North Island Electrification Study

Prepared for KiwiRail
Prepared by Beca Limited

31 May 2021

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Revision History

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Contents

Appendices

Executive Summary

KiwiRail is committed to supporting their shareholder, the New Zealand Government, and their customers in achieving their carbon reduction targets. While rail is a relatively low-carbon mode of freight haulage, KiwiRail has identified opportunity for significant reduction in freight emissions through a transition towards a new fleet of low-emission locomotives.

Novel technologies such as hydrogen fuel cells and lithium-ion batteries are not sufficiently developed to be considered a feasible tractive option for rail freight. However, KiwiRail has been operating low-emission electric-hauled freight services through the central North Island for almost close to 40 years and much of the North Island mainline network is already fitted with the overhead electrification infrastructure needed to support electric freight services.

This study has developed a high-level scope and cost associated with ‘filling in the gaps’ in the electrification network in support of fully-electric freight services between Auckland, Tauranga and Wellington.

The scope of the study has covered four distinct North Island route segments:

- Line 1: Te Rapa (Hamilton) to Pukekohe (NIMT);
- Line 2: Hamilton to Mt Maunganui (ECMT);
- Line 3: Waikanae to Palmerston North (NIMT); and
- Line 4: Upper Hutt to Masterton (Wairarapa Line (WRL)) – this latter segment in support of passenger services only.

Additionally, the study considered where further electrification may be required in the main Auckland and Wellington rail freight depots in support of future electric operations.

The study has considered and established a scope of works for each of the following key workstreams:

- Upstream investment in the national High Voltage grid for supply of power to the railway;
- Upgrades to existing signaling systems to immunise them against electrical interference;
- Works to clear each route for install of the lineside overhead electrification infrastructure, anticipated to principally involve raising of existing bridges;
- As well as the construction of the new lineside overhead electrification infrastructure including lineside traction supply substations.

The range of estimated costs for each route segment are quite broad as would be expected for a feasibility study. Further detailed analysis will be required to establish accurate investment costs.

KiwiRail - North Island Electrification

Costing Options	Expected Estimate ($)	Range Lower	Range Upper
Line 1 - Te Rapa to Pukekohe	$430 M	$390 M	$472 M
Line 2 - Hamilton to Mt Maunganui	$426 M	$388 M	$466 M
Line 3 - Waikanae to Palmerston North	$339 M	$309 M	$371 M
Line 4 - Upper Hutt to Masterton - Option 1 - AC	$226 M	$206 M	$247 M
Line 4 - Upper Hutt to Masterton - Option 2 - DC	$83 M	$76 M	$90 M
Terminii	$8 M	$7 M	$12 M
Subtotal (Line 4 AC)	**$1428 M**	**$1300 M**	**$1568 M**
Subtotal (Line 4 DC)	**$1285 M**	**$1170 M**	**$1411 M**

1 Introduction

The NZ Government has committed the country to decarbonisation targets that require significant reductions in greenhouse gas emissions. As a state-owned enterprise, KiwiRail has a responsibility to respond to these commitments, as well as the needs of their customers, through their long-term planning. This study supports KiwiRail's efforts to prepare for a low-carbon future and will help inform strategic planning activities.

Rail as a mode of freight and passenger transport is acknowledged to provide significant advantage over road transport in terms of CO_2 emissions. Diesel-powered rail freight services offer 70% fewer emissions compared to heavy road freight transport (The Value of Rail, NZTA, September 2016). However, there is opportunity for KiwiRail to further reduce the emissions of their freight operations through a transition towards low-carbon / zero-carbon tractive power modes.

Innovative technology such as hydrogen fuel cells and lithium-ion batteries are becoming more prevalent globally as a low-emission power option. However, these developing technologies are not presently deemed feasible for rail freight services within the New Zealand network. Fortunately, the necessary technology for a low-carbon rail freight power option is already in existence today. Indeed, the North Island Main Trunk (NIMT) was partially electrified in the 1980s allowing for the operation of electric-hauled freight services between Te Rapa and Palmerston North (by the EF class fleet of electric locomotives). Today, over 75% of the NIMT is electrified, with the suburban (Auckland, Wellington) infrastructure having been constructed or renewed in the last 12 years.

The vast majority of the North Island rail freight traverses the two mainline routes: North Island Main Trunk (NIMT) and East Coast Main Trunk (ECMT). These routes provide for freight connectivity between the largest North Island cities of Auckland, Hamilton, Tauranga and Wellington. Of this North Island rail freight, a relatively small percentage of route-kilometres are currently operated as electric-hauled services. Clearly further electrification of the North Island mainlines will allow for growth in electric freight services and provides opportunity for a significant decrease in emissions.

The EF electric-locomotive fleet is currently undergoing a 10-year life extension, potentially providing time for development of hydrogen and battery technologies before further investment in low-emission rolling stock will become necessary. Such options will need to be considered; however they remain infeasible presently. Overhead electrification will remain the benchmark for further investment in low-emission rail freight. Particularly for the North Island mainline services given the existing infrastructure.

This study has developed a high-level scope and cost for electrifying the remaining segments of the NIMT route and the ECMT. This will support the establishment of an investment baseline for transition to electric-hauled rail freight services in the North Island that can be tested against other feasible low-carbon options that may emerge.

2 Purpose

The purpose of this study is to support the intelligent debate of investment options for a transition to low-emission rail freight services. This study will support options assessment by providing a robust cost estimate for further electrification of the North Island rail network.

3 Scope

The scope of the study was the development of a feasible scope of works and ‘order-of-magnitude’ cost estimate associated with electrification of specific route segments of the North Island rail network. The scope of works to be developed was to make allowance for:

- Upstream investment in the national High Voltage grid for supply of power to the railway;
- Upgrades to existing signaling systems to immunise them against electrical interference;
- Works to clear each route for install of the lineside overhead electrification infrastructure, anticipated to principally involve raising of existing bridges;
- As well as the lineside overhead electrification infrastructure and traction substations.

This study may support or inform a future business case for investment options.

Coverage

The scope of the study has covered four distinct North Island route segments:

- Line 1: Te Rapa (Hamilton) to Pukekohe (NIMT);
- Line 2: Hamilton to Mt Maunganui (ECMT);
- Line 3: Waikanae to Palmerston North (NIMT); and
- Line 4: Upper Hutt to Masterton (Wairarapa Line (WRL))

Each of these lines was investigated for electrification at 25 kV AC although line 3 is proposed to also involve a short extension of DC electrification to a freight passing loop just North of the existing extent of electrification.

The study has investigated a second option for line 4 whereby two short lengths of 1600 V DC electrification would provide for recharge of on-board batteries. This option is anticipated to offer a better value solution that full AC electrification for this route segment as passenger services, rather than freight services, are the primary driver for electrification.

Transformative

The development of study assumptions in regards future rolling stock and future timetabled services was required to reflect a ‘transformation’ of current railway operations. Establishing a clear and consistent view of a transformative future state has not been straightforward. Through the study we have sought to define a sensible basis that acknowledges both an anticipated step-change in service levels whilst recognising the constraints of the existing network.

The study was required to consider a 30-year (2050) horizon as the basis for future service levels and noting future timetable assumptions should not be ‘overly constrained’ by existing infrastructure.

Drivers

As described in the introduction, the principal driver for further electrification is transition towards a predominantly electric-hauled North Island rail freight service. However, the study was required to make sensible allowance for future electric passenger services also.

In particular, Greater Wellington Regional Council (GWRC) seeks to replace their currently diesel-hauled services between Wellington and Palmerston North (co-operated with Horizons Regional Council), and Wellington and Masterton, with low-emission services. GWRC are currently considering options for a new passenger rolling stock fleet that will replace the existing diesel-hauled services as well as allowing for capacity increase on other routes.

Extent of Electrification

In terms of electrification of the route segments, the study has allowed for all main lines/through lines and all passing loops within the route segment limits. In addition, electrification of some sidings has been allowed for including arrival/departure roads for some adjacent customer yards. The extent of electrification of sidings is likely to change following more detailed analysis of regional freight operations and confirmation of the extent to which services can rely on the anticipated onboard ‘last-mile’ capability of the future electric locomotive fleet.

Terminii

In order to provide for a future fully-electric freight service from Auckland to Wellington, the study has also considered further electrification of freight arrival/departure roads into the Westfield, Southdown and Wellington freight yards. As these roads exist outside the route segments covered by our study the costs have been captured within a separate Terminii estimate.

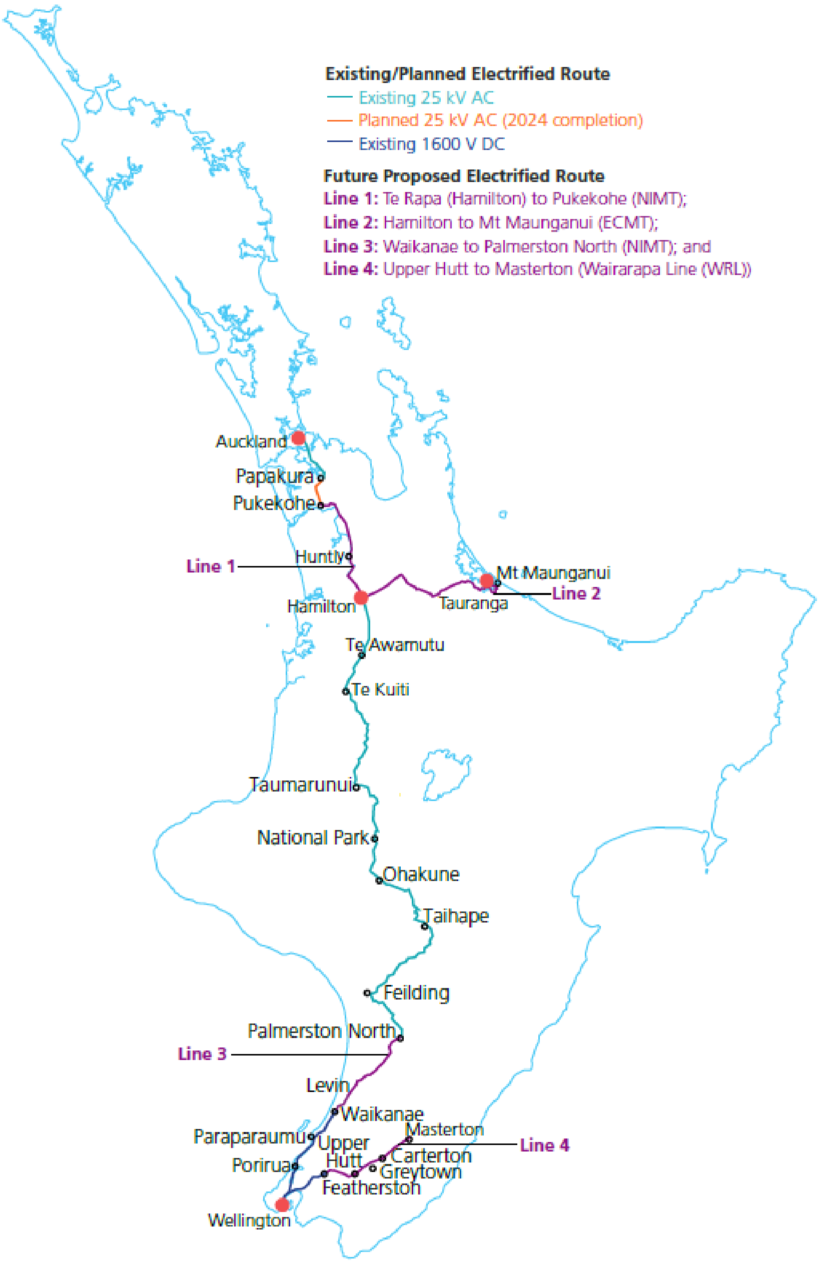
Operations and Maintenance Assets

The study has included allowance for capital expenditure associated with future maintenance activities. This includes additional depot areas/buildings, additional hi-rail plant, access roads, hi-rail access points, spares, etc. The study has not considered opex generally however, including the future cost of power or the cost of operating and maintaining the new infrastructure.

4 Existing Electrification

As described above there is already a significant extent of electrified railway across the North Island network.

The first North Island rail routes to be electrified were for passenger services on the Wellington suburban network. The Johnsonville line was electrified at 1600 V DC in 1938 followed soon after by the NIMT between Wellington and Paekakariki. In the late 1940's the same 1600 V DC overhead line system was installed on the WRL between Wellington and Upper Hutt.



Electrification of the 412 km section of the NIMT between Te Rapa and Palmerston North at 25 kV AC had originally been proposed as a measure to increase the capacity of the route. After declining traffic volumes caused the proposal to be shelved it was reinvigorated as a measure to reduce the nation's dependence on imported oil. The system was constructed between 1984 and 1988.

In the early 2010's the need to improve the reliability of metropolitan passenger services in our largest cities led to investment in new rolling stock and the electrification of the suburban rail network in Auckland at 25 kV AC, with the southern extent being Papakura, as well as extension of the Wellington DC system on the NIMT between Paekakariki and Waikanae.

More recently a renewal programme has resulted in the replacement of much of the aged overhead line infrastructure between Wellington station and Paekakariki. A further programme of renewal is currently underway on the WRL between Wellington station and Upper Hutt. These renewals have involved replacement of all lineside overhead line equipment including traction structures and include for construction of further traction substations to support increased passenger services.

A further project has commenced to extend the Auckland electrification southwards to Pukekohe. Construction of this 25 kV AC extension is forecast to complete in 2024. Additionally it is anticipated the proposed new third main running from Westfield Junction to Wiri will be electrified for freight services.

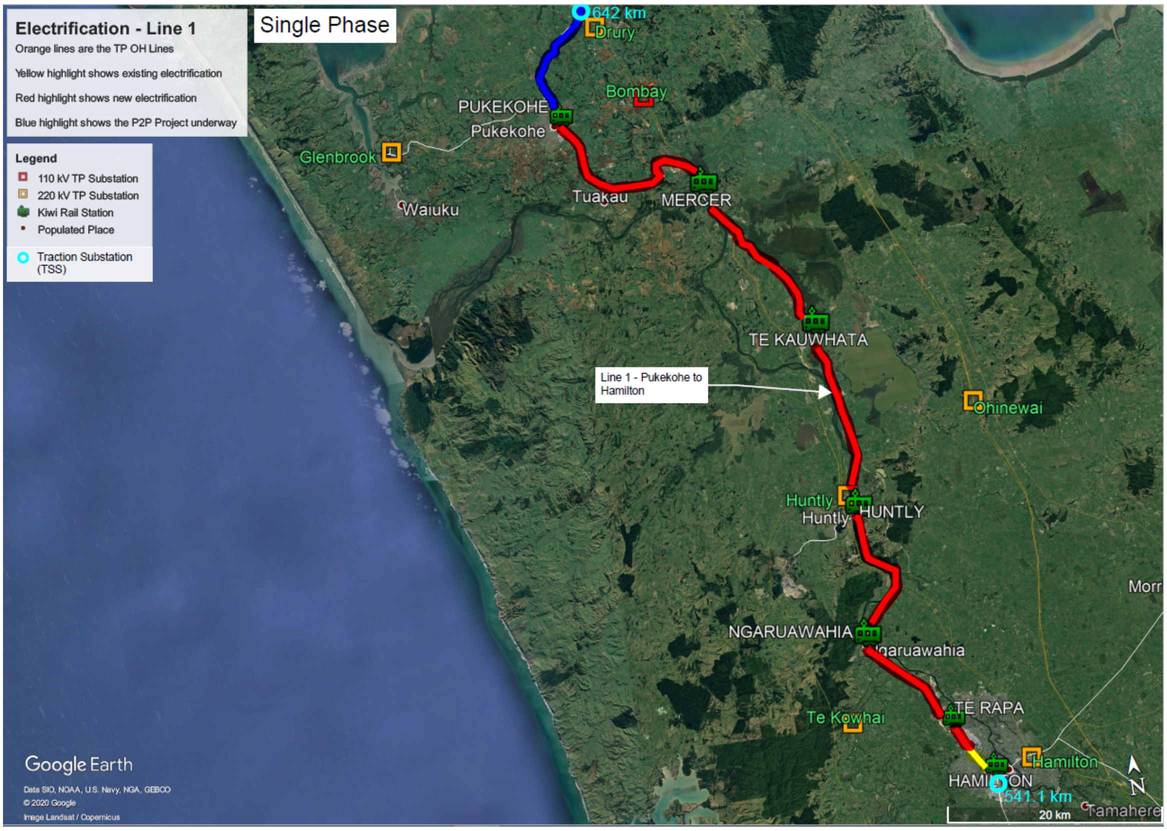
5 Nomenclature

The following nomenclature has been developed for use throughout this report:

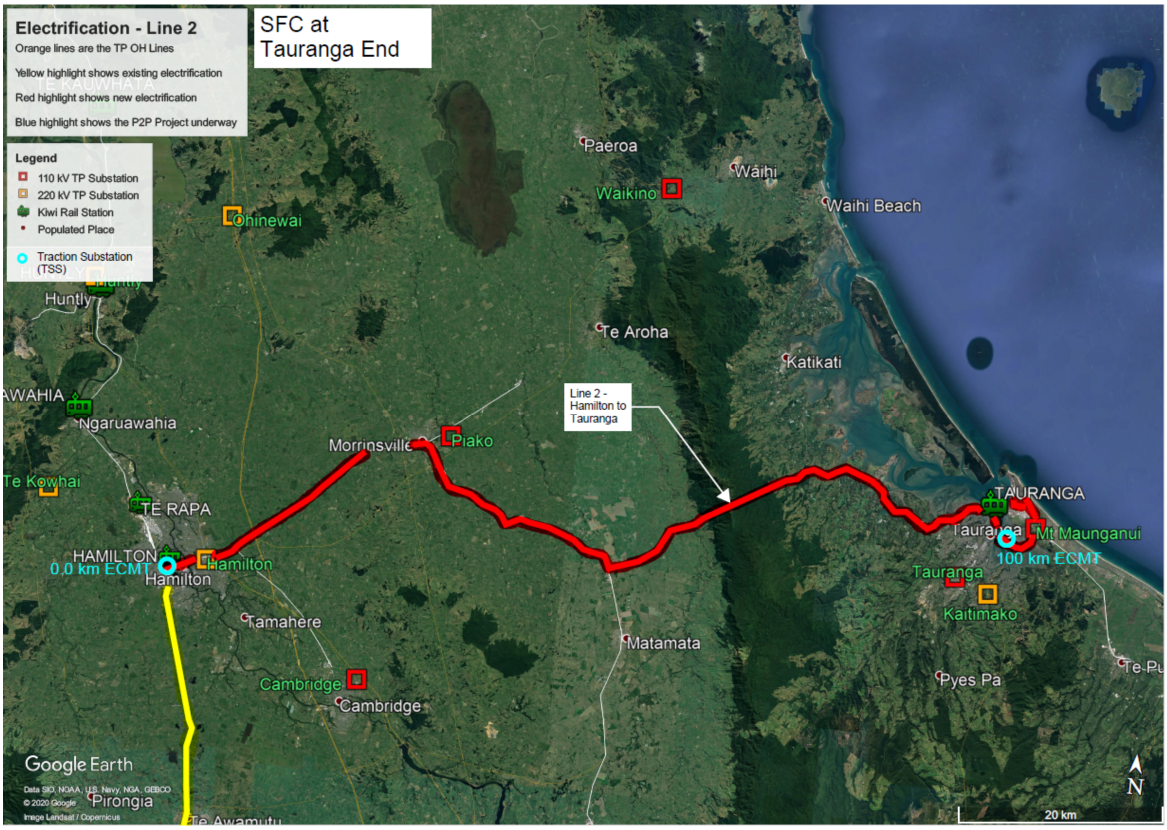
Line No.	Line Name	GXP Names(s)	TSS Name(s)
Line 1	Te Rapa to Pukekohe	Hamilton (HAM), Drury (DRY)	Hamilton Drury
Line 2	Hamilton to Mt Maunganui	Hamilton (HAM), Kaitimako (KMO)	Hamilton Matapihi
Line 3	Waikanae to Palmerston North	Paraparaumu (PRM), Bunnythorpe (BPE)	Waikanae Bunnythorpe
Line 4	Upper Hutt to Masterton (25kV AC)	Greytown (GYT)	Featherston
	Upper Hutt to Masterton (DC for battery recharge)	Ahura (Powerco ZS) Featherston (Powerco ZS)	Masterton Featherston

The maps below provide a view of each of the lines together with nearby Transpower grid exit points GXP and the existing/proposed traction substation (TSS) locations. In each map the red line generally indicates the future overhead electrification while the yellow shows existing overhead electrification. In the first map the blue line shows the route to be electrified under the Papakura to Pukekohe project, currently underway.

