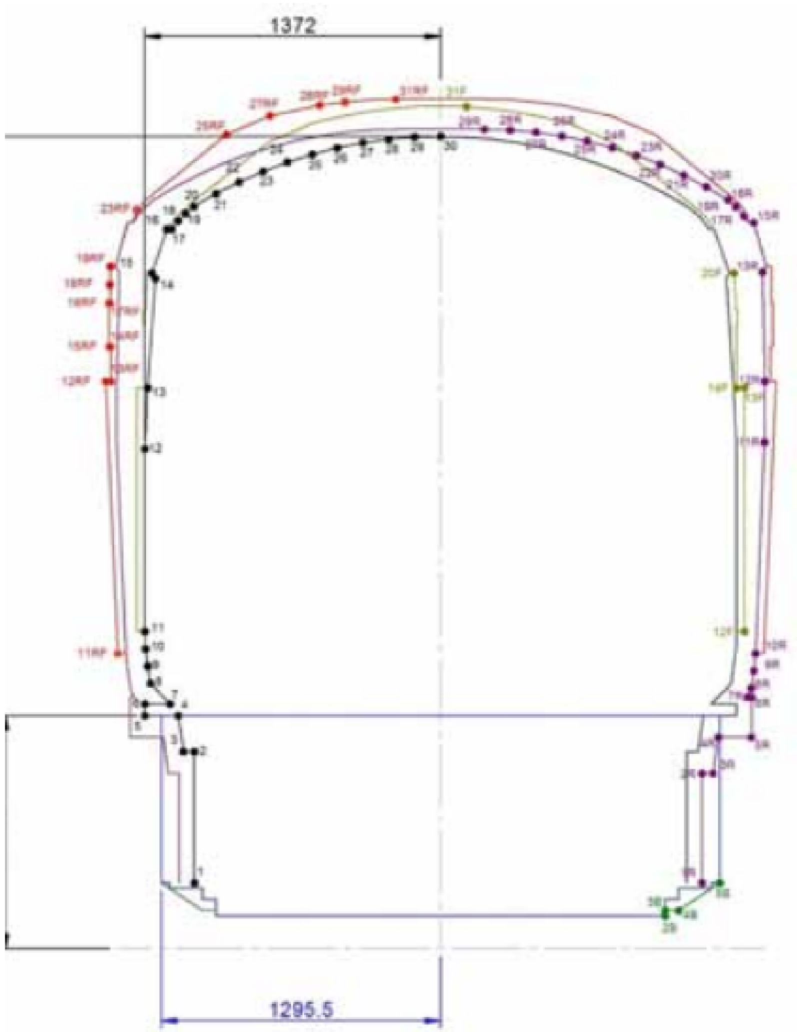
For granular subgrades, such as sands and gravels, or underlying rock, their strength is significantly higher than that of clay, making them less prone to progressive shear failure or excessive deformation due to deviator stress. As a result, the methods discussed in the paper are not suitable for these types of subgrades. When designing for these materials, one should consider the thickness of the granular layer from the perspective of other types of failures, such as slope stability collapse or excessive consolidation settlement caused by the material's self-weight. For instance, by setting a critical value for a specific stress or strain indicator based on the critical conditions under which these problems occur, the designed thickness should ensure that the operational values of these indicators remain below the critical thresholds.

3 Task 3

3.1 a)

This new line is a short addition, about 7 kilometers (roughly 4.3 miles) in length, dedicated to passenger transport. Consequently, we've chosen the C1 type passenger vehicle standard gauge as outlined in "The V/S SIC Guide to British Gauging Practice."[2] The C1 gauge is designed specifically for standard-length passenger vehicles, about 20 meters (approximately 65 feet) long, though versions for shorter vehicles also exist. These vehicles typically feature traditional metal spring suspension systems, with a standard bogie center spacing of 14 meters. Details about the vehicle design and gauge limits are illustrated in the accompanying diagram.

