Queensland Competition Authority

FINAL

AURIZON NETWORK REVIEW OF BALLAST UNDERCUTTING SCOPE AND COSTS

20 NOVEMBER 2015

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EXECUTIVE SUMMARY

CMT and Marsden Jacob Associates (the Review Team) were commissioned by the Queensland Competition Authority to conduct an independent assessment of the efficiency[1] of Aurizon Networks ballast undercutting scope and costs for the 2014 Draft Access Undertaking (UT4).

CMT were then tasked to comment on these aspects in relation to the Central Queensland Coal Network (CQCN) taking into consideration the specific context of this system.

The methodology adopted to conduct this review comprised three major components which included:

- A review of current publications, research work, modelling and Aurizon Network reports to assess the technologies and processes applied by Aurizon Network in determining ballast condition and developing their undercutting scope forecasts.
- A review of the actual forecast scope.
- An analysis of the Aurizon Network costing model and a comparative review of forecast costs against historical trends and an independent cost build up.

On completion of this assessment the Review Team found that:

1. Aurizon Network uses a variety of methods to determine their future maintenance undercutting scope:

    - For mainline undercutting requirements Ground Penetrating Radar (GPR) data is primarily used to ascertain the condition of the ballast. Fouling rates and ballast undercutting requirements are then determined from GPR data sets; fouling is rated by the volume-based Percentage Void Contamination (PVC) index.
    - For turnout undercutting requirements a combination of trial pits, tonnage usage wear rates and design life are used.

    As a relatively new technology GPR has its limitations, however, overall Aurizon Network's use of GPR data to determine mainline ballast condition is more efficient and has advantages over the traditional trial pit, tonnage usage wear and design life methodology employed previously. The use of traditional methods to determine turnout undercutting requirements is considered reasonable in view of the limitations of reflected radar waveform technologies.

2. Aurizon Network uses an intervention PVC level of 30%, that is, when 30% of the voids within the ballast bed below sleeper are filled. Contemporary international opinion supports the theory that ballast cleaning is deemed appropriate when 30% of the voids are filled with fines, and absolutely necessary when greater than 40% are filled. Hence a preliminary intervention threshold of 30% is considered prudent for the CQCN.

3. The approach taken by Aurizon Network to develop the mainline forecast uses only the GPR results and ignores both adverse impacts on the infrastructure such as tonnage usage rates and beneficial impacts on the rate of fouling such as the recently implemented coal management veneering program. This creates a risk of under or overestimating the future undercutting task and may oversimplify the calculation of fouling rate over time. However, Aurizon Network have stated that the implementation of the new Network Asset Management System (NAMS) will, in the future, allow for efficient documentation and information mining and hence will provide an efficient and robust method of combining condition information with historic trends and asset material characteristics to make informed asset maintenance decisions. However, this does not detract from the fact that UT4 forecasts are lacking in this regard and the Review Team believes that a small investment in statistical expertise could significantly improve the knowledge base ahead of the NAMS system being operational.

4. The cost analysis review revealed that the unit cost per kilometre for mainline undercutting increases significantly (in both nominal and real terms) across the project period. Two main drivers behind this cost increase were:

[1] A comprehensive efficiency assessment based upon the best available information was undertaken. It should be noted that a detailed industry benchmarking exercise was not included as part of this assessment.

- Escalating internal charges due to increased outsourcing of staff and reduced full-time resources.
- Increases in on-track vehicle maintenance costs due to requirements for additional equipment to complete the increasing number of kilometres that need to be undercut.

5. The cost analysis review identified significant increases in Aurizon Network's ballast-related expenses over the UT4 period. Two key issues were identified:
   - On-site sourcing of ballast is increasing the cost of ballast by around $1 million in FY 16 and FY 17. This is not considered prudent, because ballast can be accessed considerably more cheaply through other means.
   - Due to age and inefficiencies of the current undercutting machine the RM900 a significant volume of ballast is not able to be screened and returned. Changing to newer machines could facilitate cleaning of more ballast with elevated PVC levels, and reduce fleet maintenance costs and expected ballast costs.

6. The Review Team identified the following underlying required changes and recommendations to Aurizon Network scope and unit costs:
   - Cost increases from on-site sourcing in FY16 ($992,574) and FY 17 ($1,166,529) should be removed.
   - Cost for GPR capture in FY 15 should be removed as these works are not being undertaken.
   - The number of Turnouts should be reduced from 169 to 121 due to previous period shortfalls.