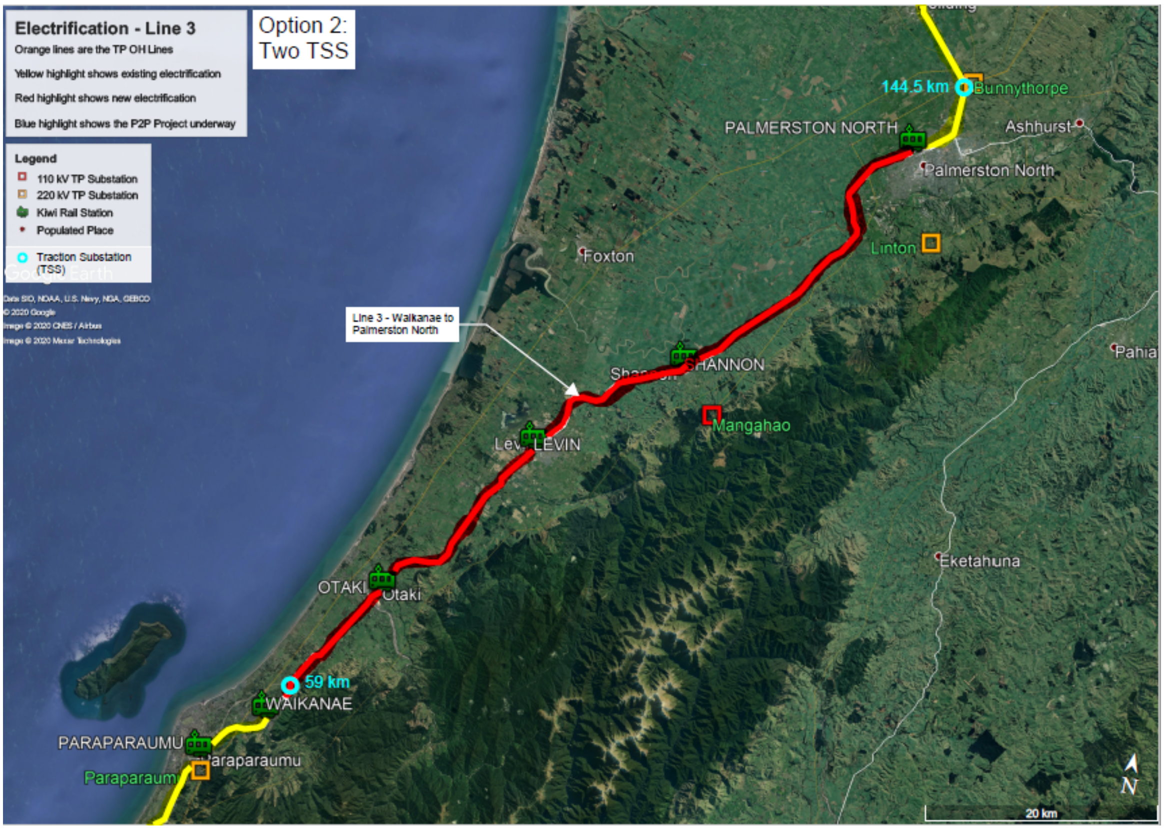
Aerial View of Line 1



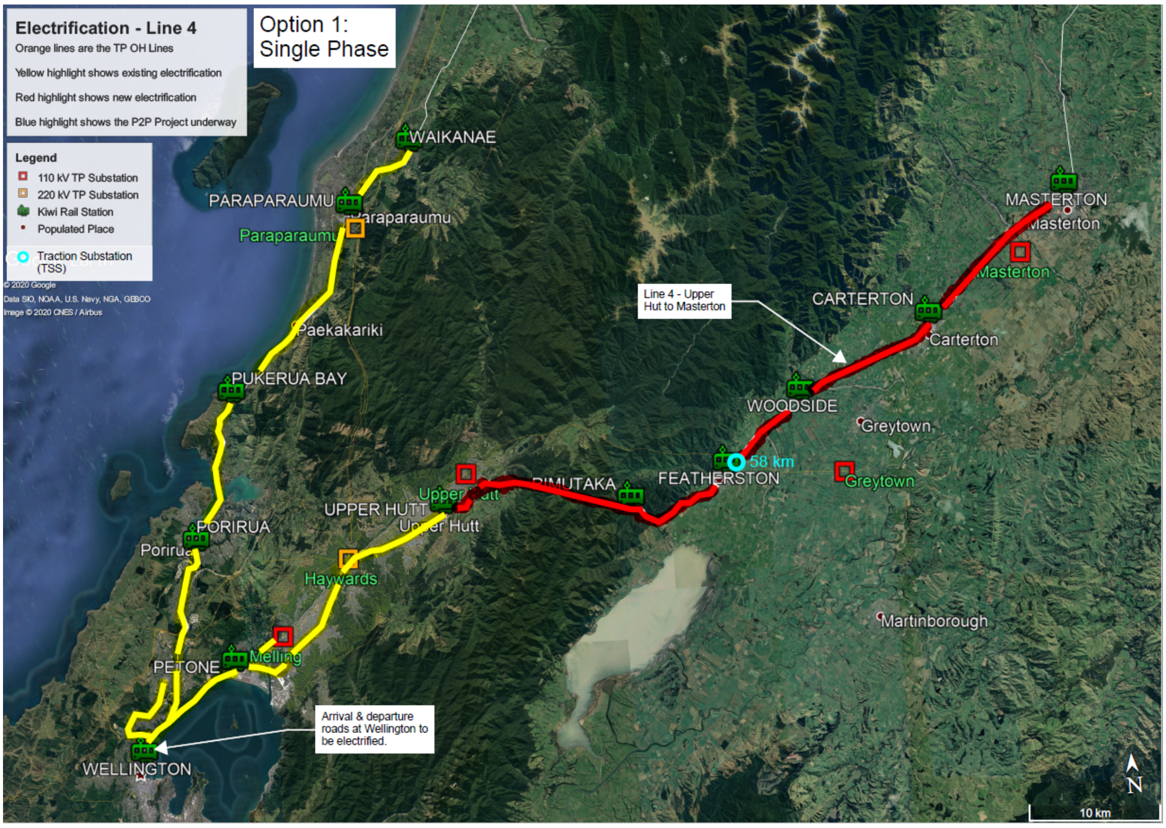
Aerial View of Line 2



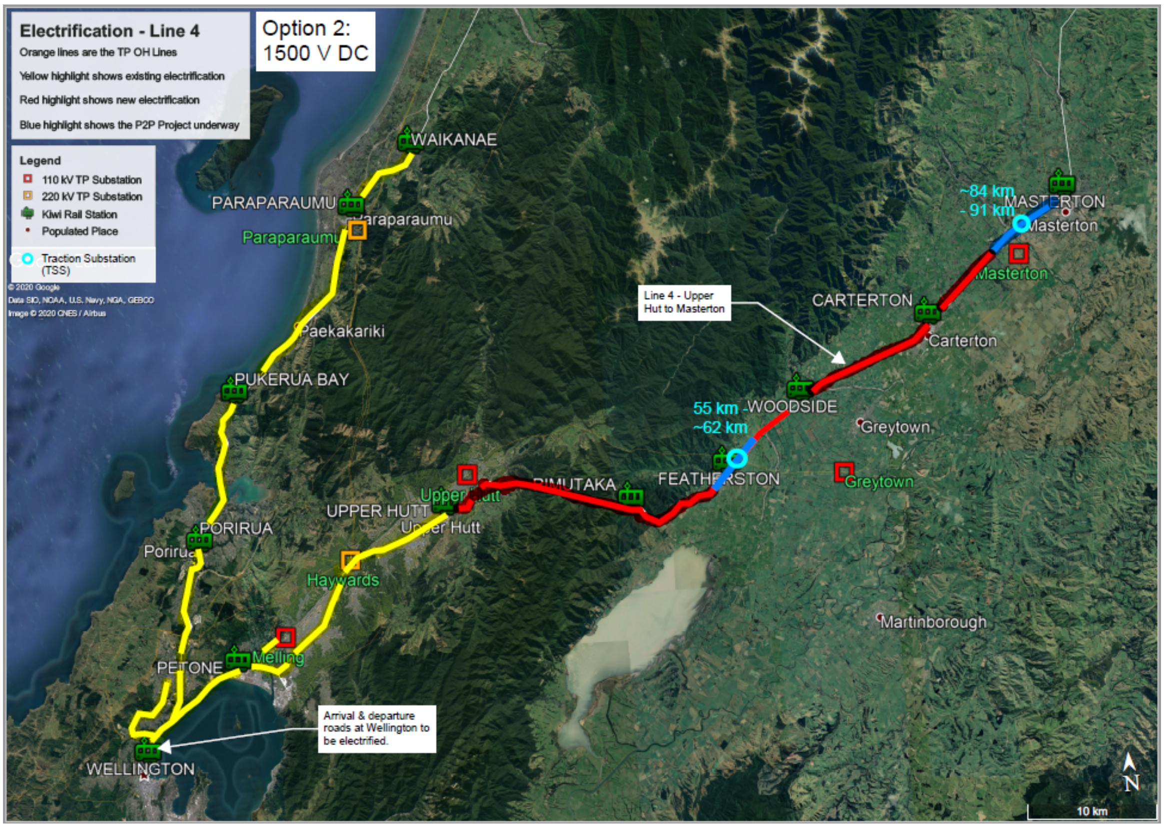
Aerial View of Line 3



Aerial View of Line 4 - Option 1



Aerial View of Line 4 - Option 2 (Note: extent of new DC electrification is shown in blue)



6 Timetable Assumptions

6.1 Future Timetable Development

The proposed electrification system must have suitable capacity to accommodate service growth over time. KiwiRail have proposed year 2050 as a sensible horizon date on which to base the study. The electrical traction system must be sized to accommodate the heaviest peak load. Therefore a 2050 peak hour service level has been established. The 2050 peak hour service level has been extrapolated from a present-day baseline peak for each line segment.

The following input data has been used to establish the baseline and future peak number of services, with consideration given to both freight and passenger services:

- The pre-covid North Island Master Train Plan (KiwiRail);
- The Wellington Area 2026 (Wairarapa Line services) timetable (GWRC);
- The Wellington Area 2026 (NIMT services) timetable (GWRC); and
- Consultation with various KiwiRail staff, regarding forecast future service levels for both passenger and freight services.

Analysis and extrapolation of the above-mentioned input data resulted in the establishment of the following consolidated 2050 peak hour service level assumption.

Line No.	Line Name	Hourly Max.	Value	Headway
Line 1	Te Rapa to Pukekohe	Current max train/hr (2030) future max/hr (2050) future max/hr	4 6 10	Evenly spaced
Line 2	Te Rapa to Mt Maunganui	Current max train/hr (2030) future max/hr (2050) future max/hr	4 6 10	Evenly spaced
Line 3	Waikanae To Palmerston North	Current max train/hr (2030) future max/hr (2050) future max/hr	3 6 10	Evenly spaced
Line 4	Upper Hutt to Masterton	Current max train/hr (2030) future max/hr (2050) future max/hr	4 6 8	Evenly spaced

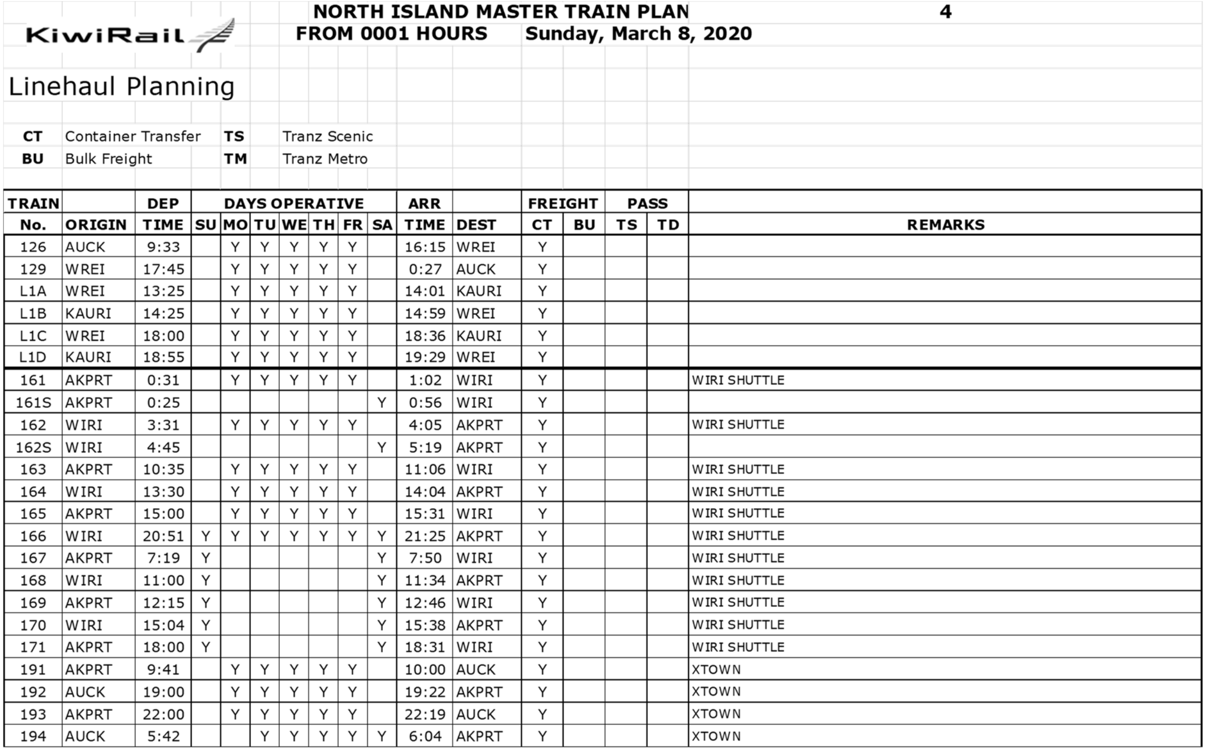
The peak hour service levels proposed above provide allowance for both freight and passenger traffic as discussed in more detail in subsequent sections.

6.2 Methodology

The North Island Master Train Plan was used to determine the current peak hour service level. The Train Plan provides the following information for each service in a 24-hour period;

- Type of service (freight or passenger);
- Origin of service;
- Origin departure time;
- Destination of service;
- Destination arrival time; and
- Days of the week the service operates.