[2] http://www.rssb.co.uk/Library/groups-and-committees/2013-guide-vehicle-structure-sic-guide-to-british-gauging-t926.pdf



C1 Gauge

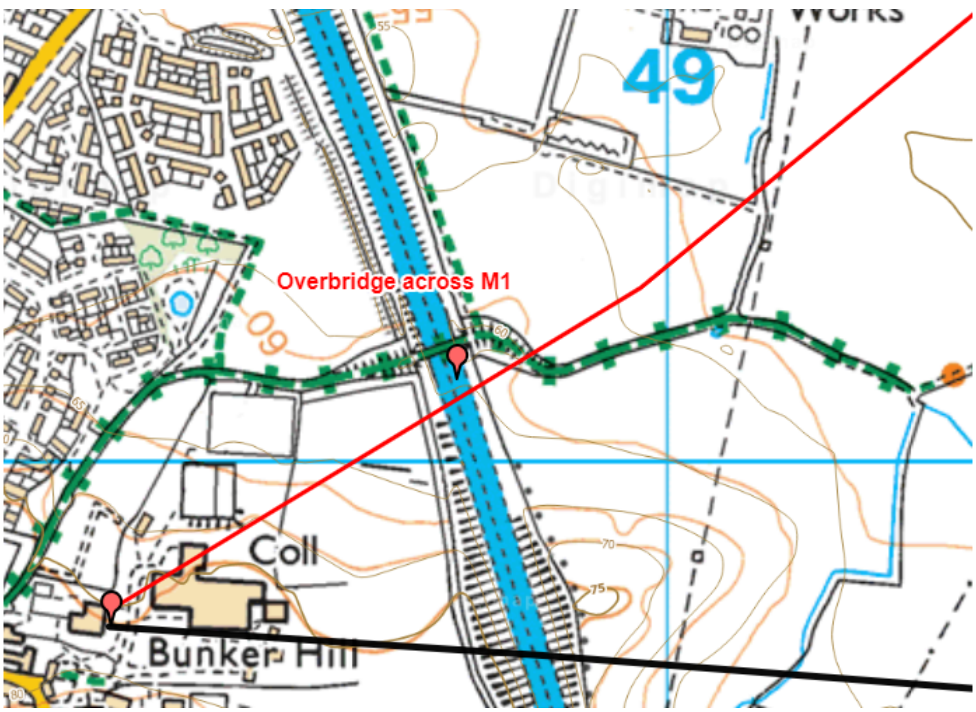
For the tunnel constructed at the 2000-meter mark of the new line, it's crucial to maintain a minimum distance of 100mm between the vehicle's loading gauge and the tunnel, which is the recommended clearance. This ensures that, even under the most adverse conditions, there's no risk of collision, a vital consideration for passenger safety. Maintaining infrastructure is equally critical to prevent deformation that could result in insufficient clearance.

Note that building a vehicle that truly meets C1 and can actually operate is going to be quite a challenge. This is mainly because air suspension allows for much more movement of the vehicle body than traditional steel springs do. Therefore, providing enough infrastructure space to accommodate suspension movement at all positions would be very costly. As a result, a dynamic measurement process was developed to allow the introduction of vehicles with air suspension.

3.2 b)

Based on the data retrieved from the Geoindex, along the predetermined route, there are two types of bedrock present. The first half of the route features mudstone, while the second half consists of both mudstone and siltstone. For the purposes of this analysis, the bedrock condition in the first half of the route is classified under the category of Murcia Mudstone:

$$\phi = 30$$
$$c = 5$$
$$\gamma = 20$$



For determining the elevation and slope, according to the route map, it's noted that at the 500-meter mark, there is a need to cross the M1 motorway. This will require an embankment(silt, clay) project. It can be assumed:

$$\beta = 15 \ degrees, H = 6m$$

$$\frac{c'}{\gamma H} = \frac{5}{20 \times 6} = 0.042$$

the nearest table in the appendix, from Whitlow, is that for:

$$\begin{aligned}
\frac{c'}{\gamma H} &= 0.050, \\
\phi' &= 20^\circ, \\
\cot\beta &= 3.73...4:1, \\
m &= 2.33, \quad n = 1.98, \\
r_u &= 0.4, \\
\therefore F &= m - n \times r_u = 2.33 - 0.4 \times 1.98 = 1.538.
\end{aligned}$$