   The impact of these changes on the scope and unit costs is presented in the Table (a).

Table (a) Changes and recommendations to Aurizon Network scope costs based on methodology review

(Nominal $)	FY14 Actual	FY15	FY16	FY17	Total
C01 + C14 - Mechanised Ballast Undercutting	43,153,814	54,277,115	62,967,919	66,200,150	**226,598,998**
GPR Costs	1,200,000	0	1,200,000	1,200,000	**3,600,000**
C03 + C13 -Turnouts	5,589,777	5,082,093	5,191,594	5,624,942	**21,488,406**
C02 - Other Ballast Undercutting	4,616,411	4,723,179	4,900,792	5,178,787	**19,419,169**
Underbridges	0	0	0	0	0
Total Ballast Undercutting Costs	**54,560,002**	**64,082,388**	**74,260,305**	**78,203,879**	**271,106,573**

7. Furthermore, the results from the comparative review of historic trends and independent cost build up indicates that the underlying scope/cost recommendation for the mainline unit cost should be constrained to $400,000 per kilometre in $FY15 and escalated by MCI thereafter (see Table (b)).

Table (b) Changes and recommendations to Aurizon Network scope cost based on cost review

(Nominal $)	FY14 Actual	FY15	FY16	FY17	Total
C01 + C14 - Mechanised Ballast Undercutting	43,153,811	51,684,880	54,530,000	58,909,502	**208,278,193**
GPR Costs	1,200,000	0	1,200,000	1,200,000	**3,600,000**
C03 + C13 -Turnouts	5,589,777	5,082,094	5,191,594	5,624,942	**21,488,407**
C02 - Other Ballast Undercutting	4,616,411	4,723,179	4,900,792	5,178,787	**19,419,169**
Underbridges	0	0	0	0	0
Total Ballast Undercutting Costs	**54,560,000**	**61,490,152**	**65,822,386**	**70,913,231**	**252,785,769**

Note: To avoid double counting the proposed cost reduction for on-site sourcing (see Table a) has been removed from the C01 cost estimate.

1. BACKGROUND

1.1. QUEENSLAND COMPETITION AUTHORITY

The Queensland Competition Authority (QCA) is an independent statutory body responsible for assisting with implementing competition policy in Queensland. The QCA's role is to achieve regulatory outcomes that uphold efficient supply and use of regulated services. This is achieved through the promotion of competitive markets in Queensland and by ensuring that the users of essential economic infrastructure pay fair and reasonable prices for the use of the infrastructure.

1.2. AURIZON NETWORK

Aurizon Holdings Limited is a national provider of rail and road based freight transport. Aurizon Network Pty Ltd (Aurizon Network), a wholly owned subsidiary of Aurizon Holdings Limited, is the Rail Infrastructure Manager of the 2,670km Central Queensland Coal Network (CQCN) (refer Figure 1).

Aurizon Network controls, manages, operates and maintains the below-rail assets on the Central Queensland Coal Network (CQCN). It delivers below-rail services to the CQCN's major mines and is the largest coal export rail network in Australia.