Excerpt from the North Island Master Train Plan



KiwiRail

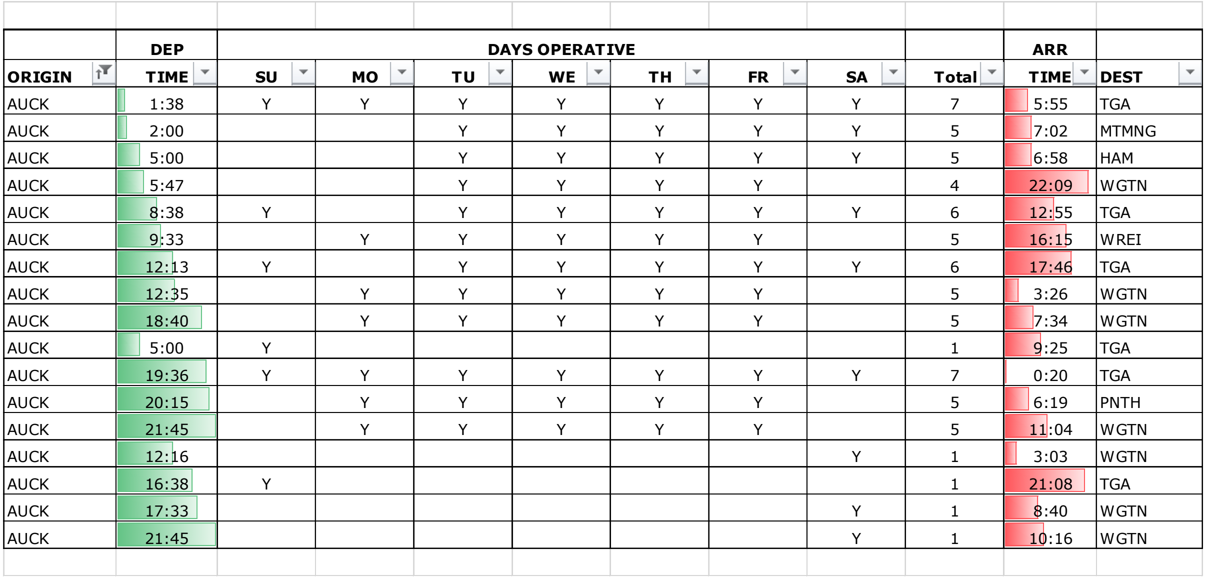
NORTH ISLAND MASTER TRAIN PLAN 4
FROM 0001 HOURS Sunday, March 8, 2020

Linehaul Planning

CT Container Transfer **TS** Tranz Scenic
BU Bulk Freight **TM** Tranz Metro

TRAIN		DEP	DAYS OPERATIVE							ARR		FREIGHT		PASS		
No.	ORIGIN	TIME	SU	MO	TU	WE	TH	FR	SA	TIME	DEST	CT	BU	TS	TD	REMARKS
126	AUCK	9:33		Y	Y	Y	Y	Y		16:15	WREI	Y				
129	WREI	17:45		Y	Y	Y	Y	Y		0:27	AUCK	Y				
L1A	WREI	13:25		Y	Y	Y	Y	Y		14:01	KAURI	Y				
L1B	KAURI	14:25		Y	Y	Y	Y	Y		14:59	WREI	Y				
L1C	WREI	18:00		Y	Y	Y	Y	Y		18:36	KAURI	Y				
L1D	KAURI	18:55		Y	Y	Y	Y	Y		19:29	WREI	Y				
161	AKPRT	0:31		Y	Y	Y	Y	Y		1:02	WIRI	Y				WIRI SHUTTLE
161S	AKPRT	0:25							Y	0:56	WIRI	Y				
162	WIRI	3:31		Y	Y	Y	Y	Y		4:05	AKPRT	Y				WIRI SHUTTLE
162S	WIRI	4:45							Y	5:19	AKPRT	Y				
163	AKPRT	10:35		Y	Y	Y	Y	Y		11:06	WIRI	Y				WIRI SHUTTLE
164	WIRI	13:30		Y	Y	Y	Y	Y		14:04	AKPRT	Y				WIRI SHUTTLE
165	AKPRT	15:00		Y	Y	Y	Y	Y		15:31	WIRI	Y				WIRI SHUTTLE
166	WIRI	20:51	Y	Y	Y	Y	Y	Y	Y	21:25	AKPRT	Y				WIRI SHUTTLE
167	AKPRT	7:19	Y						Y	7:50	WIRI	Y				WIRI SHUTTLE
168	WIRI	11:00	Y						Y	11:34	AKPRT	Y				WIRI SHUTTLE
169	AKPRT	12:15	Y						Y	12:46	WIRI	Y				WIRI SHUTTLE
170	WIRI	15:04	Y						Y	15:38	AKPRT	Y				WIRI SHUTTLE
171	AKPRT	18:00	Y						Y	18:31	WIRI	Y				WIRI SHUTTLE
191	AKPRT	9:41		Y	Y	Y	Y	Y		10:00	AUCK	Y				XTOWN
192	AUCK	19:00		Y	Y	Y	Y	Y		19:22	AKPRT	Y				XTOWN
193	AKPRT	22:00		Y	Y	Y	Y	Y		22:19	AUCK	Y				XTOWN
194	AUCK	5:42			Y	Y	Y	Y	Y	6:04	AKPRT	Y				XTOWN

Excerpt from analysis sheet used to establish current peak hour service levels



	DEP	DAYS OPERATIVE								ARR	
ORIGIN	TIME	SU	MO	TU	WE	TH	FR	SA	Total	TIME	DEST
AUCK	1:38	Y	Y	Y	Y	Y	Y	Y	7	5:55	TGA
AUCK	2:00			Y	Y	Y	Y	Y	5	7:02	MTMNG
AUCK	5:00			Y	Y	Y	Y	Y	5	6:58	HAM
AUCK	5:47			Y	Y	Y	Y		4	22:09	WGTN
AUCK	8:38	Y		Y	Y	Y	Y	Y	6	12:55	TGA
AUCK	9:33		Y	Y	Y	Y	Y		5	16:15	WREI
AUCK	12:13	Y		Y	Y	Y	Y	Y	6	17:46	TGA
AUCK	12:35		Y	Y	Y	Y	Y		5	3:26	WGTN
AUCK	18:40		Y	Y	Y	Y	Y		5	7:34	WGTN
AUCK	5:00	Y							1	9:25	TGA
AUCK	19:36	Y	Y	Y	Y	Y	Y	Y	7	0:20	TGA
AUCK	20:15		Y	Y	Y	Y	Y		5	6:19	PNTH
AUCK	21:45		Y	Y	Y	Y	Y		5	11:04	WGTN
AUCK	12:16							Y	1	3:03	WGTN
AUCK	16:38	Y							1	21:08	TGA
AUCK	17:33							Y	1	8:40	WGTN
AUCK	21:45							Y	1	10:16	WGTN

North Island Master Train Plan (Analysis)

The following analysis was undertaken;

- Each service was allocated to Line 1 – 4 based on the origin and destination.

  Note: Services that traversed two line segments were counted in each line. For example, Service MP1 (Container Transfer) departs Auckland 0138 and arrives Tauranga 0555, this service is analysed in both Line 1 and Line 2.
- GWRC-operated passenger services were allocated to Line 3 and Line 4 for completeness.
- Services were then analysed according to departure location in chronological order to determine the maximum number of trains in a given hour on a given day.

The results show a present day maximum of 4 trains per hour in any one hour for any day of the week.

Extrapolation for Future Service Levels

KiwiRail does not have an established view of the future service levels across their full network, forecast for the 30-year horizon established for our study. Therefore, extrapolation of the current service levels relied upon consideration of predicted growth in freight and passenger demand. Detailed analysis of such demand growth over the 30-year horizon was beyond the scope of this study however sensible assumptions were able to be established through consultation within KiwiRail, highlights of the discussion being captured below.

Extrapolation considered which lines would experience peak traffic during commute hours (due to passenger services being a dominant factor) as opposed to those lines which were more freight focussed. It was assumed freight traffic would be relatively light during peak commute hours and hence future peak service levels do not need to simultaneously reflect both peak passenger and peak freight expectations.

6.3 Future Electrified Passenger Services

The following considerations were given to future electrified passenger services.

Te Rapa to Pukekohe services

Northern Explorer

- Currently a single daily service in each direction (peak summer months).
- To be electrified in the future but there was little basis for assuming a significant increase in service levels.
- This service also applied to the Palmerston North – Waikanae section.

Te Huia service

- Just commenced in April 2021 as diesel-hauled at two return services daily.
- This could sensibly increase to three return services daily however very unlikely to grow beyond this without significant further investment.
- Reduced journey time is required to drive higher passenger volume and this would only be achieved through new ‘high-speed’ rolling stock and either straightening of the existing route or a new dedicated route.
- We have adopted scenario B from the Ministry of Transport study into high speed rail along this corridor.
- Scenario B assumes straightening of the existing track, largely in the section South of Pukekohe, and services travelling at speeds of up to 160km/hr.

Extension of Auckland Transport (AT) services to Pokeno

- AT may extend their services from Pukekohe to Pokeno (taking advantage of future electrification) however we have assumed such services would not operate in competition with the future high-speed Te Huia service.

Hamilton to Tauranga services

- The Kaimai tunnel currently imposes significant constraint on the potential for future passenger services. The tunnel lacks necessary telecommunication and fire suppression capabilities as may be required to establish a rail safety case process as there is no existing passenger service in operation (expected to be subject to higher standard than services with ‘grandfather rights’ through similar tunnels elsewhere on the network)

- This study has been directed to not be ‘overly constrained’ by existing infrastructure. Accordingly, in developing our high-voltage and traction solutions for line 2, we have also made allowance for possible future passenger services through the Kaimai tunnel.

Regional metro commute services

- There is general agreement that no allowance should be made for metro commuter services in such locations as Palmerston North, Masterton or Tauranga (Hamilton discussed above).

Waikanae to Palmerston North services

- This existing KiwiRail-operated Capital Connection service has been assumed to grow to two services a day, operated by GWRC (and Horizons) using their future EMU fleet.
- The GWRC supplied 2026 timetable provides for proposed passenger services North of Waikanae.

Wairarapa line services

- The GWRC supplied 2026 timetable provides for proposed passenger services North of Upper Hutt.

6.4 Future Electrified Freight Services

The uplift for future freight services has relied upon guidance provided through consultation with KiwiRail staff. The original guidance provided as input to this study by KiwiRail suggested service frequency growth of 40% as well as growth in maximum tonnage of each service.

Given that the current maximum freight service levels are generally 4 trains per hour (TPH) a future peak hour freight service level of 8 TPH was considered sensible (note: for Lines 1-3 only).

6.5 Consolidation of Future Freight and Passenger Services

When the assumed increases in passenger services were overlaid with the assumed increases in freight services a future peak hour service level of 10 TPH was established for line 1-3. This allowed for the operation of passenger services through the peak commute hour during which time no or minimal freight services would be anticipated to operate, whilst also meeting the assumed future peak hour for freight traffic (which would be expected to occur outside of peak passenger service operation).

To determine the future traction load the maximum service level has generally been tested for three scenarios: a peak passenger services period, a peak freight period and a period with a split of freight and passenger services.

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7 Rolling Stock Assumptions

7.1 Reference Electric Locomotive

KiwiRail provided a recommended future electric locomotive for use in the study. The features of the locomotive can be summarised below:

- Bo-Bo + Bo-Bo dual body loco (a permanently coupled pair);
- 4.5 MW
- 160 tonnes gross;
- With “last mile” capability; and
- Maximum axle load of 20 tonnes.

In response to this we identified the JR Freight Class EH200 locomotive as a sensible reference assumption. This locomotive requires 4.5 MW at the wheel (5.25 MW at the pantograph) and operates at a sensible max speed of 110 km/hr.

Note: we propose a different bogie arrangement, Co-Co + Co-Co, than that outlined above in order to overcome adhesion limitations (refer below). However this bogie arrangement exists in use on the North Island network today and can easily be applied to our reference locomotive.

Regardless of the bogie arrangement that will be adopted, it is clear that the future electric locomotive developed for the North Island network will be designed for their ‘typical’ service requirement. Heavy fast trains, as may be required by exception, are expected to be operated with two locomotives if gradients require.

Future Service Level

Existing North Island freight services operate with the following maximum tonnage:

Te Rapa to Bunnythorpe:	1700 tonnes; and
Elsewhere:	2200 tonnes.

It is anticipated future freight operations would require an ability to carry increased tonnage hence we have assumed a maximum of 2500 tonnes throughout the network.

Analysis of Future Locomotive Performance

We reviewed the design locomotive assumption for various scenarios to confirm acceptability for use in our study. Our findings demonstrate a 4.5 MW electric locomotive is a sensible assumption, able to haul current freight services up the maximum grades in the North Island and being able to support possible future service tonnages.

We have analysed three case scenarios with the following summary:

- Case 1 – Heaviest existing freight service on central NIMT – 1700 t in Raurimu Spiral: a Dual-body BoBo (around 160 t consist) is enough to deliver the needed tractive effort and still meets the axle load limit. Power (4.5 MW) is limiting the speed to around 31 kph;
- Case 2 – Heaviest future freight service on our new lengths of electrification – 2500 t in 1:66 straight ramp : figures very close to the “1700 t in Raurimu Spiral” case. Same conclusion; and
- Future Case 3 – Heaviest future freight service, but applied to the central NIMT: 2500 t in Raurimu Spiral: need of a heavy locomotive consist (>210 t), which means 2*Co-Co to meet axle load limits. Power (4.5 MW) is limiting the speed to around 23 kph.

We are comfortable a single 4.5 MW future electric locomotive has capacity to haul current services and would be able to support possible future freight services (albeit with a change to Co-Co rather than Bo-Bo bogies, not considered an issue as these exist on current fleet). We note future increase on the max axle load limit may allow Bo-Bo to become feasible, however we're not certain any increase would be achieved within the likely timeframe for introduction of the new electric locomotive fleet.

It is assumed, two locomotives would be used for any future services required to haul >2500t. Indeed it is considered likely two locomotives would be used for 2500t services up Raurimu spiral to provide greater timetable resilience.

Case 3 analysis is provided below:

Use case & needs:

- Haul a 2500 t train up Raurimu Spiral
- Raurimu Spiral is 1.1 km long in its steepest/sharpest curve section, with a gradient of 1:52 and an average radius of 150m
- This means an equivalent slope of ~2.5% and a tractive effort of around 675 kN to haul the wagons train + loco.
- With a usual friction coefficient of 0.33 (clean rail, locos sanding), the total adhesive weight (loco's weight) should not be less than 210 t

Limiting factors:

- Locomotive Max effort (torque): a DL loco with an electric transmission can deliver 370 kN. A coupled unit with 740 kN would make it – not limiting.
- Adhesion (adhesive weight): DL, EF locomotives have a unit weight of 107-108t each. A coupled unit with 215 t would make it – but limiting.
- Axle load: with the above figures, it is likely that a dual-body Bo-Bo locomotive cannot be considered (26 t), thus imposing 2*Co-Co (17.5 t). Existing NIMT limit is 18 t.
- Power: does not limit the climbing capability. But it limits the maximum achievable speed: a 4.5 MW limit means a max speed of around 23 kph.

Conclusion:

- Coupled or dual-body Co-Co is the only option for this case. Physics limit it much more than the Loco's design.
- Starting in the spiral is possible but it will take time to clear it. The max speed will remain limited by the maximum power output though.

7.2 Reference Passenger EMU (Line 1, Line 2)

Under scenario B of the Ministry of Transport study into high speed rail along the Hamilton to Auckland Corridor, it is assumed a 'high speed' tilting EMU would operate along a route improved through major track-straightening upgrades.

Our study has therefore used as a reference point the Bombardier Electric Tilt Train operated by Queensland Rail. This 25 kV AC Electric Multiple Unit (EMU) has an operating speed of 160 km/hr and requires 8 MW at the pantograph.

This reference EMU has also been used as the basis for possible future passenger services on line 2 (currently a freight-only route).

7.3 Reference Passenger EMU (Line 3, Line 4)

The existing Greater Wellington passenger fleet are EMUs (single mode currently for DC traction only). GWRC intend to procure a new fleet of trains that would replace existing diesel-powered services that currently operate North of Waikanae on the NIMT and North of Upper Hutt on the WRL. These new EMU are proposed to be tri-mode, with a combination of 1600 V DC / 25 kV AC / Other (battery, diesel, hydrogen, bio fuel, etc).

While the ‘Other’ mode is yet to be confirmed the current assumption is on-board batteries, and it is this that gives rise to option 2 for Line 4. The Ricardo report for GWRC, Discrete Electrification for Train Propulsion Part 1, has investigated this option and has proposed the DC overhead line option that has been scoped under this study as option 2. Ricardo has based their analysis on a train model with a 360 kWh battery.

Future traction load calculations for passenger services within the Greater Wellington sections of the study have been based on 2.7 MW 8 car set EMU’s (which reflect the current rolling stock fleet power requirement).

For line 4, no allowance has been made within the future traction load calculation for the current diesel-hauled freight service to go electric, as most of the route from Napier will remain unelectrified.

8 Overhead Line Workstream

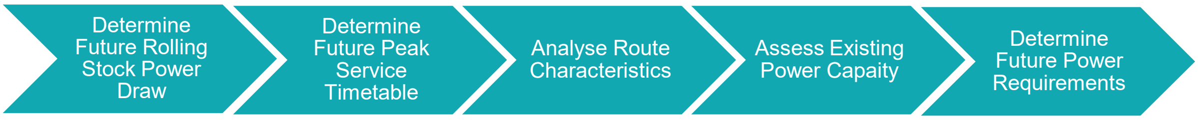
8.1 Methodology

The Traction Supply scope of work includes the lineside KiwiRail High Voltage (HV) Traction Supply Substations (TSS's), and Overhead Line Equipment (OHLE) contact and catenary system, which provides power directly to the pantograph of the train.

The inputs used to inform the traction supply scope of work include:

- An assessment of existing network usage by way of rolling stock and service patterns currently deployed within the study area to establish a baseline service pattern;
- An assessment of the existing traction supplies which border the study area, to determine if spare capacity exists to support future electrification extensions;
- A determination of proposed future traction loads;
- An assessment of route configurations to establish a baseline Bill of Quantities of key items such as single and multiple track lengths, sidings and loops lengths, turnouts and crossovers quantities; and
- Assumptions relating to HV GXP's, rolling stock – freight and passenger, peak timetabled service numbers, peak service headways, track speeds and geometry, stopping patterns, freight loads, reliability, degraded mode requirements, track configurations.