The safety factor is greater than 1.25, indicating that the slope is stable. Calculations show that with a D value of either 1 or 1.25, the safety factor remains above 1.25. Therefore, it can be concluded that for embankment projects using mudstone, employing a slope ratio of 4:1 and a height of 6 meters is practical and feasible in engineering terms.

4 Task 4

4.1 a)

1. Basis of choice:

*Service Interval.*The layout of the track should be mainly considered from the service interval: If the service interval is high, we need to consider whether a single track line can meet such train frequencies. Because a single track line can only operate trains in one direction at a time, if trains in both directions meet, one of the trains will have to wait at the passing loop location. According to the details of this project: the service interval for 2035 is 30min, with a journey time of 26min, and trains operate in both directions. Our calculations show that with a service interval of 30 minutes and a journey time 26 minutes each way:

$$30 - (26 \times 2) < 0$$

This means we must plan for situations where two trains are heading in opposite directions. Thus we have two options: design a double track or a single track with a passing loop.

*Operating time.*Choosing to design a specific departure interval that allows two trains to meet at a predetermined location and installing a passing loop there is an attractive option. Given the total length of the route from Shepshed to Leicester North Station is 20.1 km, which is measured from the Digimap website, if the actual speed is 80% of the designed line speed and assuming no interruptions, the total travel time would be:

$$20.1/(150 \times 0.8) \times 60 = 10.05\ min$$

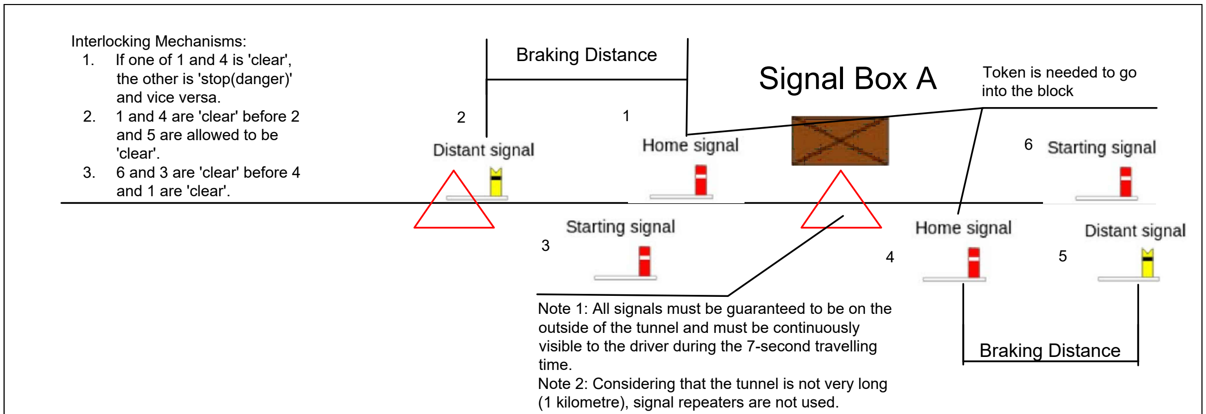
This means that waiting for another train to pass in the passing loop is time feasible.

2. Final decision:

Therefore, waiting for a "pass" once is completely acceptable. Considering the traffic demand here is not very high, and to ensure cost-effectiveness in the engineering project, I believe choosing a single track with a passing loop is a viable option.