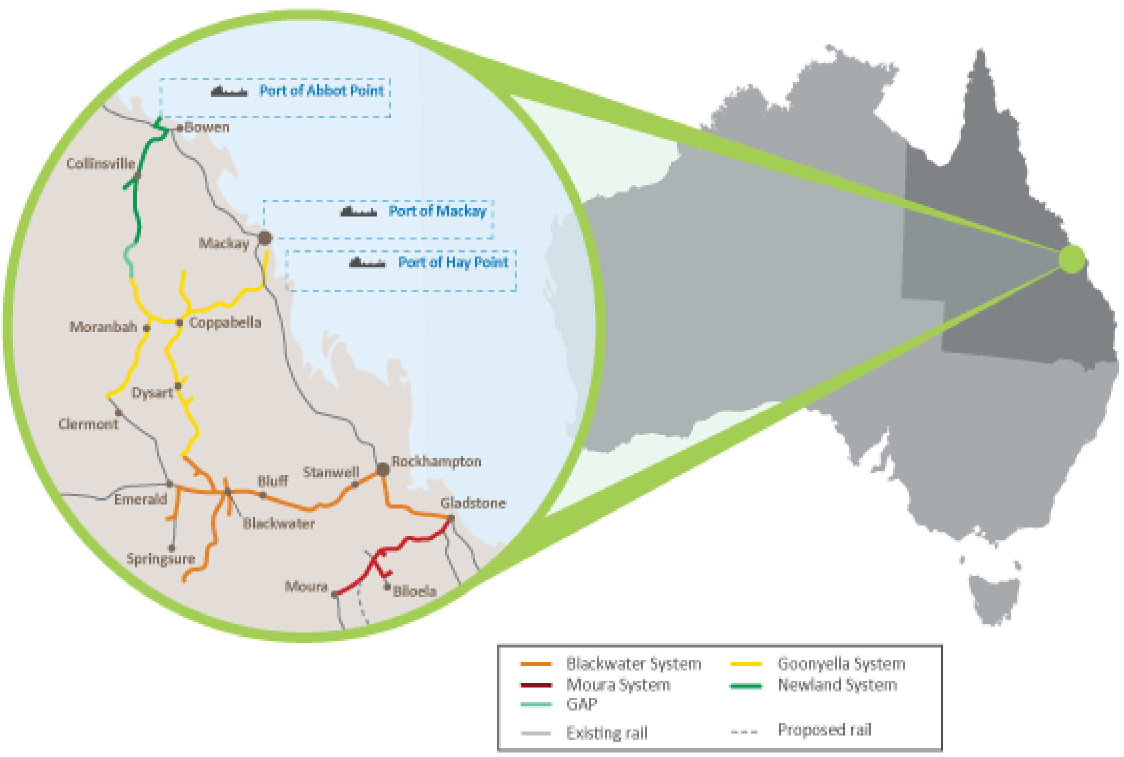

Figure 1 Central Queensland Coal Network

Given its monopoly position, Aurizon Network could set unjustifiably high prices for access to the network or prevent or hinder access in above-rail services. Therefore, to protect access seekers and holders from these possibilities, the CQCN is regulated as a declared service under Queensland's access regime since 1998.

Under section of the *Queensland Competition Authority Act 1997* (the Act), Aurizon Network provides a voluntary draft access undertaking which sets out its proposed terms and conditions of access to the declared service. The QCA decides whether to approve the voluntary draft access undertaking.

1.3. Draft Access Undertaking

In April 2013, Aurizon Network formally submitted its 2013 Draft Access Undertaking (DAU) to replace the previous 2010 Access Undertaking which was due to expire at the end of June 2013. In August 2014, Aurizon Network withdrew the 2013 DAU and submitted a revised 2014 DAU. This withdrawal did not extend to the Explanatory Material, which included the UT4 Maintenance Submission supporting the 2013 DAU.

The 2014 DAU (or UT4) is proposed to apply from FY14 to FY17 (the UT4 period).

The QCA has made two Draft Decisions on the 2014 DAU and Explanatory Material, being the:

- Maximum Allowable Revenue (MAR) Draft Decision (September 2014); and
- Policy and Pricing Draft Decision (January 2015)

Operating and maintenance costs form a key component of Aurizon Network's MAR. In September 2014, the QCA released its Draft Decision on the MAR for the 2014 DAU.

1.4. Draft Decision on MAR

Of particular relevance to this project, the QCA's MAR Draft Decision proposed an adjustment to the scope of ballast undercutting, effectively reducing costs by approximately one-third. The QCA made this decision on the basis that:

- there appeared to be a lack of clarity regarding the methodology Aurizon Network had adopted to assess the ballast undercutting scope for the UT4 period
- the scope of ballast undercutting should reflect the intervention rate consistent with the GPR-derived intervention rate of 600MNT,[2] rather than pre-GPR intervention rate of 400MNT, which appeared to be the one used by Aurizon Network
- there was inconclusive evidence of a substantive need for corrective ballast undercutting in the UT4 period based on the outcome of the 2013 condition-based assessment.

In December 2014, Aurizon Network responded to the QCA's MAR Draft Decision, with a revised methodology to calculate its ballast scope and ballast cost build up. Aurizon Network proposed the scope and costs shown in Table 1.