Future Traction Power Requirements Analysis Process



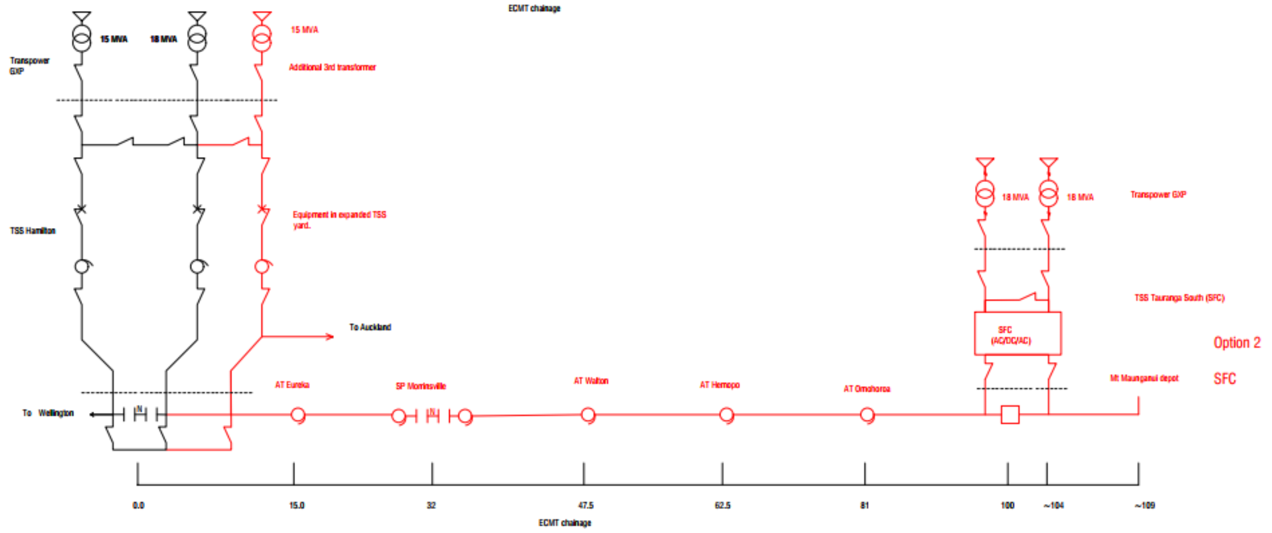
Input data has been derived from a combination of information provided by KiwiRail, benchmarking against Beca / Systra knowledge and experience on projects of a similar nature, and industry standards.

The choice to install a 2 x 25 kV or 1 x 25 kV traction system should ultimately be the result of simulation studies. However, assessment of input data, benchmarking the key characteristics of traction loads and route distances, and consideration given to the existing NIMT 25 kV system, the following system configurations have been proposed:

- Line 1 2 x 25 kV system;
- Line 2 2 x 25 kV system;
- Line 3 2 x 25 kV system; and
- Line 4 1 x 25 kV system.

High Voltage Single Line Diagrams were prepared for each line segment, to identify quantity, capacity and location of Traction substation equipment. These are provided in Appendix J, however please note these 'wok-in-progress' diagrams include some initially considered HV supply options that were eventually discarded (refer section 9 for details on discarded HV supply options).

Proposed HV Single Line Diagram – Line 2



8.2 Traction Loads

The traction load is the power required to support a proposed service level. It determines the rating and capacity of HV supply transformers and traction supply system.

The system is to be designed based on the proposed maximum one-hour peak traction load. That is, the power required for the maximum number of trains passing a given point for any given hour.

Traction loads are best determined through the application of traction simulation software using actual rolling stock characteristics, service timetables, track distance, gradient, and speed details.

For the purpose of this study, the one-hour peak traction load was determined by the following calculation:

- Traction power per train (MVA) x Maximum number of proposed trains per hour = The Maximum 1 Hour Peak Traction Load.

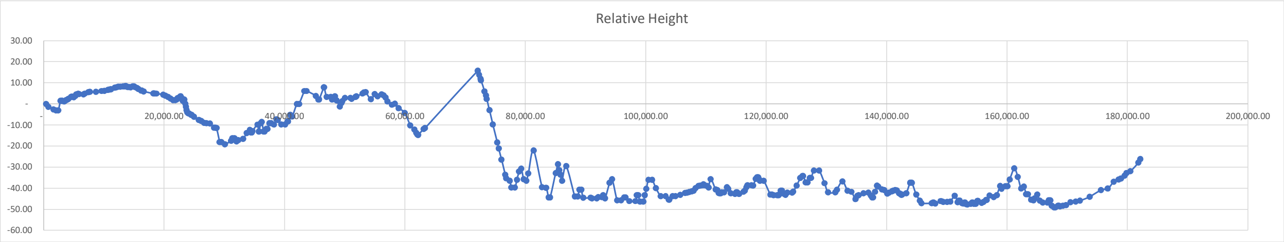
Traction Power Per Train

The traction load per train has been calculated using the following formula:

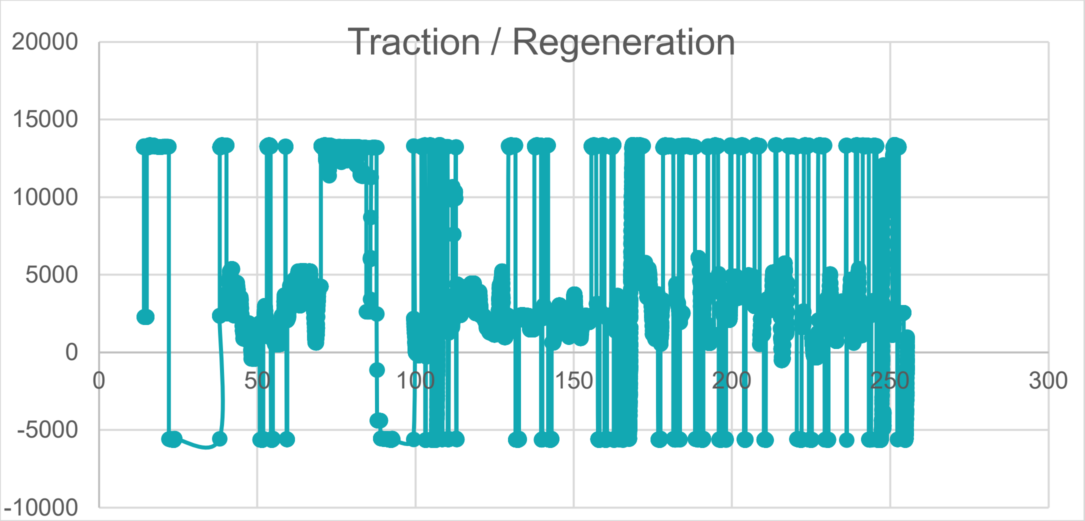
- Percentage of Time Spent in Traction Mode (%) x Power Rating of Train (MVA).

The traction load per train has been assessed based on data taken from comparable rolling stock over a comparable journey.

Raw track gradient data provided by KiwiRail was graphed to provide a longitudinal profile for each route. An example is provided in the figure below.



The following Traction / Regeneration graph represents a 250 km journey of a single comparable rollingstock across a similar track profile.



From the Traction / Regeneration analysis, the following assumptions have been used for the purpose of this study:

- Time in traction mode: 25 to 30%;
- Time in regenerative braking: 20 to 22%;
- Time coasting: 50%; and
- 100% of the time for auxiliary power.

Therefore, the traction load for a 5.25 MVA Locomotive can be calculated as such:

- 0.25 x 5.25 MVA = 1.3 MVA for each journey of 1 hour.

Similarly, the traction load for an 8 MVA EMU, can be calculated as such:

- 0.25 x 8 MVA = 2 MVA for each journey of 1 hour.

Therefore, the peak hour traction load for a maximum of 8 x 5.25 MVA locomotive per hour is calculated at:

- 1.3 MVA x 8 = 10.4 MVA

The calculation for a peak hour of 10 TPH with a combination of 5 x 5.2.5 MVA Locomotives and 5 x 8 MVA EMU's would be:

- 0.25 x 5.25 MVA x 5 TPH (6.5 MVA) + 0.25 x 8 MVA x 5 TPH (10 MVA) = Total Load of 16.5 MVA

Note: Regenerative braking will mostly be burnt off on single track areas with the estimated low number of trains. However in areas with double track and a higher probability of receptive trains, regenerative power may be utilized to lower the traction allowance of 25%.

8.3 Line 1 - Te Rapa to Pukekohe

8.3.1 Existing Service Pattern

- Peak Service 4 trains per hour

The existing traction load assessment is applicable to Hamilton TSS only.

Hamilton TSS is the northern end of the existing electrified NIMT.

Existing Traction Load Assessment

Type	Rated Load	Time in traction per hour	Number of trains per hour	Traction Load
Existing Electric Loco	3 MVA	0.25	4	3 MVA
Traction Load				**3 MVA**

8.3.2 Existing Traction Supplies

- Current 25 kV electrification project 'Papakura to Pukekohe' includes for construction of a proposed new Drury TSS with 1 x 40 MVA supply.
- Existing Hamilton TSS has 1 x 18 MVA and 1 x 15 MVA supplies in duty / stand-by supplying the NIMT to the south.
- Estimated existing traction load on Hamilton TSS is 3 MVA, this load is applicable to the NIMT as the only currently electrified line.

8.3.3 Future (2050) Traction Load

- Peak 2050 service level - 10 trains per hour

Future Traction Load Assessment – Split Passenger and Freight

Type	Rated Load	Time in traction per hour	Number of trains per hour	Traction Load
Future Electric Loco	5.25 MVA	0.25	5	6.5 MVA
EMU	8 MVA	0.25	5	10 MVA
Traction Load				16.5 MVA
Allowance for regenerative power supply				(1.25 MVA)
Total Traction Load				**15.25 MVA**

Future Traction Load Assessment – Peak Passenger

Type	Rated Load	Time in traction per hour	Number of trains per hour	Traction Load
Future Electric Loco	5.25 MVA	0.25	0	0 MVA
EMU	8 MVA	0.25	8	16 MVA
Traction Load				16 MVA
Allowance for regenerative power supply				(1.25 MVA)
Total Traction Load				**14.75 MVA**

Future Traction Load Assessment – Peak Freight

Type	Rated Load	Time in traction per hour	Number of trains per hour	Traction Load
Future Electric Loco	5.25 MVA	0.25	8	10.4 MVA
EMU	8 MVA	0.25	0	0 MVA
Traction Load				10.4 MVA
Allowance for regenerative power supply				(1.25 MVA)
Total Traction Load				**9.15 MVA**

8.3.4 Route Configuration

- Total distance 86 km, inclusive of 74 km of double track (we have assumed 100% double-track in our estimate).
- Double track provides for power exchange between trains (regenerative braking trains providing power to trains in traction).

8.3.5 Proposed System

The proposed solution for Line 1 is a 2 x 25 kV Auto Transformer system from Hamilton to meet the proposed 25 kV extension at Pukekohe to supply the estimated 2050 future traction load of 15 MVA over the route length of approximately 88km's.

This solution would require the installation of an additional 15 MVA supply into Drury TSS and utilising existing supply capacity within the Hamilton TSS.

The system would include Auto Transformer (AT) posts at approximately 15km spacing and 1 x Sectioning Post (SP).

Drury TSS

The Papakura to Pukekohe (P2P) project proposes to install 1 x 40 MVA supply.

It is intended to install an additional 15 MVA supply to support the electrification extension to Te Rapa. As well as the equipment associated with the new transformer, an additional autotransformer and AT post will be required at Drury TSS and installation of new 25 kV feeder wires onto the Drury-Pukekohe OHL equipment as a retrofit of this section to support an AT traction system south of Drury.

Hamilton TSS

Hamilton TSS currently has 1 x 18 MVA and 1 x 15 MVA supplies, operated in a duty / standby arrangement.

It is the position of this study that there is sufficient spare capacity within the existing Hamilton TSS supply to support the future electrification extension to Pukekohe.

**Note: It is proposed to augment Hamilton TSS with 1 x additional 15 MVA supply to cater for the proposed electrification to Tauranga. Further explanation is covered under Line 2.*

8.3.6 Reliability

Redundancy is N-1, utilising 2 x supplies at each site* on a duty / standby arrangement. Degraded mode capability cannot be confirmed in the absence of simulation, however it could be expected to provide 70% of peak hour services (7 out of 10tph) at a degraded speed.

**Note: Hamilton TSS will have an N-2 redundancy with 3 x supplies.*

8.4 Line 2 - Hamilton to Mt Maunganui

8.4.1 Existing Service Pattern

- Peak Service 4 trains per hour

The existing traction load assessment is applicable to Hamilton TSS only.

Hamilton TSS supplies the Northern end of the existing electrified NIMT.

Existing Traction Load Assessment (applicable to NIMT services)

Type	Rated Load	Time in traction per hour	Number of trains per hour	Traction Load
Existing Electric Loco	3 MVA	0.25	4	3 MVA
Traction Load				**3 MVA**

8.4.2 Existing Traction Supplies

- Existing Hamilton TSS has 1 x 18 MVA and 1 x 15 MVA supplies in duty / stand-by supplying the NIMT to the south.
- Estimated existing peak traction load on Hamilton TSS is 3 MVA, this load is applicable to the NIMT.

8.4.3 Future (2050) Traction Load

- Peak 2050 service level - 10 trains per hour

Future Traction Load Assessment – Split Passenger and Freight

Type	Rated Load	Time in traction per hour	Number of trains per hour	Traction Load
Future Electric Loco	5.25 MVA	0.25	5	6.5 MVA
EMU	8 MVA	0.25	4	8 MVA
Total Traction Load				**14.5 MVA**

Future Traction Load Assessment – Peak Passenger

Type	Rated Load	Time in traction per hour	Number of trains per hour	Traction Load
Future Electric Loco	5.25 MVA	0.25	0	0 MVA
EMU	8 MVA	0.25	6	12 MVA
Total Traction Load				**12 MVA**

Future Traction Load Assessment – Peak Freight

Type	Rated Load	Time in traction per hour	Number of trains per hour	Traction Load
Future Electric Loco	5.25 MVA	0.25	10	13 MVA
EMU	8 MVA	0.25	0	0 MVA
Total Traction Load				**13 MVA**

8.4.4 Route Configuration

- Total distance 107 km, predominately single-track configuration.
- Passing loops are distributed along the route, each of approximately 900 m in length.

8.4.5 Proposed System

The proposed solution for Line 2 is a 2 x 25 kV Auto Transformer system from Hamilton to Mt Maunganui to supply the estimated 2050 future traction load of 15 MVA over the route length of approximately 107 km's.

This solution would require an additional 15 MVA supply within Hamilton TSS and a new 2 x 25 kV TSS to be located at Matapihi towards the Mt Maunganui end of the route.

The system would include AT posts at approximately 15 km spacing and 1 x SP.

Hamilton TSS

Hamilton TSS currently has 1 x 18 MVA and 1 x 15 MVA supplies, operated in a duty / standby arrangement.

It is proposed to augment Hamilton TSS with an additional 1 x 15 MVA supply to support the electrification extension to Mt Maunganui.

The 3 x supplies within Hamilton TSS would be arranged to support each of the three line segments: east towards Mt Maunganui, North towards Pukekohe, and South on the NIMT.

Matapihi (Tauranga) TSS

It is proposed to install a new 25 kV TSS at Matapihi.

The Matapihi TSS will have 2 x 20 MVA supplies.

8.4.6 Reliability

Redundancy is N-1, utilising 2 x supplies at each site* on a duty / standby arrangement. Degraded mode capability cannot be confirmed in the absence of simulation, however it could be expected to provide 70% of peak hour services (7 out of 10tph) at a degraded speed.

**Note: Hamilton TSS will have an N-2 redundancy with 3 x supplies.*

8.5 Line 3 – Waikanae to Palmerston North

The existing Wellington Electrified Area 1600 V DC network terminates at Waikanae.

The proposal is to extend the DC system a short distance to a passing loop North of Waikanae station. From there the electrified network would be further extended, in a 2 x 25 kV system, to join the south end of the existing NIMT electrification at Palmerston North.

8.5.1 Existing Service Pattern

- Peak Service 4 trains per hour

The existing traction load assessment is applicable to Bunnythorpe TSS only.

Bunnythorpe TSS supplies the southern end of the existing electrified NIMT.

Existing Traction Load Assessment (applicable to NIMT services)

Type	Rated Load	Time in traction per hour	Number of trains per hour	Traction Load
Existing Electric Loco	3 MVA	0.25	3	2.25 MVA
Traction Load				**2.25 MVA**

8.5.2 Existing Traction Supplies

- Existing Bunnythorpe TSS has 1 x 18 MVA and 1 x 15 MVA supplies in duty / stand-by supplying the southern end of the NIMT.
- Estimated existing peak traction load on Bunnythorpe TSS is 2.25 MVA, this load is applicable to the NIMT.

8.5.3 Future (2050) Traction Load

- Peak 2050 service level - 10 trains per hour.

Future Traction Load Assessment – Split Passenger and Freight

Type	Rated Load	Time in traction per hour	Number of trains per hour	Traction Load
Future Electric Loco	5.25 MVA	0.25	5	6.5 MVA
EMU	3 MVA	0.25	5	3.75 MVA
Total Traction Load				**10.25 MVA**

Future Traction Load Assessment – Peak Freight

Type	Rated Load	Time in traction per hour	Number of trains per hour	Traction Load
Future Electric Loco	5.25 MVA	.25	8	10.4 MVA
EMU	3 MVA	.25	0	0 MVA
Total Traction Load				**10.4 MVA**

8.5.4 Route Configuration

- Total distance 80 km, predominately single-track configuration
- Passing loops are distributed along the route, each of approximately 600 m in length.

8.5.5 Discarded Options

Extend the 1600 V DC system

1600 V DC traction is best suited to short haul services of frequent stopping and starting service patterns. Substations in a 1600 V DC system are typically spaced between 5 and 8 km apart. Therefore a potential 10 further TSS's would be required to extend the existing 1600 V DC system to meet the 25 kV NIMT system at Palmerston North.

Due to the high initial capital investment required, on-going asset maintenance costs, and relative low traction loads, this option was discarded.

Extend the 25 kV system to Waikanae with a single supply from Bunnythorpe TSS

The projected future traction load on Bunnythorpe TSS is <15 MVA. There is sufficient capacity within the current Bunnythope TSS design to provide this load to Waikanae with the assistance of an SVC to support the voltage on the Waikanae end of the 25 kV system. Making this a cost effective option.