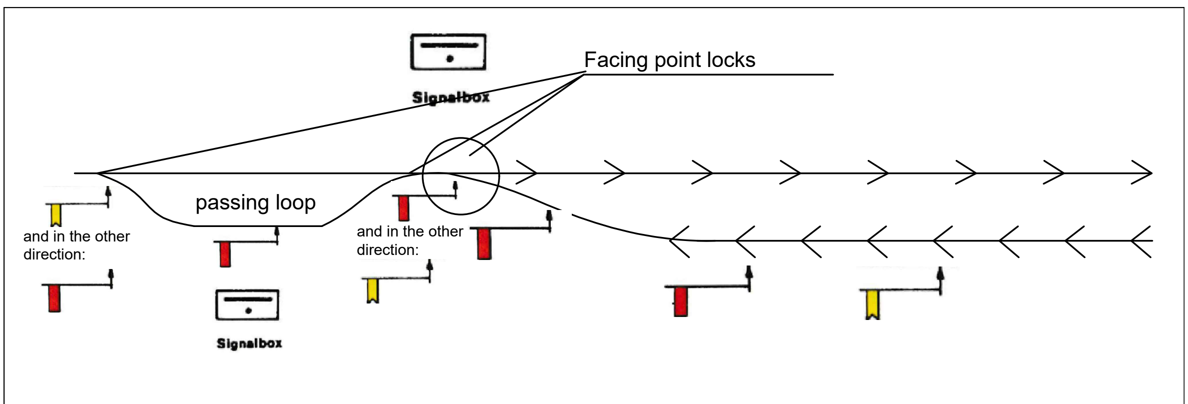
4.2 b)

The figures below show the specific signalling design of the line, focusing on two key control points: the tunnel at 2,400 metres and the connection to the existing line at 7,000. The figures also highlight where the passing loops are set up on the line, how the signalling is designed to operate.



distance	500	2400
control point	overbridge across M1	a tunnel under Bellevue Hill

FIGURE 12. Signalling system design diagram 1



distance	7000
control point	connect with existing line

FIGURE 13. Signalling system design diagram 2

4.3 c)

I believe that the use of interlocking mechanisms is necessary to reduce the risk of accidents occurring, this is because of the undulating terrain and general sight distance conditions on the designed route, as is the case at signal box A in Figure 12. Therefore there is a risk of misjudgement by the signaller, i.e. a signal indication (clear) to release a train to another train on the premise that there is a train on top of a Block. The interlocking mechanism avoids such errors and ensures that the correct signal indication is given to the train operator.

At the same time, it is necessary to use track circuits, which allow the driver to activate the emergency brake if he does not recognise the signal correctly and enters a block with a train. In addition, there should be facing point locks at the passing loop and at the merging point with the existing line to avoid derailment of trains trying to go in both directions at the same time due to incorrect setting of the turnouts.

5 Task 5

5.1 a)

This route recommends choosing electrified railway, so EMU (electric multiple unit) is selected. At the same time, referring to the annual passenger number of 903271, it is estimated that each train has 6 carriages is more suitable, so Class 395 is selected. Therefore, it is assumed that the input data table is determined as follows.

	Class 395
Mass per car	48
Proportion powered axles (by mass)	0.67
Ncars	6
Traction coefficient	0.11
Power	560
Proportion of power usable	0.9

According to the requirements of the task, the situations at both ends need to be analysed. The slope near Shepshed Station is fifteen per thousand, while the slope near Loughborough Station is zero.

Based on the above information, the speed profile can be calculated as shown below.