Table 1 Aurizon Network's proposed scope and costs in 2014 DAU

Parameters	2013-14	2014-15	2015-16	2016-17	TOTAL
Scope – Km's @ 300mm depth	118	140	140	140	538
Scope - Turnouts	68	54	57	57	236
2014 DAU Revised Costs ($million nominal)	54.56	66.25	76.24	80.44	277.46
2014 DAU Revised Costs ($million FY12)	51.43	60.80	68.26	69.86	250.35

To support the revised ballast scope and cost build-up, Aurizon Network provided additional information to that it provided prior to the QCA's MAR Draft Decision.

[2] Aurizon Network expresses its intervention rate for ballast undercutting in two ways: contamination levels (i.e ballast undercutting is required once a segment reaches a certain Percentage Void Contamination (PVC) level); and usage levels (i.e. ballast undercutting is required once a certain amount of coal (in million net tonnes (MNT)) has travelled over the segment.

Subsequent to Aurizon Network's submission of the revised proposed ballast undercutting scope and costs for the UT4 period, the QCA commissioned CMT Solutions Marsden Jacob Associates (known forthwith as the Review Team) to assess Aurizon Network's revised ballast undercutting scope and costs. The outcomes of the assessment guide the QCA on what constitutes an efficient scope and cost for the CQCN undercutting task for the UT4 period.

1.5. BALLAST

1.5.1. General

Ballast is a selected crushed and graded aggregate material which is placed upon the railroad roadbed for the purpose of providing drainage, stability, flexibility, uniform support for the rail and ties (sleepers) and distribution of the track loadings to the subgrade and facilitating maintenance[3].

New ballast contains approximately 40-45% voids[4] and has the size, shape, density and grading requirements specified to suit the operational requirements and environment. However, although all Australian Railway systems have differing grading requirements, all have a maximum size of 53 or 63mm and are limited to approximately 0.7% of dust passing a 75µm sieve.

The frequency of railway maintenance undercutting is linked to the quality of ballast, which changes continually due to the generation of fine particles (fouling) caused by attrition and ballast degradation. Ballast degradation is a factor of repeated stress from rail loading (attrition), contaminants (either air-borne and/or (mud) rising from the sub-grade), ballast quality, infrastructure and environmental conditions.

The proportion of fouling is generally regarded as the proportion of 'fines', normally expressed as a percentage of the total sample, where the definition of fines being when the grain size falls below the smallest permissible grain size for the ballast. Research indicates the main cause of ballast fouling by attrition is the traffic load, with the rate of development of fines, for heavy haul railways, at about 3.6 – 5.2 kg per million tonnes of traffic[5]. Other sources of fouling include contamination or spillage.

In the CQCN, it has been noted that historically most of the ballast fouling is by coal infiltration and ballast breakdown. This ratio range of contamination was in the order of 70% - 95% coal to 5% - 30% ballast[6]. The introduction in the CQCN of veneering systems and stricter vigilance on wagon loading at the mine load outs should be reducing the differential in this range.

When ballast has reached the end of its life through fouling, intervention and replacement of spoiled ballast is required to avoid impact damage to track and rolling stock.

1.5.2. Ballast undercutting

Ballast on the CQCN is normally graded between 40 and 63mm nominal diameter[7]. The ballast undercutting process aims to extract the fouled ballast of everything below the 40mm diameter and replace it with new ballast. The ballast undercutter achieves this by screening fouling material from ballast particles, recycling screened ballast back into track and dumping fouling material. When assessing the ballast condition prior to ballast undercutting, the track maintainer will determine the percentage of ballast which:

- is fully fouled and cannot be "recycled"
- can be screened and potentially put back into the track (i.e. the screenable percentage).

The latter is called the screenable percentage and generally one would expect that it would be around the 60-70%.

[3] AREMA Manual Volume 1. Chapter 1, Part 2 (2003)
[4] Degradation characteristics of ballast in the field and their measurement, Ionescu. Daniela; LaTrobe 2006
[5] Track Compendium, Lichtberger, Bernhard; Eurailpress
[6] Alternative testing method for the measurement of coal fouling, Feldman, Frank, Nissen, Darryl
[7] 98% passing through the 53mm sieve, 53% passing the 37.5mm and 7% passing the 26.5mm sieve

If fouled ballast includes wet clay, the ballast is 0% screenable and needs to be dumped. In this case new ballast will be required to fully replace the fouled ballast that cannot be screened. Where a percentage of the ballast is to be screened, new ballast will be required to supplement the unscreenable percentage as well as any portion that is screened but found to be not returnable.