However, having a single end feed over a route length of 80 km introduces reliability and resiliency issues. In the event of total loss of supply in the Bunnythorpe TSS, and/or OHW damage along the route, this would result in stranded rolling stock without the option of back feed from the opposite end. Due to the lack of operational resiliency, this option has been discarded.

8.5.6 Proposed System Solution

The proposed solution for Line 3 is to extend the 2 x 25 kV Auto Transformer system from Palmerston North to meet the 1600 V DC system near Waikanae to supply the estimated 2050 future traction load of 10 MVA over the route length of approximately 80 km's.

The 1600 V DC system would be extended a short distance to a freight passing loop just North of Waikanae to allow the existing DC EMU fleet to operate to Waikanae. Our estimate has not separately costed this item, rather the AC OHL estimate includes allowance for this short length of DC OHL

This solution would require a new 2 x 25 kV TSS at the Waikanae end and utilising existing supply capacity within the Bunnythorpe TSS on the northern end.

The system would include AT posts at approximately 15 km spacing and 1 x SP.

Bunnythorpe TSS

Bunnythorpe TSS currently has 1 x 18 MVA and 1 x 15 MVA supplies, operated in a duty / standby arrangement.

It is the position of this study that there is sufficient spare capacity within the existing Bunnythorpe TSS to support the future electrification extension to Waikanae.

Waikanae TSS

It is proposed to install a new 25 kV TSS at Waikanae.

The Waikanae TSS will have 2 x 12.5 MVA supplies.

8.5.7 Reliability

Redundancy is N-1, utilising 2 x supplies at each site on a duty / standby arrangement. Degraded mode capability cannot be confirmed in the absence of simulation, however it could be expected to provide 70% of services (7 out of 10tph) at a degraded speed.

8.6 Line 4 – Upper Hutt to Masterton

The existing Wellington Electrified Area 1600 V DC network terminates at Upper Hutt.

We have assessed two options. Option 1 is to extend the electrified network from Upper Hutt, in a 1 x 25 kV system, to Masterton. Option 2 is to provide 2 short lengths of DC overhead line to provide for recharge of on-board train batteries. It is generally accepted that full AC electrification is not likely to represent a value-for-money option, however the study has included this for comparative purposes.

8.6.1 Existing Service Pattern

- Peak Service 4 trains per hour.
- There is no existing traction loads for consideration on this line segment.

8.6.2 Existing Traction Supplies

There is no existing 25 kV traction supply for consideration on this line segment.

8.6.3 Future (2050) Traction Load

- Peak 2050 service level - 8 trains per hour.

Future Traction Load Assessment

Type	Rated Load	Time in traction per hour	Number of trains per hour	Traction Load
Future Electric Loco	5.25 MVA	0.25	0	0 MVA
EMU	3 MVA	0.25	8	6 MVA
Total Traction Load				**6 MVA**

8.6.4 Route Configuration

- Total distance 58 km, predominately single-track configuration.
- Passing loops are distributed along the route, each of approximately 600 m in length.

8.6.5 Discarded Option

Extend the 1600 V DC system from Upper Hutt

1600 V DC traction is best suited to short haul services of frequent stopping and starting service patterns.

Substations in a 1600 V DC system are typically spaced between 5 and 8 km apart. Therefore a potential further 7 TSS's would be required to extend the existing 1600 V DC system to Masterton.

Due to the high initial capital investment required, on-going asset maintenance costs, and relative low traction loads, this option was discarded.

8.6.6 Proposed System – 25 kV AC Option

The proposed solution for Line 4 is a 1 x 25 kV system to supply the estimated 2050 future traction load of 6 MVA over the route length of approximately 58 km's.

A single TSS is proposed to be located at approximately the midpoint of the Upper Hutt to Masterton route, at Greytown.

Note, Auto Transformers are not required in a 1 x 25 kV system.

Greytown TSS

It is proposed to install a new 25 kV TSS at Greytown.

The Greytown TSS will have 2 x 12.5 MVA supplies.

8.6.7 Reliability

Redundancy is N-1, utilising 2 x supplies at Greytown on a duty / standby arrangement.

Degraded mode capability cannot be confirmed in the absence of simulation, however it could be expected to provide 70% of services (7 out of 10 tph) at a degraded speed.

8.6.8 Proposed System - DC Battery Charging Option

This option considers the use of Dual Mode 1600 V DC / Battery operated rolling stock.

The proposal is to install 2 x 7 km sections of 1600 V DC overhead electrification for charging of the rolling stock batteries.

The first charging section is to be located between the 58 Kilometre Point (KP) and 65 KP, approximately at the midpoint of the Upper Hutt to Masterton route.

The second charging section is to be located between the 84 KP and 91 KP, which is on the Masterton end of the route.

Each of the charging sections would be supplied by a 1600 V DC TSS, each TSS would comprise 2 x 2 MVA supplies on a duty / stand-by arrangement and located approximately at the midpoint of each of the charging sections.

For clarification, it is noted that the Ricardo report produced for GWRC (Ref. ED13960) suggests the 2 x 7km electrified charging sections to be placed at the 16 KP to 23 KP, and 46 KP to 54 KP respectively. However, these figures assume the Upper Hutt to Masterton route starts at 0 KP at Upper Hutt and extends to a 58 KP at Masterton. These suggested locations are approximately at the mid-point and end point of the route. A similar philosophy has been adopted under this study.

8.7 Typical OHL Arrangements

Open Track Areas

The OHL system chosen for the basis of the estimate is the V160 regulated tension OHWS typically used by SNCF in France. Basic system parameters are as follows:

- Electrical Supply: 25kV-50Hz:
- Max line Speed: 160 km/h;
- Max admissible train current: 1500 A;
- Nominal contact wire height: 5.50 m;
- Minimum contact wire height: 4.64 m;
- Maximum contact wire height: 6.20 m;
- Stagger: +/-200 mm;
- Half tension length: 700 m;
- Full tension length: 1400 m; and
- Max wind speed for unrestricted service: 110 km/h.

Electrical characteristics are as follows:

- Catenary: Bronze 65 mm^2;
- Catenary tension: 10 kN at 15ºC;
- Contact Wire: 107 mm^2;
- Contact wire tension: 10 kN at 15ºC;
- ATF: Aluminium 228 mm^2;
- ATF tension: 9 kN at 15ºC; and
- Earth Wire: 93 mm^2.

Single Track Cantilever (STC) and Twin Track Cantilever (TTC) typical arrangement cross sections have been developed to illustrate the basic system layout. The proposed system maximum design speed is 160 km/hr.

Typical span lengths range from a maximum of 63 m (16 masts / km) down to 43 m 22 masts / km).

STC’s are based on 10m (+/– 0.5m) 200 UC masts.

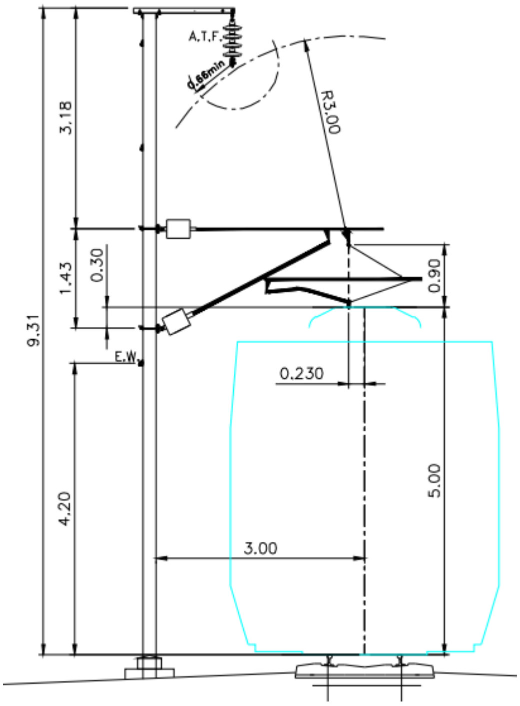
TTC’s are based on 11m (+/– 0.5m) 250 SHS masts.

Footing types typically used by SNCF are direct buried, potted post type. However, for the purpose of this study allowance has been made to align with the Auckland Electrification specification of a poured footing with a rag bolt assembly to accommodate a mast with a baseplate.

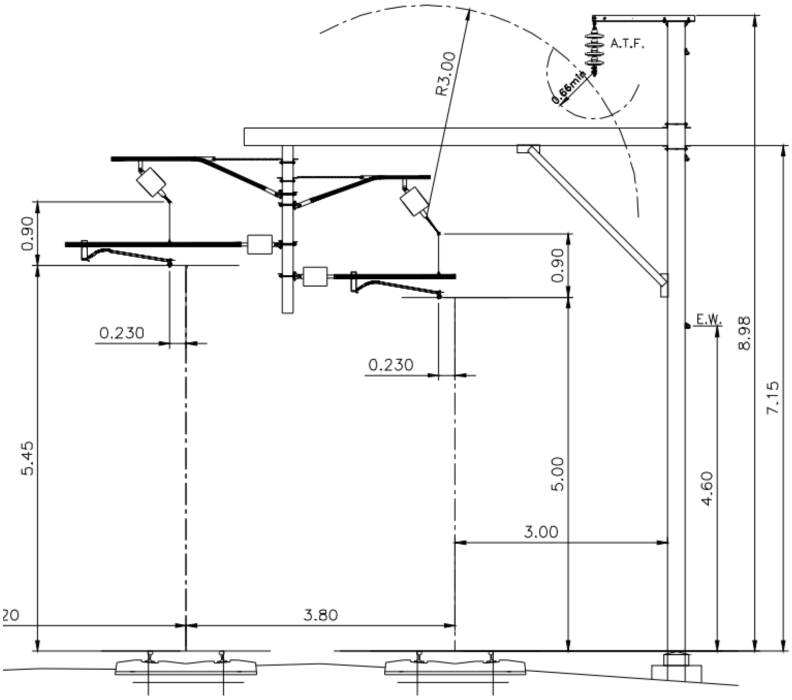
The auto transformer feeder is suspended from the top of the mast, trackside, above the cantilever arm.

In a three-track area such as an Up and Down main plus a passing loop, a combination of an STC and TTC would be utilised.

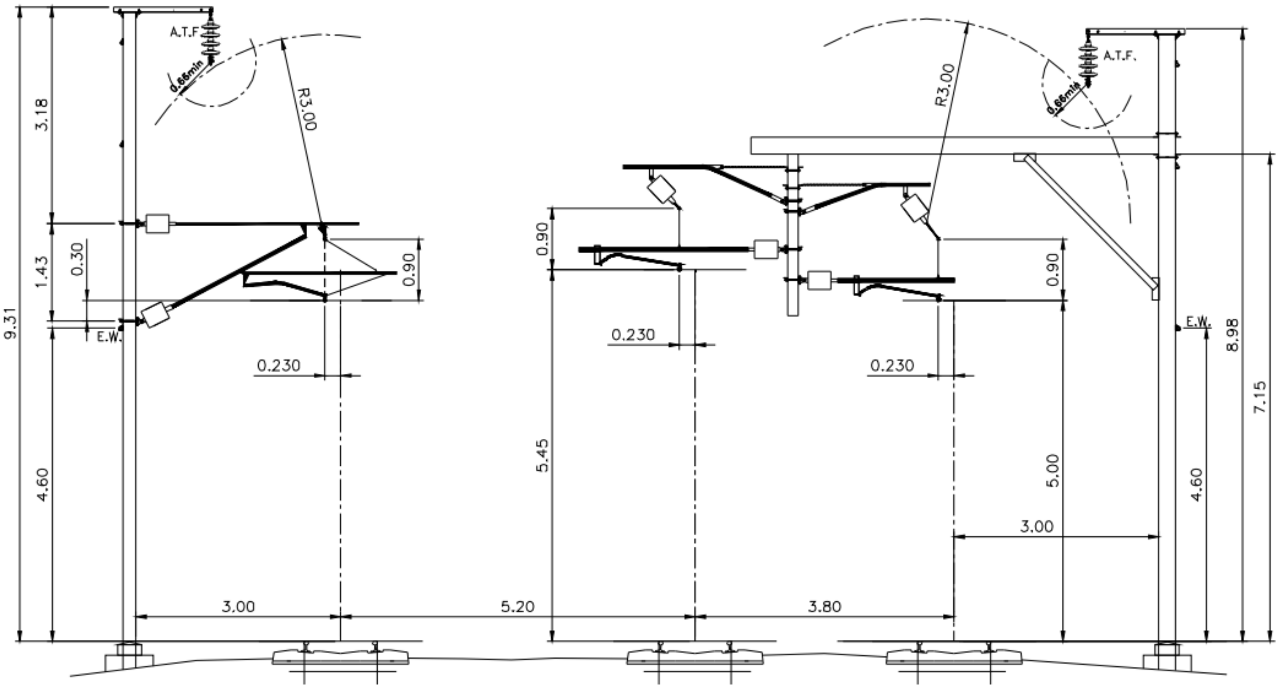
Typical Single Track Cantilever cross section



Typical Twin Track Cantilever cross section



Typical Three Track Arrangement cross section



Tunnels

There are three main tunnels within the study area, in addition to a cut-and-cover section of route through Hamilton CBD.

For the purposes of this study we have assumed any requirement to reinstate passenger use of the existing underground station in Hamilton, necessitating upgrades to the OHL arrangement to meet passenger safety requirements, would be funded by other projects. Hence such costs have been excluded.

Line Segment	Tunnel Name	Tunnel Length (m)	Track Chainage (klm)
Hamilton to Mt Maunganui	Kaimai	8885 m	63.343 – 72.198 (ECMT)
Hamilton to Mt Maunganui	Hamilton CBD	~500m	~0.500 – 1.000 (ECMT)
Upper Hutt to Masterton	Maymorn (Maoribank)	572 m	36.654 – 37.226 (WRL)
Upper Hutt to Masterton	Remutaka	8779 m	39.269 – 48.048 (WRL)

Typical tunnel OHW cross sections were developed from tunnel cross-sectional sketches dating from 1949. The Overhead Line Equipment is constrained by the tunnel heights of 5.1-5.2 m from top of sleeper to underside of the tunnel soffit.

Due to clearance constraints two options have been considered :

- A twin contact-wire system (catenary) with tensioning equipment (More likely to be spring tensioning); or
- Conductor beam system type. (solid conductor bar).

Both systems would require approximately the same room for installation, and both would require approximately the same amount of supports within the tunnel. The conductor beam system typical span lengths are between 8 m and 12 m and the catenary system between 9 m and 13 m.

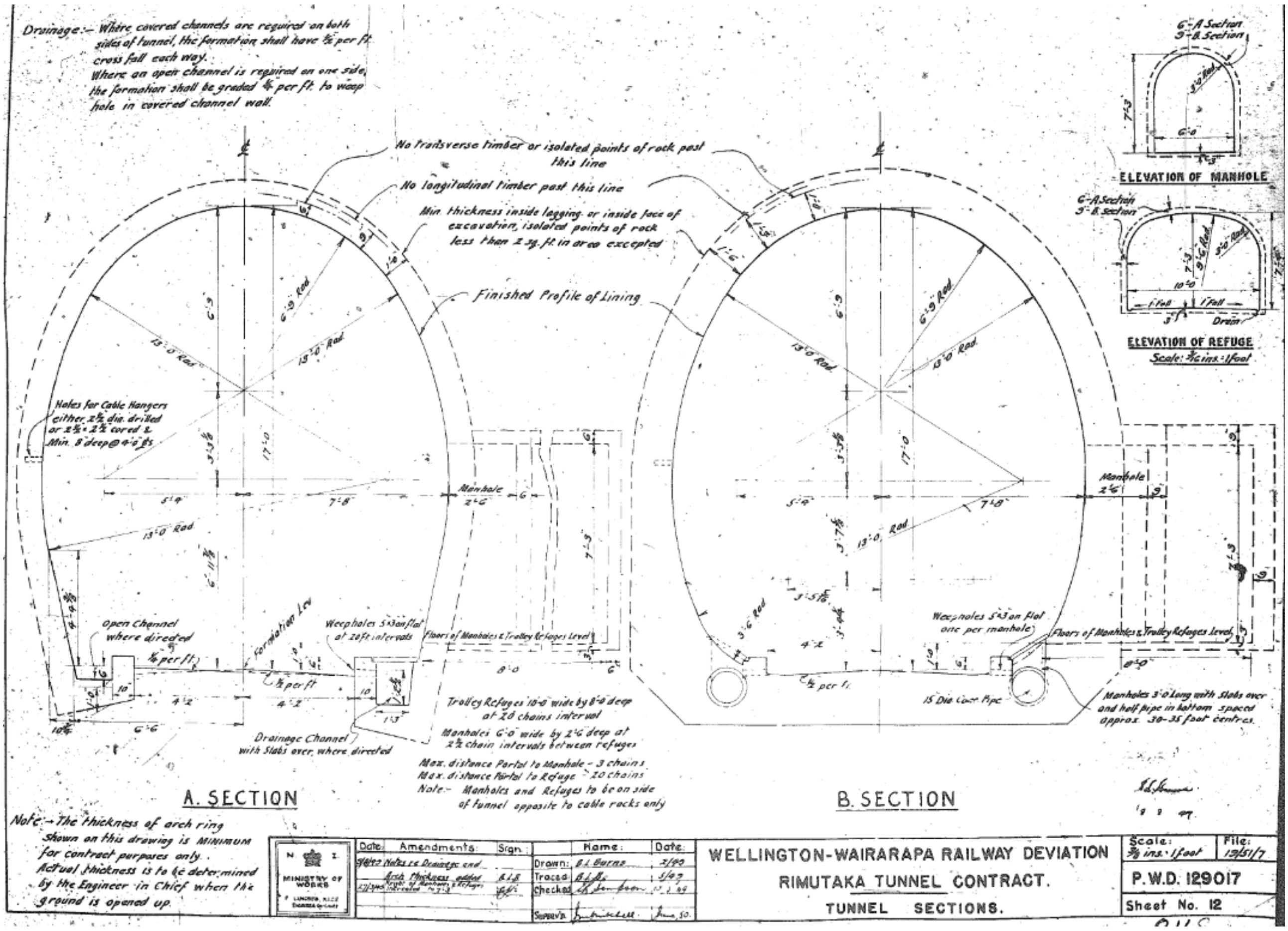
It is believed that material cost of the conductor beam system could be roughly 1.5 times the cost of the twin contact wire.