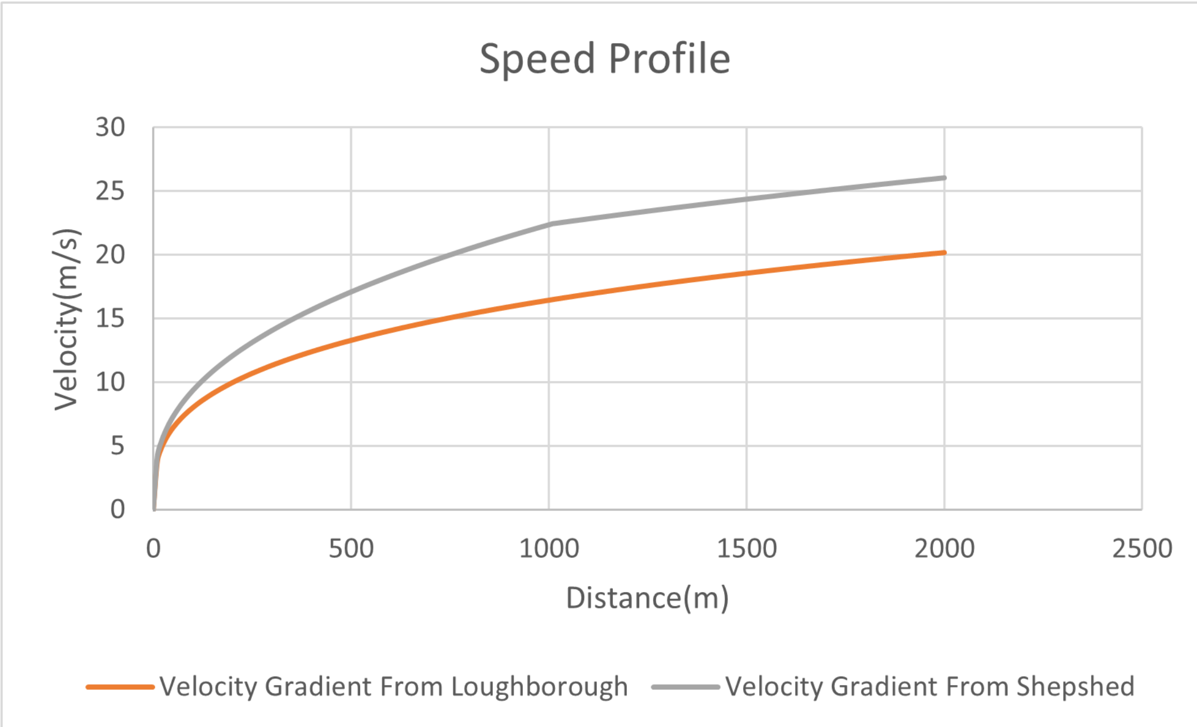


FIGURE 14. Speed Profile

5.2 b

Step 1: Source levels

A_{track} and A_{train} are coefficients for source levels. For this case, since the ballasted track and EMU are used, these parameters can be set as:

$$A_{track} = 0$$

$$A_{train} = +8.0$$

So for the EMUs, when they are running at their high speed, which is the line speed 150km/h, the sound power level can be calculated as:

$$L'_W, i = 12.7 + 8 + 0 + 20\log_{10} 150 = 64.22$$

And for the freight train, the SPL for the locos under power is:

$$L'_W = 94.1 - 10\log_{10} 50 = 77.11$$

The sound power level for modern locos rolling noise is the same as that of freight wagons:

$$L'_W = 12.7 + 8 + 0 + 20\log_{10} 50 = 54.68$$

Step2: Combine source contributions

There are 2 EMUs per hour in each direction(6 cars)

(a) EMU carriages = 24 per hour:

$$L_{W',\mathrm{tot},i} = 64.2 + 10\log_{10}(24) = 78\ \mathrm{dB}$$

Freight: 1 per day in each direction

(b) Locos under power: 2/18 per hour

$$L_{W',\mathrm{tot},i} = 77.1 + 10\log_{10}\left(\frac{2}{18}\right) = 67.5\ \mathrm{dB}$$

(c) Locos rolling noise: 2/18 per hour

$$L_{W',\mathrm{tot},i} = 54.7 + 10\log_{10}\left(\frac{2}{18}\right) = 45.2\ \mathrm{dB}$$