However, considering the advantages over the initial investment, it is believed that over the life cycle of the design it would be 3 times cheaper than the twin contact wire system.

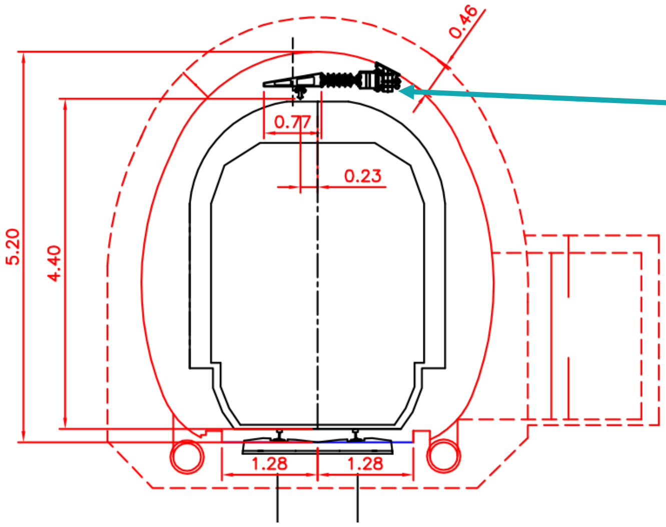
The advantages include:

- The dynamic performance is far superior than that of the twin contact wire system;
- No need for tensioning equipment in the tunnel as the solid conductor is not tensioned;
- The is no risks of a wire snapping in the tunnel and causing expensive repairs and service delays;
- No need for long and complicated overlaps in tight space as the overlap is provided by running; conductor beams in parallel for a short length; and
- It requires less maintenance than the twin contact wire system, providing both costs savings and HSE benefits through less time required on track for maintenance personnel.

Tunnel Base Design cross section

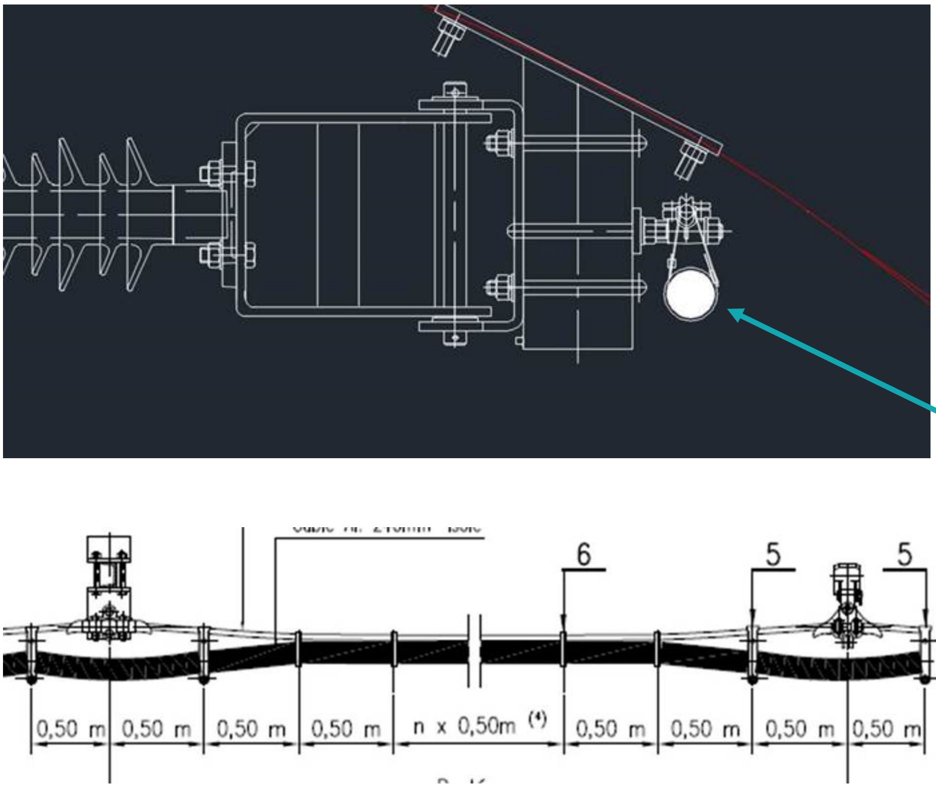


Typical Tunnel Solid Conductor Beam cross section



Insulated AT Feeder - refer detail below

Insulated AT Feeder detail



Insulated AT Feeder supported from Earth Wire

8.8 Construction Methodology

The rates database established by Systra for overhead electrification assumes ‘greenfield’ construction. As the proposed route segments to be electrified are already operational it was imperative that we adjust the rates to make allowance for the constraint on construction access and costs associated with bus replacement of passenger services. This section of the report captures the consideration of this allowance including some high-level assumptions established for the construction approach and expected rates of productivity.

The critical path of the construction program will be those activities requiring ‘on-track’ access, where a combination of re-scheduling of services, pilot working, and block of line will be required to enable the work to be undertaken.

Analysis of the current North Island timetables indicate Line 1 has the highest number of train movements per day (circa 47 Tuesday to Friday), followed by Line 2 (circa 39 Tuesday to Friday), then Line 3 and 4 which have very similar figures (circa 30-32 Tuesday to Friday). However, across each of the line sections the lowest number of train movements per day occur on Saturday’s, Sunday’s and Monday’s. It is therefore expected that the majority of on-track work will be undertaken across these days.

The following percentage allocation of on-track works to be undertaken, across days of the week has been assumed. This assumption has supported the uplift of the OHL lineside construction works rates to reflect the loss of productivity due to working on an operational railway and the higher labour costs due to weekend and night working.

Work Period	Percentage of total on-track works
Saturday (24 Hrs, multiple shifts)	35%
Sunday (24 Hrs, multiple shifts)	35%
Monday to Friday nights (10 Hrs)	20%
Monday to Friday days (10Hrs)	10%

The general sequence of the OHLE installation will be as follows:

- Civil work - Structure footings and foundations.
- Civil Work - Standing of structures and associated hardware.
- Electrical work – Install wiring (earth wire, AT feeder, catenary, contact).

Civil Work (Predominately off-track work activity)

It is envisaged that overhead wiring structure footings will be a combination of formed and poured footings requiring a bolted structure base plate, and bored direct buried *potted post* type footings.

With footings positioned 3m from centre line of rail, it is assumed these works can generally to be carried out Monday to Fridays. These works will be managed to be performed predominately off-track and utilise a range of supporting safe working arrangements to minimise disruption to train services, including:

- Partial possession of the railway corridor.
- Use of compulsory stop boards.
- Piloting of services through worksites, ensuring all plant and equipment shifted off-track to a place of safety
- In double track areas - Where bi-directional signaling and track layouts permit, services may be routed around worksites.

Electrical Work (Predominately on-track work activity)

Due to the lower density of train movements on Saturday’s, Sunday’s and Monday’s it is anticipated that the majority of Electrical works will be done across these days.

As these works are performed on track from Rail mounted MEWP vehicles, operational arrangements would be required to provide suitable track access working periods, these may include:

- Re-scheduling of particular services
- Use of compulsory stop boards.
- Piloting of services through worksites, ensuring all plant and equipment shifted off-track to a place of safety.

- Use of passing loops as refuge for work vehicles and or rail traffic.
- Block of line track possessions (in particularly for tunnel related works).
- In double track areas - Where bi-directional signaling and track layouts permit, services may be routed around worksites.

Productivity

Overall project schedule for each of the line sections will depend on the availability of usable track access to undertake those activities deemed on track, including OHLE civil and electrical works, as well as route clearance works.

To minimise project time frames it is envisaged 2 x separate works fronts will be activated for both the civil and electrical works. The work fronts will be strategically placed to maximise track access according to timetabled train movements and track configurations.

It is anticipated that a single work front, consisting of 2 x teams on a 12 hour rotating shift basis across the three days could deliver 1.5km of wiring (inclusive of earth wire, AT feeder, Catenary, and Contact), based on a combination of operational support arrangements.

With 2 x work fronts, each achieving similar productivity, it is assumed a total OHLE install rate equivalent of 3km per week will be achieved. Staging will see the civil works starting well in advance of, and in preparation for, the electrical work to follow. Likewise, the electrical works will be staged to be completed after the completion of the civil works.

The following estimated project time frames for lineside OHLE works have been assumed.

Line Section	No of Work Fronts	Estimated OHLE Duration
Te Rapa - Pukekohe	2	2 years
Hamilton – Mt Maunganui	2	1 year 6 months
Waikanae - Palmerston North	2	1 year 2 months
Upper Hutt – Masterton (AC)	2	1 year

8.9 Capex for Opex

With an expanded electrified network, consideration has been given to additional maintenance facilities, spares and equipment which may be required to support the ongoing operations and maintenance of the additional electrified route segments.

We have assumed that no land take is required for any additional depots and or storage facilities. We have also assumed that existing track access roads and hi rail access points will be sufficient for traction maintenance purposes, this based on the need for suitable access to maintain the existing track and signaling systems on these routes. Accordingly, no allowance has been made for construction of further corridor access facilities.

Assessing each of the lines individually, the following further assumptions and allowances have been made with regards to new assets to support maintenance.

8.9.1 Line 1 – Te Rapa to Pukekohe

Depots

It is assumed that the existing AEA and Hamilton depots will be sufficient to service this line, therefore no allowance has been made for further maintenance or storage depots.

Spares

An allowance has been made for spare materials to replace a single OHW tension length, Auto Transformer, Circuit Breakers, etc.

Plant and Equipment

Allowance has been made for the allocation of 1 x additional Hi Rail traction maintenance vehicle for use on this route segment.

8.9.2 Line 2 – Hamilton to Mt Maunganui

Depots

It is noted that there is an existing depot at Hamilton which provides support to the Northern end of the NIMT and it is assumed this depot will also be sufficient to provide support to the southern end of the Mt Maunganui to Te Rapa section.

However, as Mt Maunganui forms the end of the electrified section of a major freight route, allowance has been made for a new 200sqm depot at Mt Maunganui, accommodating offices, workshop and storage facilities.

Spares

An allowance has been made for spare materials to replace a single OHW tension length, Auto Transformer, Circuit Breakers, etc.

Plant and Equipment

Allowance has been made for the allocation of 1 x additional Hi Rail traction maintenance vehicle for use on this route segment.

8.9.3 Line 3 – Waikanae to Palmerston North

Depots

It is assumed that existing depots at Wellington and Palmerston North, and storage depot at Waikanae, will be sufficient to accommodate any additional support and storage required for the Waikanae to Palmerston North section.

Spares

An allowance has been made for spare materials to replace a single OHW tension length, Auto Transformer, Circuit Breakers, etc.

Plant and Equipment

Allowance has been made for the allocation of 1 x additional Hi Rail traction maintenance vehicle for use on this route segment .

8.9.4 Line 4 – Upper Hutt to Masterton (both options)

Depots

Due to the relative low density of rail traffic and shorter length of electrification extension, it is assumed that the existing depot at Wellington will be sufficient to provide any additional support required for the Upper Hutt to Featherstone section.

Spares

An allowance has been made for spare materials to replace a single OHW tension length, Auto Transformer, Circuit Breakers, etc.

8.10 Estimate

Overhead Line Equipment (OHLE)

The Overhead Line Equipment (OHLE) estimate is based on a Bill of Quantities (BoQ) based scope of work of typical key system components per line segment, being:

- Open area single track equivalent in km's (inclusive of single and double main line, passing loops, and sidings);
- Total number of turnouts;
- Total number of crossovers;
- Tunnel area single track equivalent in km's; and
- Total number of overbridge considerations.

The key components unit rates are inclusive of all labour, material, plant and equipment required to install, test and commission the system, including:

- Masts, anchors, foundations, cantilevers, brackets, insulators, fixings;
- Catenary and contact wire, droppers, in-span feeders;
- Tensioning equipment, air gaps, overlaps, neutral sections; and
- Earth wire, AT feeders, traction return cabling, terminations.

The BoQ was established through analysis of the Signaling and Interlocking (S&I) diagrams, provided by KiwiRail, for each line segment. Assumptions have been made on quantity and length of loops and sidings, and associated turnouts and crossovers.

The BoQ was priced in Euro against the Systra / SNCF benchmark key component rates which are used for other rail projects of a similar nature. Euro rate adjustment has been made to represent the NZ market by undertaking a Euro / NZD cost comparison exercise on key items such as OHW masts, footings and labour rates. Further adjustment has been made to the rates to reflect 'non-greenfield' working. This makes allowance for the impact of constructing the new overhead line on an operational railway.

The Estimate was then converted into an NZD amount.

Traction Substations (TSS)

The Traction Substation (TSS) scope of work reflects the HV Single Line Diagram's developed to identify TSS locations and equipment quantities for each line segment.

The TSS estimate includes for all labour, material, plant and equipment required to install, test and commission, the solutions described within this document for each line segment.

The scope of work for each TSS commences at the termination point of the incoming HV feeder circuits.

Key components of the TSS scope include:

- HV switchgear, protection relays;
- SCADA equipment;
- Auxiliary supplies, batteries;
- Civil works;
- Earthing and bonding;
- Interconnecting cables, busbars;

- Track feeder cables;
- Trackside auto transformer points; and
- Trackside sectioning points.

The TSS's have been estimated in Euro against the Systra / SNCF benchmark key component rates, knowledge and experience gained from other rail projects of a similar nature. Euro rate adjustment has been made to represent the NZ market by undertaking a Euro / NZD cost comparison exercise on key items such as labour rates.

The Estimate was then converted into an NZD amount.

8.11 Assumptions/Risks

Traction power systems are generally sized to have sufficient capacity to support a proposed service level across a defined area with defined rolling stock and known freight and or passenger loadings. This is achieved through computer simulated load studies to determine the adequacy of the proposed traction power system infrastructure elements, and then appropriate provision made for future service level expansion

For the purpose of this study to provide a feasible scope of works and 'order-of-magnitude' cost estimate for a traction power provision with a 30-year (2050) capability, the system capacity has been calculated, based on a number of assumptions relating to rolling stock, timetable and service levels, where defined inputs are unknown.

8.11.1 Timetable Assumptions

With reference to section 6 of this report, the following assumption has used for the proposed service levels.

Line No.	Line Name	Hourly Max.	Value	Headway
Line 1	Te Rapa to Pukekohe	(2050) future max/hr	10	Evenly spaced
Line 2	Te Rapa to Mt Maunganui	(2050) future max/hr	10	Evenly spaced
Line 3	Waikanae To Palmerston North	(2050) future max/hr	10	Evenly spaced
Line 4	Upper Hutt to Masterton	(2050) future max/hr	8	Evenly spaced

8.11.2 Rolling Stock Assumptions

With reference to section 7 of this report, the following assumption has been used for the proposed rolling stock traction load.

Line No.	Line Name	Type	Rating
Line 1	Te Rapa to Pukekohe	Freight Loco Passenger EMU	5.25 MW 8 MW
Line 2	Te Rapa to Mt Maunganui	Freight Loco	5.25 MW
Line 3	Waikanae To Palmerston North	Freight Loco Passenger EMU	5.25 MW 3 MW
Line 4	Upper Hutt to Masterton	Passenger EMU	3 MW

Note: Single locomotive to be used on freight services.

8.11.3 Infrastructure Assumptions

Track

Straightening of the existing track, largely in the section South of Pukekohe, will be undertaken to accommodate passenger services travelling at speeds of up to 160km/hr.

Existing single track configurations on lines 2, 3, and 4 to remain.

OHLE

A Contact wire height of 4.4m from top of rail is permissible within tunnel areas.

Block of line track possessions to be made available as required for installation.

Quantity and length of main line, loops, sidings, and associated turnouts and crossovers, has been established through analysis of the Signaling and Interlocking (S&I) diagrams, provided by KiwiRail, for each line segment.

TSS

Suitable KiwiRail owned land is available at nominated locations for traction substations.

Main Train Control Centre SCADA works and all associated SCADA cabling to accommodate additional traction infrastructure, to be carried out by others.

Service routes with spare capacity for AT SCADA cabling are available.

Substation HV feeding arrangements of N-1 is acceptable for all locations.

HV traction transformers are supplied by Transpower and located within Transpower GXP sites.

8.11.4 Capex for Opex

New depots are generally not required except for one facility at Mt Maunganui.

New corridor access facilities are generally not required.

A new hi-rail vehicle will be required for each of lines 1-3.

8.11.5 OHLE Constructability Assumptions

Civil works will be predominantly off-track, while the electrical install works will be predominantly on-track and subject to loss of productivity due to working around the operational railway.

A productivity of 3 km per week is estimated for the electrical install activity, which will commence following some/all of the civil works such that a lag is maintained between the civil and electrical works.

9 HV Workstream

9.1 Methodology

The required locations and power requirements for the new traction substations (TSS) were determined by Systra under the OHL workstream. The approach taken was to plot these TSS locations overlaid with the national grid network, on a google earth view of the railway lines (refer the maps provided in section 5). The nearest appropriate Transpower grid exit point (GXP) for each of these TSS was identified and enabled feasible options for supply to be established for discussion with Transpower.

To help define the work required at each GXP a possible substation extension strategy was developed. These are indicated as ‘Bluebeam’ mark-ups of the Transpower operating (existing) single line diagrams (SLDs) included in Appendix D and switchyard layouts in Appendix E. These indicate the switchgear and land area required for the new equipment to be installed at each GXP, to be used as a basis for developing cost estimates. We have allowed for the same switching arrangement as was installed for the existing NIMT supply transformers, including NERs for the centre tapped 55 kV winding.

Sensible underground cable routes between the GXP and TSS have been established through review of aerial maps (refer cable route sketches in Appendix F). These formed a basis for determining cable route lengths for costing.

9.2 Engagement with Transpower

Transpower were approached early in the process to inform them of the intention of this project. They advised that in their view, given the early ‘high level’ stage of this process, developing costs using the TEES cost database as was our intention is not the best way to develop a cost estimate. The TEES database is quite detailed so is better suited to pricing projects that have been developed to the conceptual design stage.

Transpower offered to develop estimates for the upgrades required for their system using a top-down parametric process they described as the ‘out turn’ method. This uses actual (not estimated) costs from recently completed projects of a similar nature to what would be required for KiwiRail.

During our meeting with Transpower on 24 February 2021 (see minutes of meeting in Appendix C) Transpower warned that due to unbalanced load concerns modelling would be required to confirm the acceptability of connecting connect single phase transformers to their 220 kV system. Transpower indicated a relatively high level of confidence in a positive outcome from such modelling and thus we have taken the optimistic view that a Static Frequency Convertor (SFC) will not be required for these connections. This remains a risk.

Transpower advised it would not be acceptable to connect single phase transformers to their 110 kV system. Therefore 3 phase 110/33 kV transformers and SFC have been allowed for Line 4 Option 1, installed at the 110 kV Greytown (GYT) GXP.

Transpower also raised concerns regarding resilience of the supply under maintenance scenarios. However, the proposed supply arrangements mirror those for the existing NIMT electrification and hence are assumed to be acceptable to KiwiRail. Compete loss of power from a GXP, due to say a transformer failure while the other transformer was under maintenance, would lead to a revised feeding arrangement of the overhead line system from adjacent TSS. This would be expected to affect service levels but not lead to shutdown of the railway.

Transpower were advised that the new locomotives will be capable of regenerative braking through the traction supply system. The expected maximum regeneration would be no more than 5 MW. Transpower advised this would be acceptable subject to the installation of suitable protection.

GXP Substation	Option	Code	Voltage (kV)	Existing KiwiRail Transformers (MVA)	New KiwiRail Tranformers (MVA)	(Voltage)	(Vector)	Peak Load (MVA)	Comments
Drury	-	DRY	220	40 (Note 1)	15	220/55	Ii0	29.5	Include costing for connecting the Huntly-Otahuhu No. 2 circuit in the the DRY 220 kV buses as it seems likely this may be necessary to reinforce supply
Hamilton	A	HAM	220	15 + 18	15	220/55	Ii0	33	Install a third (new) transformer. It is understood this would be an expensive option as a building may need to be demolished.
Hamilton	B	HAM	220	~~15 + 18~~	30 + 30	220/55	Ii0	33	Replace T7 and T8 'in situ' with two new 30 MVA transformers
Kaitimako	-	KMO	220	-	20 + 20	220/55	Ii0	14	*No change*
Bunnythorpe	-	BPE	220	15 + 18	-	-	-	-	No new transformers required
Paraparaumu	-	PRM	220	-	12.5 + 12.5	220/55	Ii0	11	Two transformers required to provide supply security.
Greytown	-	GYT	110	-	12.5 + 12.5	110/33	Dyn	11	1) Two required to provide supply security. 2) SFC installed at remote end for each supply.
		Note							
		1	Installation underway under a separate project						

9.3 Scope of HV Upgrade – Line 1

To supply this line a single phase 15 MVA, 220/55 kV transformer will need to be installed at the 220 kV Drury Substation (DRY). We have proposed this will be located within the existing 220 kV switchyard, at the south east corner just outside the control building. The transformer will be connected to 220 kV Bus B as a 40 MVA transformer to supply KiwiRail will be connected to 220 kV Bus A.

It is anticipated that to supply the new loads the Huntly – Otahuhu No. 2 circuit will need to be connected to the Drury 220 kV buses. The cost estimated for this work has been kept separate to the cost estimate for this project. This is because at this stage it is not clear which project should cover this cost as in addition to KiwiRail, Counties Power intends to take supply from DRY in the near future.

Review of the Advisian '2025 AEA Capability Review' report indicates the 40 MVA transformer at Drury has been sized to provide 'N – 1' backup to the full Auckland Electrified Area (AEA) should any of the other feeder supplies further north fail. This approach to network resilience is intended to allow for continued passengers services without a meaningful drop in performance under the feeder out of-service (OOS) scenario. Therefore, under normal operation this transformer would have plenty of capacity to provide backup for the 15 MVA transformer supplying Line 1 to Hamilton.

As noted in the previous section, the traction supply solutions developed under this study replicate the NIMT installation rather than the AEA installation. Under the NIMT installation, adjacent supplies can support a feeder OOS scenario but not without a reduction in capacity, likely meaning peak services cannot be operated without some level of disruption. This is considered generally acceptable given the further electrification is primarily in support of freight services rather than passenger services however resilience requirements should be further developed to reflect the specific future operational needs of each line segment.

It is further noted that the current AEA does not provide for future electric freight operations and hence further upgrade to the feeder supply network may be required to maintain the current level of passenger service resilience.

9.4 Scope of HV Upgrade – Line 2

Supply to this line will be required at both ends. These will be:

9.4.1 Hamilton

To supply the Hamilton end of this line a single phase 15 MVA, 220/55 kV transformer will need to be installed at the Hamilton Substation (HAM). We have proposed this will be located within a switchyard extension outside the eastern side of the existing 220 kV switchyard. The 220 kV ring bus would be extended into this area with two pairs of bus disconnectors to allow the transformer to be connected. This connection point would be at the opposite end of the bus to the two existing KiwiRail supply transformers, thus improving reliability of supply.

Transpower suggested that instead of installing an additional transformer it may be more economical to replace the two existing KiwiRail supply transformers T7 and T8 with two larger 30 MVA transformers. This option was not adopted due to concerns over the likely need to upgrade the 55 kV supply circuit and switchgear. While this option may be more expensive and offer reduced resilience (as compared to the additional transformer option) it is worth further consideration due to potential whole-of-life cost advantages given KiwiRail would be left with all new assets.

9.4.2 Kaitimako

To supply the Mt Maunganui end of this line two single phase 20 MVA, 220/55 kV transformers will need to be installed at the 220 kV Kaitimako Substation (KMO). We have proposed these will be located within the switchyard, one at each end of the 220 kV bus. The bus would need to be extended to allow for these connections and some of the existing bus disconnectors will need to be replaced to allow for connection. This connection arrangement would allow for at least one transformer to be available for any maintenance outage scenario, thus allowing a reliable supply.

Transpower advised that due to existing supply constraints it would not be feasible for KiwiRail to take supply from either of the two 110 kV GXPs in the Tauranga region (Tauranga (TGA) or Mt Maunganui (MTM) substations). The cost of upgrades required would be very high. Additionally taking supply at 110 kV would mean this would need to be balanced 3 phase rather than single phase so expensive SFCs would also be required at the TSS. The possibility of taking supply from one of these 110 kV GXPs could be reassessed at a later stage in case the constraint(s) has been remedied.

9.5 Scope of HV Upgrade – Line 3

No additional transformers are required at the Bunnythorpe GXP to supply the Palmerston North end of this line.

To supply the Waikanae end of this line two single phase 12.5 MVA, 220/55 kV transformers will need to be installed at the 220 kV Paraparaumu Substation (PRM). We have proposed these will be located alongside each other in the old disestablished 110 kV part of the switchyard. They would each be connected one to each of the two 220 kV circuits supplying the switchyard. The switchyard would need to be extended to make these connections, which would be made by short lengths of 220 kV cable. This connection arrangement would allow for at least one transformer to be available for any maintenance outage scenario, thus allowing a reliable supply.

Transpower advised they are considering the long-term future possibility of constructing a new 220 kV GXP at Otaki to reinforce supply to the local lines company (Electra Ltd). This possible supply option was not considered further as at this stage this GXP is just a future possibility and its cost would likely exceed $40 M. If this GXP supply option was to be requested from Transpower it is presently unclear how its cost would be shared between KiwiRail and Electra Ltd.

9.6 Scope of HV Upgrade – Line 4 – Option 1

To supply this line two 3 phase 12.5 MVA, 110/33 kV transformers will need to be installed at the 110 kV Greytown Substation (GYT). We have proposed these two transformers would be located outside the existing 110 kV switchyard, on the western side of the substation. They would be connected one to each of the two separate 110 kV buses. The transformers would each be connected to its own 33 kV TSS feeder cable circuit. These would supply a TSS located centrally on the line, at the 58 km point on the line, just north of Featherston. Two SFCs would be required at the TSS to convert the 3 phase 33 kV to 25 kV single phase.

9.7 Scope of HV Upgrade – Line 4 – Option 2

For this option two 7 km sections of the traction line at Featherston and Masterton would operate at 1600 V DC. We have allowed for taking 3 phase supplies at 11 kV from the nearest local lines company (Powerco) zone substations. Dedicated 11 kV feeder circuits from the zone substations have been assumed to minimise the possibly unacceptable effect of voltage variation on existing Powerco customers if supply is taken from an existing feeder. The TSS feeders would be 3 core 185 mm^2 Al XLPE cables installed in 150 mm ducts. Since these circuits would effectively operate in 'duty/standby' mode they can be installed in the same trench, spaced 300 mm, without concern over thermal derating.

9.8 Cable Route Arrangements

We recommend running underground cable circuits between the GXPs and TSSs. While the installation costs for underground cables may be more expensive than overhead lines, objections from the nearby local inhabitants as well as the consenting and planning costs are likely to be much less, thus making this option simpler and more economic. Feasible cable routes and cross-sections for each cable route type are provided in the sketches in Appendix F. These formed a basis for determining cable route lengths for costing.

We have allowed for running 38/66 kV single core 300 mm^2 Al XLPE cables for the two phase 55 kV circuits, installed in 150 mm uPVC ducts, spaced 500 mm apart in the same trench, at a depth of at least 1000 mm. Ducts will also be installed for running fibre optic (FO) cables for communications and protection.

For Line 4 option 1 we have allowed for running 3 x 1 core 300 mm^2 Aluminium, with XLPE insulation, solid bonded copper wire screens and MDPE or similar outer sheaths. While for Line 4 option 2 we have allowed for running 3 core 185 mm^2 Aluminium, with XLPE insulation, solid bonded copper wire screens and MDPE or similar outer sheaths.

9.9 Estimates

Our cost estimates were largely developed using the Transpower TEES cost database. This database covers the costs of detailed component plant installation and is suited for costing projects that have been developed to the concept stage. This method is less suited for the 'feasibility' stage of this project.

Transpower determined what they describe as 'out turn' costs based on costs experienced for similar projects. Transpower cautioned that these 'out turn' estimates would likely be higher than TEES based estimates, implying that TEES may not cover as much as it should and tends to be optimistic in not allowing for the cost of dealing with site specific difficulties.

The out-turn costs that Transpower provided proved to be comparable to the TEES based estimate that Beca developed for the station plant and installation costs. However, after adding project related on-costs and contingencies our final estimates for this work were greater than the upper bound for the range of costs provided by Transpower. We have elected to retain the TEES costings unadjusted.

9.10 Assumptions/Risks

The following assumptions were used when developing the HV supply component the cost estimate:

- Transformer and switchgear details are based on the existing NIMT 220/55 kV single phase supply transformers;
- Transformer rated power is as established under this study, to cover projected power requirements in 2050;

- Where two transformers are installed they are arranged to provide ‘N – 1’ security, effectively available to operate in ‘duty/standby’ mode;
- GXP connections are configured to ensure supply can be maintained whenever any transformer or its switchgear is removed from service for maintenance;
- It is assumed that it will be acceptable to Transpower to take 2 phase (unbalanced) supply from each of the 220 kV GXPs. This will need to be confirmed by Transpower after they undertake system modelling. If Transpower determine taking 2 phase supply is unacceptable it will be necessary to take 3 phase supply and install static frequency converters (SFCs) at the TSS;
- Switchgear and cables for the connection between the GXPs and the TSSs are rated 66 kV, this being the next standard voltage above that necessary to carry two phase 55 kV;
- The circuits connecting the GXPs to the TSSs will all be run as underground cable circuits;
- Because of the ‘N – 1’ security arrangement it is assumed that both circuits to any TSS will not be operating at full load at the same time, thus can be run in close proximity within the same trench;
- A fibre optic (FO) cable will be installed in a separate PVC duct with the power cables between each GXP and TSS, for SCADA and protection purposes;
- No allowance has been made for any harmonic filtering that may be required;
- For the two phase supplies the assumed cable size is 2 x 1 core 300 mm^2 Aluminium, with XLPE insulation, solid bonded copper wire screens and MDPE or similar outer sheaths, capable of carrying 20 MVA as required for the supply from Kaitimako;
- For the three phase 33 kV supplies required for Line 4 Option 1 the assumed cable size is 3 x 1 core 300 mm^2 Aluminium, with XLPE insulation, solid bonded copper wire screens and MDPE or similar outer sheaths, capable of carrying 12.5 MVA;
- For the three phase 11 kV supplies required for Line 4 Option 2 the assumed cable size is 3 core 185 mm^2 Aluminium, with XLPE insulation, solid bonded copper wire screens and MDPE or similar outer sheaths, capable of carrying 2 MVA;
- Cable routes generally run in the rail corridor or alongside roadways where possible, to avoid running across private land as much as possible; and
- Thrust boring has been allowed for wherever state highways or busy roads are crossed.

10 Clearance Workstream

10.1 Methodology

For the purpose of this study bridges which cross a railway line have been identified and further categorised to establish for high level costing purposes the scope of bridge treatment required to enable electrification of the track beneath these bridges.

10.2 Identification of Rail Overbridges

It was originally our intention to make use of point cloud scanning data for each line to identify conflicts between existing built infrastructure within the railway corridor and the clearances required to construct an overhead line system. This would have allowed us to identify low bridges as well as other issues such as station canopies and limited clearance cutting embankments/retained slopes.

Unfortunately, this data was not quickly available for use in this study and a more belt's-and-braces approach was employed.

In lieu of the point cloud data, bridge data was gathered from alternative sources listed as follows:

- Terrain and satellite imagery sourced from Google Maps, Google Earth and open source KiwiRail GIS;[1]
- Construction record drawings of overbridges retrieved from Waka Kotahi New Zealand Transport Agency and local authorities; and
- Inspection Reports provided by KiwiRail.

These information sources were studied to collect the following information for each rail overbridge:

- Bridge location and KiwiRail Bridge Number for referencing purposes;
- State highway or local road crossing on the bridge over the railway;
- District where located;
- Asset owner;
- Basic geometric information including estimated bridge width, number of traffic lanes, total bridge span, number of spans;
- Age of the bridge;
- Type of construction and construction materials; and
- Vertical clearance between top or rail and bridge deck soffit.

This information has been collated into Appendix H.

10.3 Categorisation of Rail Overbridges

10.3.1 Treatment Categories

Based on collected and populated data all rail overbridges were categorised as follows in terms of the treatment required to accommodate overhead line equipment:

- Do nothing: Applicable to bridges of modern construction for which it would be appropriate to assume a minimum clearance of 5.0 m or bridges for which a clearance of minimum 5.0 m can be proven, such as via construction record drawings;
- Raise bridge: Based on the type of bridge construction, established either from construction record drawings obtained or due to the age of the bridge, it is assumed that the bridge deck can be raised to

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[1] Publicly accessible Information: https://gis.kiwirail.co.nz/maps/?viewer=levelcrossings

accommodate overhead line equipment. Generally this requires that the bridge deck is supported on bearings and is not integral with the piers and abutments; and
- Replace bridge: Due to the type of construction and/or age of bridge it is assumed that it would not be financially or technically viable to modify the existing substructure in order to raise the bridge deck or replace the existing deck with a new superstructure onto the existing piers and abutments.

10.3.2 Assumptions

For the above categorisation the following assumptions have been made:

- Bridges with existing clearances of >5 m can receive a waiver from KiwiRail standards (i.e. an acceptable bespoke OHL design can be established that will meet clearance requirements, based on experience from previous electrification projects) which would otherwise require 5.5 m clearance;
- Bridge raising solutions have been developed to provide for 1m average increase in clearance, based on an estimated range of existing clearances of 4.2 m to 4.8 m, see further details in section 10.4 of this report;
- Where in the absence of confirmed data the existing clearances had to be estimated, other criteria, in particular the age of the structure was taken into consideration to assess the likely clearance (see notes below); and
- For bridge replacements an area cost rate for a replacement structure has been applied and multiplied by the anticipated area of the replacement bridge footprint

In regard to age of construction, the following trends were observed by comparison of bridges across all rail sections subject to this study:

- Bridges built up to the end of the 1960's appeared to provide vertical clearance of less than 5 m;
- Bridges built since the 1970s appeared to provide vertical clearances of more than 5 m;
- Bridges built since the 1990's appeared to provide vertical clearances of 5.5 m (current KiwiRail standard); and
- The majority of reinforced concrete box culverts accommodating rail lines appeared to provide clearances of less than 5 m.

10.3.3 Limitations in Bridge Data and Categorisations

The following limitations apply to the data collected:

- In many instances, in the absence of construction record information basic geometric information could only be estimated; and
- Assumptions in regard to bridge clearances were formed based on observing trends in the bridge data being collected as described above.

10.4 Bridge and Approach Raising Options

10.4.1 Overview

The following raising concept solutions have been developed for rough order costing purposes to accommodate situations in which:

- The rail track is at grade, meaning that the extensive embankment approaches lead up to the railway overbridge to provide the vertical clearance to crossing of the railway line; and
- The road crossing the railway is at grade, meaning that the railway is situated in a cutting or localised depression relative to the overall topography, including the road alignment.

Therefore, in addition to structural bridge raising concepts, concepts for raising the bridge approaches have also been developed.

10.4.2 Bridge Raising Concepts

Structural retrofit options have been developed to reflect the different types of bridge structures encountered:

- Single span bridge;
- Multi-span bridges; and
- Reinforced concrete box culverts.

The retrofit concepts for single span bridges and multi-span bridges have the retrofit works at the abutments in common. At the back of the abutments a discrete number of reinforced concrete bored piles are installed. The piles support the additional weight of the raised abutment beam and provide for additional seismic resilience, since the seismic weight of the retrofitted bridge structure also increases. It also assumed that in the case of multi-span bridge retrofits the increased seismic weight at the piers is also transferred to the abutments to eliminate the need for seismic strengthening at the piers.