(d) Freight wagons: 2x20/18 per hour

$$L_{W',\mathrm{tot},i} = 54.7 + 10\log_{10}\left(\frac{2\times 20}{18}\right) = 58.2\ \mathrm{dB}$$

Combine different train types:

$$L'_{W,\mathrm{tot}} = 10\log_{10}\left(10^{7.8} + 10^{6.75} + 10^{4.52} + 10^{5.82}\right) = 78.4\ \mathrm{dB}$$

Since the train accelerates gradually from a stop to its maximum speed in the section near the station, it is necessary to calculate the combined sound power level at a particular location based on the speed at that location, and therefore the corresponding combined sound power level is calculated using the average speed gradient per hundred metres calculated in the first subquestion, as shown in the figure below. As there are very few buildings on either side of the line from Shepshed station, the noise situation is not analysed for this section of the line, but only for the 2,000 metres around Loughborough station, which is densely built up and representative for the analysis.

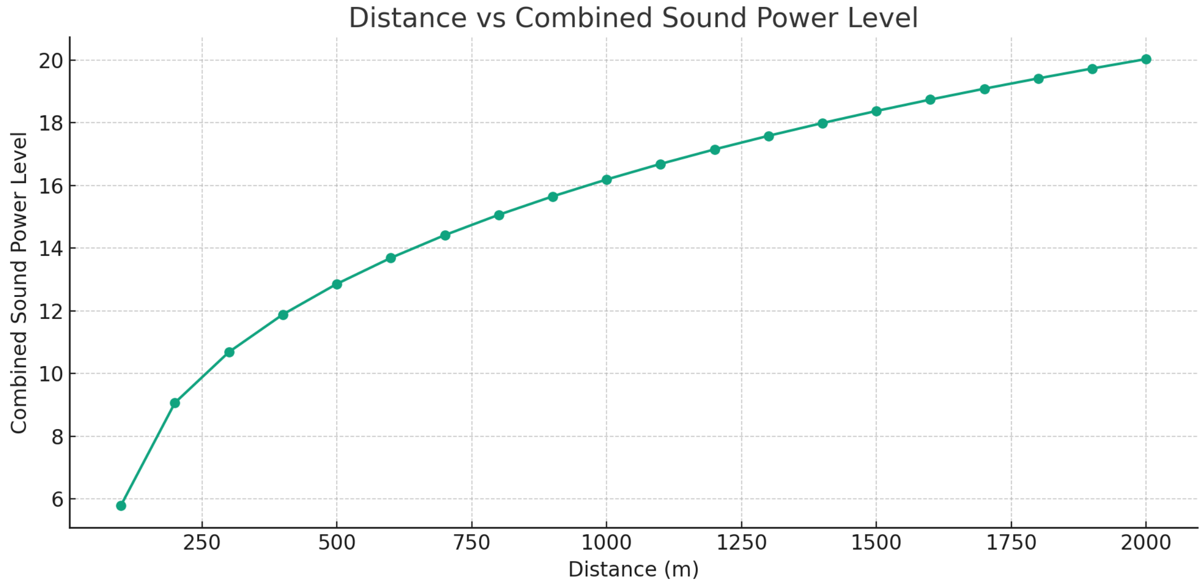


FIGURE 15. combined sound power level

The graph above shows how the combined sound power level changes as mileage and velocity increase.

Use the distance attenuation equation to calculate the corresponding distances of 50dB, 55dB and 60dB for each 100 metre distance point and plot the corresponding noise contours on the map.