For multi-span bridge retrofits, it has been assumed that the pier walls or pier crossheads can be raised by the addition of a new concrete beam above the existing crosshead or wall and the additional gravity load can be resisted by the existing pier foundations without the need for additional underpinning to resist increased gravity load effects, since the increase in load is relatively low.

For all bridge raising solutions it is assumed that a new bridge deck will be provided onto the existing piers and abutments and that the existing span geometry is retained. Bridge decks are assumed to be hollow core planks or concrete beams with slabs for concrete bridges, and steel composite beams for steel bridges.

The treatment of reinforced concrete box culverts is quite different since box culverts resist significant lateral pressures under both non-seismic and seismic loading conditions due to their type of construction, and raising of the culvert height increases the soil pressures imposed onto the box culvert. Also if a box culvert was raised simply by lifting the roof slab, the reinforcement in the walls is unlikely to be adequate.

Therefore for box culverts the retrofit of contiguous bored pile walls has been assumed which will then allow a transfer of lateral soil pressures from the existing box culvert to the retrofitted piled wall and support of a new deck structure from the piles, all of which can be constructed outside of a Block of Line, except for demolition of the roof slab and installation of the new bridge deck.

For these bridges retrofit solutions significant works are envisaged to be carried out in advance to a Block of Line to minimise disruptions to train operations, although BOL’s will still be required to remove the existing bridge decks, raise the piers and abutments and install new bridge decks.

Sketches have been provided (refer Appendix G) to illustrate the retrofit concepts above while highlighting high level construction sequencing and methodology for rough order costing purposes.

10.4.3 Approach Raising Concepts

Based on the situations described above two concepts have been developed to suit the situations described in section 1.4.1 (refer Appendix G).

The raising options differ mainly in the approach length affected and the positioning of retaining structures to minimise the increase in road embankment footprint, which may otherwise have resource consent implications, such as exceedance of a designation of a state highway or other infringement on third party property holdings.

11 Signaling Workstream

Siemens were commissioned by KiwiRail to provide a high-level view of the cost to upgrade the signaling on each of the route segments proposed for further electrification. The output of this exercise is captured in the Siemens memo provided in Appendix B.

The costings generally reflect a full resignaling of each route segment, excluding some small pockets where signaling upgrades have already occurred and also excluding line 4 which is proposed for upgrade in advance of electrification.

The high-level scope of signaling works and costs have been established through comparison with previous/current projects. In particular the signaling upgrade of the Otaki passing loop and the planned upgrade associated with the electrification between Papakura and Pukekohe. Scope of works does not include allowance for ETCS level 2 but does make allowance for SIMBIDS on line 1 which is double-tracked. It is further assumed that existing power supplies and fibre-optic comm capacity will be sufficient for the new signaling equipment.

The Siemens scope and costs did have some key exclusions which have been separately priced. These include:

- Point machines;
- KiwiRail costs; and
- Civil works for new signaling including foundations for signals, LOCs, WOCs, generator huts, Axle counter heads, etc, and a new combined services route (CSR) where KiwiRail have indicated existing ducting is deficient.

Siemens do not provide an indication of their confidence in the costs but do note the baseline project costs are generally a few years old.

12 Estimating Workstream

12.1 Basis of Estimate

The cost estimate has been split into the individual lines (1-4), and further split per workstream; Clearance, Overhead line equipment (OLE), Traction substation, High Voltage and Signaling.

The inputs for the individual workstreams have been described within this report and summarised below. More detailed estimate summaries are provided in Appendix A.

12.1.1 Clearance

- Costs for the bridge works are based upon typical m2 sections, extrapolated for the various structure deck sizes.
- Considerations for urban and rural construction have been included within the costs.

12.1.2 OLE

- Typical rates per km have been established by Systra. Various key components have been checked against typical NZ rates, which has then been factored into the base cost.
- As these base costs were largely based upon green-field sites, an uplift percentage has been applied to each line to allow for construction on an operational railway, particularly to allow for loss of productivity and increased labour costs.

12.1.3 Traction Substation

- Typical rates for items have been established by Systra. Various key components have been checked against typical NZ rates, which has then been factored into the base cost.

12.1.4 High Voltage

- Typical rates for switchyard works have been developed by Beca using Transpower’s TEES estimating system. Indicative budget indications have been provided by Transpower. The physical works costs developed by Beca are within the range provided by Transpower.
- Typical rates for cable works have been developed using first principal methodologies. Different rates for greenfield, thrust bored and asphalt treatment have been created, with approximate percentage weightings against each rate based on the indicative route shown on google earth.

12.1.5 Signaling

- Pricing included for lines 1-3 as per Siemens initial pricing submission.
- No pricing received from Siemens for line 4, this is considered excluded from this scope and included within an existing KiwiRail committed budget.
- Signaling related civil engineering works costs have been developed utilizing a mixture of methods. Beca have included an allowance for duct routes, pits & UTX's for the fibre optic route as provided by KiwiRail. The bases, foundations and points machines etc. to support the signals installation has been quantified where possible from information provided by Siemens and priced as a percentage addition where Beca were unable to quantify specific base numbers. The cost of the civil engineering works for the signals equate to approximately 20-32% of the Siemens supplied signals costs.

12.1.6 On-Costs

We have made the following allowances in addition to the physical works costs for other project related costs, such as:

- 1% for protection costs/ BOL costs etc;
- 3% for traffic management and temporary works;

- 1% for environmental compliance;
- 18% for contractor preliminary and generals (off-site overheads and profit deemed included within the rates);
- 13% for consultancy fees including design for the concept, developed and technical and Implementation stages of the project;
- 1.5% for KiwiRail internal costs for the concept, developed and technical and implementation stages of the project;
- 1.5% for planning and consent including consent monitoring fees; and
- Contingency, which has been assessed using a quantitative risk analysis (refer next section) and provides for a confidence range for each line. However, as an average, the effective contingency amount applied to the estimate is 27%.

12.2 Estimate Summary

The expected estimate for the full scope of electrification is $1.397bn (with AC on line 4) and $1.259bn (with lengths of DC on line 4). A summary is provided below including a breakdown by workstream.

KiwiRail - North Island Electrification

Costing Options	Expected Estimate ($)	Range Lower	Range Upper
Line 1 - Te Rapa to Pukekohe	$430 M	$390 M	$472 M
Line 2 - Hamilton to Mt Maunganui	$426 M	$388 M	$466 M
Line 3 - Waikanae to Palmerston North	$339 M	$309 M	$371 M
Line 4 - Upper Hutt to Masterton - Option 1 - AC	$226 M	$206 M	$247 M
Line 4 - Upper Hutt to Masterton - Option 2 - DC	$83 M	$76 M	$90 M
Terminii	$8 M	$7 M	$12 M
Subtotal (Line 4 AC)	**$1428 M**	**$1300 M**	**$1568 M**
Subtotal (Line 4 DC)	**$1285 M**	**$1170 M**	**$1411 M**

Total Cost Breakdown (AC)	Expected Estimate ($)
Clearance	$151 M
Overhead Line Equipment - OHL	$625 M
Traction Substation	$143 M
High Voltage (HV)	$171 M
Signalling	$340 M
Subtotal (AC)	**$1428 M**

Total Cost Breakdown (DC)	Expected Estimate ($)
Clearance	$151 M
Overhead Line Equipment - OHL	$544 M
Traction Substation	$73 M
High Voltage (HV)	$178 M
Signalling	$340 M
Subtotal (DC)	**$1285 M**

12.3 Quantitative Risk Analysis

A Quantitative Risk Analysis (QRA) has been completed as part of this study. This approach utilises Monte Carlo statistical modelling to provide a continuum of possible out-turn costs, from which the expected estimate and confidence levels can be determined. Palisade @Risk software has been used to generate 10,000 simulations of the pre-determined risk register to produce varying percentile values which are included within the estimate summary. A workshop was held with the key client and design leads where a number of key assumptions were tested and the risks of change from the base assumptions discussed. These assumptions have been input into the statistical modelling to inform the project contingency.

The mean risk generated by this analysis is then used to inform the project contingency for the project. The effective contingency values range from 25-39% of the net project cost, with an average 27% across the total value of the project. This is considered a reasonable allowance when considering the nature of, and current stage of, the project lifecycle.

The statistical modelling also reports on the 5th and 95th percentile values. These values represent the statistical probability with a level of confidence that the final out-turn cost will not exceed this value, based on a priced risk register. The 5th percentile represents a 5% level of confidence (lower bound) and the 95th percentile represents a 95% level of confidence (upper bound) that project costs will not exceed this value. Figure 1 provides a graphical representation of the cost estimate terminology.

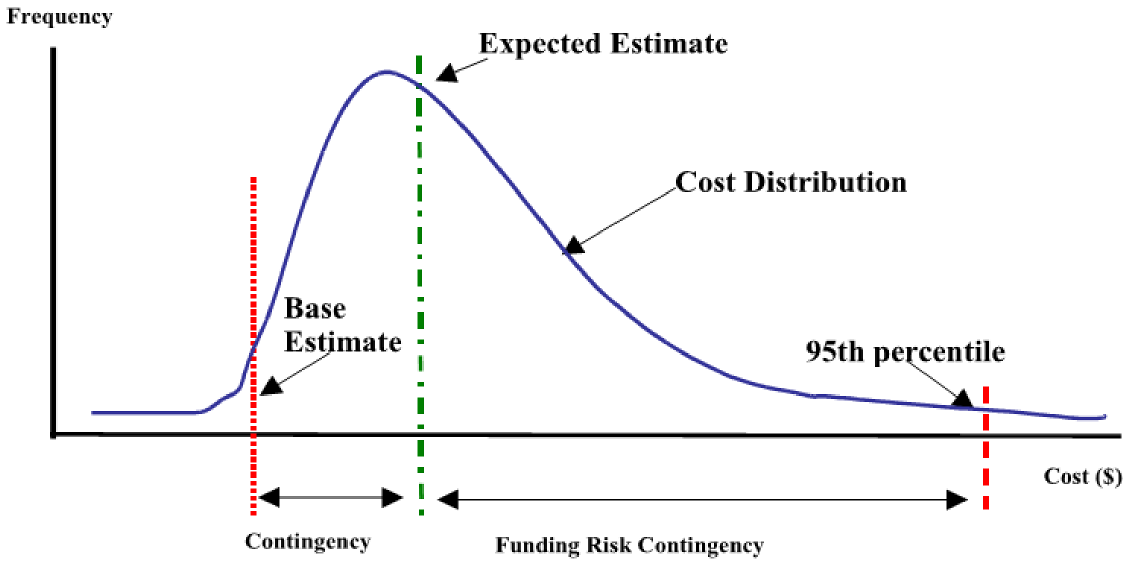

Figure 1 - Risk-adjusted cost estimate terminology (For illustration purposes)

The QRA modelling provides the P5, Mean and P95 values and effective contingency percentages as displayed within the below table.

Project Name:	**North Island Electrification - KiwiRail**							
Description:	**Residual Cost Risk Quantitative Risk Analysis - Pert Distribution**							
Summary								
Line	**Project Value (incl P&G)**	**P5**	**P5 %**	**Mean**	**Mean %**	**P95**	**P95 %**	
Line 1	$ 334,826,178	$ 54,679,975	16%	$ 94,694,826	28%	$ 137,531,867	41%	
Line 2	$ 330,305,647	$ 57,229,025	17%	$ 95,320,217	29%	$ 135,939,643	41%	
Line 3	$ 256,626,137	$ 52,327,580	20%	$ 82,269,658	32%	$ 113,906,888	44%	
Line 4 AC	$ 169,771,474	$ 36,468,932	21%	$ 56,078,073	33%	$ 76,774,476	45%	
Line 4 DC	$ 59,943,645	$ 15,635,350	26%	$ 22,648,475	38%	$ 30,215,783	50%	
Terminii	$ 5,802,996	$ 1,494,849	26%	$ 2,524,638	44%	$ 3,637,424	63%	
Total AC	**$ 1,097,332,432**	**$ 202,200,362**	**18%**	**$ 330,887,411**	**30%**	**$ 467,790,298**	**43%**	
Total DC	**$ 987,504,603**	**$ 181,366,780**	**18%**	**$ 297,457,813**	**30%**	**$ 421,231,604**	**43%**	

Line 1&2 – The effective contingency of 28%/29% for Lines 1 and 2 is similar due to the risk profiles already considered within the base estimate. The largest risks identified to these lines are the potential for additional costs for the signaling workstream, where we have modelled a best case 20% deduction to the Siemens provided pricing and a worst case 50% increase to the Siemens costs.

Line 3 – The risk profile for Line 3 is considered similar to Lines 1 and 2, however the mean risk is circa 4% higher. This is largely driven by the additional estimated value of structures which are affected within the clearance workstream of this line (~$41m physical works versus ~$17.7m and ~$21m).

Line 4 AC&DC – The risk profile for Line 4 is slightly different to Lines 1-3, and therefore attracts a different risk profile of 30% for the AC and 35% for the DC. The largest difference to Lines 1-3 is that no clearance works or signal costs have been included within the base estimate. For the valuation of the clearance items, we have considered that the absolute best case is that zero works will be required, and the worst case that 1 new structure will be required at a cost of ~$5m. For the valuation of the signals risk, we have similarly suggested that the best case will be for zero risk allowance, however the worst case a $1m allowance, for any items not already included within the committed scope of other KiwiRail projects.

Terminii – The mean risk profile for the termini has been assessed at ~39% of the physical works. This is the largest application of contingency across all of the routes. Following discussions within the risk workshop, it was considered that the termini items include the largest risk within the scoping in relation to the potential outturn lengths. For the financial modelling of this we have considered no further opportunities can be provided within the current estimated routes (i.e. the estimated length will not decrease) and assessed the potential worst case at a 40% increase to the currently assumed 5kms.

The full risk registers and statistical model results can be found in Appendix L.

12.4 Discussion Regarding Accuracy

Where risks continuously reside with escalating costs of construction projects due to unknown and unforeseen influences, it is considered that the application of Risk based estimating adds a scientific approach to the valuation of contingencies and project risks.

The estimate range provided between the 5th and 95th percentile is an indication of the degree to which the final cost outcome for a given project will vary from the expected estimated cost – it is not an additional contingency. The current P5 (lower range) value for the project is $1.31bn for the AC option and $1.18bn for the DC option. This is then increased to $1.396bn (+$85.6m) for the AC and $1.258bn (+$76.8m) for the DC Expected estimates, which includes the base contingency of ~27%. The upper range of the project, or P95 is estimated at $1.487bn for the AC option and $1.340bn for the DC option. This represents a range between the 5th and 95th percentiles of $176m for the AC option and $158m for the DC option.

This range highlights the risks that can impact the project that are difficult to predict or value. As the project gets further defined through the design stages and closer to tender this range will reduce to reflect the level of confidence in the design and information available and level of risk.

12.5 Disclaimers

This report is solely for our Client’s use for the purpose for which it is intended in accordance with the agreed scope of work. It may not be disclosed to any person other than the Client and any use or reliance by any person contrary to the above, to which Beca has not given its prior written consent.

This report must be read in its entirety and no portion of it should be relied on without regard to the report especially the assumptions, limitations and disclaimers set out in the estimate notes and elsewhere in the report.

While Beca believes that the use of the assumptions in the report are reasonable for the purposes of this study, Beca makes no assurances with respect to the accuracy of such assumptions and some may vary significantly due to unforeseen events and circumstances.

The cost estimates presented in this report have been developed for the purposes of comparing options and may be used for preliminary budgeting. They should not be used for any other purpose. The scope and quality of the works has not been fully defined and accordingly the estimates are not warranted or guaranteed by Beca. These estimates are typically developed based on budget quotes for some equipment items, extrapolation of recent similar project pricing and Beca's general experience. A functional design should be undertaken for budget setting purposes.

13 Assumptions / Exclusions / Limitations

Key assumptions that inform the scoping of the OHL, HV and Clearance workstreams are outlined within sections 8, 9 and 10. Additionally the Siemens memo articulates key assumptions that inform the scoping of the signaling upgrade scope.

These key assumptions were captured into a single sheet (refer Appendix K) in support of the QRA exercise that established the contingency sums for each line segment.

Additionally, it is worth noting the following:

- The future operation of electric-hauled freight services envisaged under this study place a significant reliance on an anticipated 'last-mile' capability of the new electric locomotives. This capability is undefined but will be critical for movements to/from private sidings and container terminal depots onto the mainline network. This technical feasibility of this capability needs to be better defined so that future studies can have greater confidence in the extent to which these 'last mile' movements can be supported.
- We have not assessed the ability for existing electrification infrastructure to support a transition from diesel-hauled to electric-hauled freight services.
  - This is not anticipated to be an issue on the central NIMT where there is plenty of capacity.
  - However this may be an issue in the AEA and WEA where the traction system has been sized to support only passenger services.
  - In particular, analyses by Others into the resilience of the AEA makes no allowance for future electrified freight services that may operate between Westfield/Southdown and Pukekohe.
  - Therefore, until proven otherwise, there is a risk that operation of freight services during peak commute times across the AEA and WEA could overload existing traction supplies and/or affect timetable resilience under perturbed scenarios.
- The traction supply solutions and HV supply solutions hinge on a variety of assumptions regarding future timetable, future rolling stock and future track configuration and are subject to a broad rule-of-thumb that the traction system need only supply 25% of the total tractive load that a line might experience during peak operation, this on the basis that trains are in tractive mode only 25% of the time.
  - The only way to gain greater confidence in the proposed solutions will be to model these systems more accurately.
  - This will require greater certainty on the timetable and rolling stock assumptions.
  - Detailed modelling of the alignment of the route including curves and vertical gradients.
  - Thereby identifying any voltage drop or wire temperature issues that may become the limiting factors for the design and therefore aspects to improve through further iteration of the design and modelling.
- Land acquisition and/or easement costs are excluded from the estimates as are escalation of rates (noting there is no view currently on the likely timing of construction of any of the proposed further electrification).