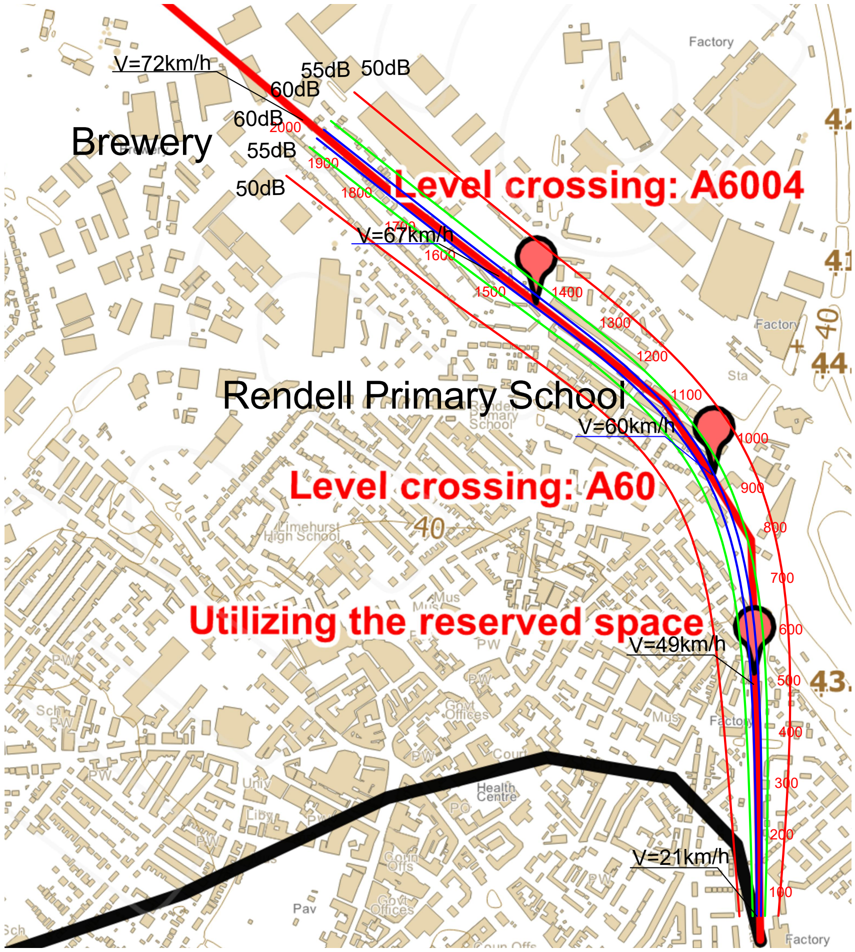


FIGURE 16. Noise Contour

According to Digimap, there are two key buildings along the route:

1. Rendell Primary School(Figure 17):

A primary school located at 1400 of the distance.

2. Charnwood Brewery(Figure 18):

A small craft brewery, 2000 metres into the route.

FIGURE 17. Rendell Primary School
source: google map

FIGURE 18. Charnwood Brewery
source: google map

According to noise limits set out in the Noise Insulation (Railways and Other Guided Transport Systems) Regulations 1996 (UK Government 1996), the prescribed daytime noise level is 65 dB and the night-time noise level is 60 dB, taking into account that the so-called façade level is 3 dB higher than the free-field noise level.

Fortunately, noise levels at both locations are below 50 dB, so no additional noise mitigation measures or insulation works are required.

One of the limitations of this calculation is that the line is designed as a single track with passing loops, so if trains travelling in opposite directions meet and one of them waits on the passing loop, its speed will drop to 0, which is not taken into account in the calculations and therefore results in the calculated value deviating from the real situation.

Another limitation of this calculation is that the Loughborough line passes through small radius curves, which do not take into account the noise generated by the contact between the bogie and the track.

References

Li, D. and Selig, E. T. (1998), 'Method for railroad track foundation design. i: Development', *Journal of Geotechnical and Geoenvironmental Engineering* **124**(4), 316–322.
URL: *https://trid.trb.org/view/485957*

UK Government (1996), 'The noise insulation (railways and other guided transport systems) regulations', `http://www.legislation.gov.uk/uksi/1996/428/made`. UK Statutory Instruments, 1996 No. 428.