The rate of return is defined as the percentage of ballast returned to the track after the ballast cleaning process. The rate of return is influenced by:

- Moisture and/or clay content of the ballast
- The extent of contamination
- Difference in depth of ballast profile from design
- Efficiency of the ballast-cleaning process

A reasonable rate of return would be in the order of approximately 35 – 60%.

Ballast can be replaced manually or mechanically through a variety of methods. However, the most common method of ballast replacement in railways is through the use of an Automated Ballast Cleaning machine, which is the main equipment used in the maintenance task of ballast undercutting (and/or ballast cleaning). On the CQCN, main line undercutting work is predominantly undertaken using the rail mounted RM900 high output ballast cleaner (see below). By contrast, undercutting at turnouts, in mainline locations where additional ballast cleaning is required and the RM900 is not available, and mainline undercutting that exceeds the capacity of the Automated Ballast Cleaning machine, is undertaken using an excavator undercutter.

Figure 2 RM-900 mainline ballast undercutting machine

Due to the narrow construction width of the bridges within the CQCN, it is not possible to undertake ballast undercutting using the RM900 machine or an on-track undercutter. Instead, ballast on bridge decks is replaced using one of two alternative methods. The track is cut at either end of the bridge and then:

- rolled off the deck longitudinally and stored on the track adjacent to the bridge; or
- the rail is unclipped from the sleepers and the track removed on a piecemeal basis.

Once the track has been cleared from the bridge, 100% of the ballast is manually removed and spoiled to a suitable area within the corridor. The deck is then cleaned to ensure it is free of contaminants before the ballast layer is replaced and the track reinstalled.

Ballast undercutting (or ballast cleaning) is a critical infrastructure preventative maintenance activity. As discussed previously fouled ballast reduces the required functionality of the track system as a whole, hence increasing both above and below rail operational costs by increasing risks such as impact damage to track and rolling stock.

Ballast undercutting costs represent a significant component of maintenance costs for railways. For Aurizon Network, the overall proposed costs in the revised UT4 submission come to $250.348m, including $51.430m of actual costs incurred during the 2013/14 financial year. This amounts to some 31% percent of the total maintenance costs for the period, which is considered larger than that experienced typically by other railway organisations.

Healthy ballast life with designed loading and no adverse environmental conditions is expected to be in the range of 15-20 years. However, if normal ballast degradation rates are combined with coal fouling of ballast, increased axle loads and increasing tonnages and subsequent traffic, intervention periods will necessitate significant increases to maintain the required service and reliability.

Timely intervention is critical to mitigate the risks of derailments through track structure failure and irregularities. This is particularly relevant for heavy haul systems such as the CQCN, and specifically critical on high density heavy lines such as the Goonyella and Blackwater systems. Aurizon has stated previously that expected ballast life on the system due to the high levels of fouling are expected to be in the range of 5 – 7 years.

Ballast undercutting needs to be undertaken in an optimised manner, because it must be undertaken before too much damage to the ballast is permitted and the ballast begins to significantly lose strength and angularity. If this happens, the ballast cleaning process becomes less efficient and potentially more costly, mainly due to slower output from the machine, higher costs due to the requirement for additional replacement ballast or due to the fact that the ballast may need to be fully replaced. The graph in Figure 3 indicatively demonstrates how the level of contamination of ballast and the required depth of excavation can significantly change the overall operational unit cost for ballast undercutting using the ballast cleaning machine. As can be seen optimum costs can increase by 50% on an 8 hour shift thus clearly indicating that overall scope costs are very sensitive to changes in the contamination levels of the ballast.

Figure 3 additionally details the variability of cost per kilometre for ballast undercutting in terms of number of kilometres achieved[8]. It shows that ballast undercutting costs vary significantly with the output of the machine, which is dependent upon the advancing speed, the excavation depth and the ballast return. As ballast becomes more contaminated, the lesser the return on the ballast and the slower the progress in cleaning. Therefore, significant economies of scale can be achieved if ballast undercutting is undertaken in an optimised manner.

In addition, if the ballast has deteriorated to a level where it needs to be fully replaced, formation work may also be required and the project is then usually considered as asset replacement rather than a maintenance task.

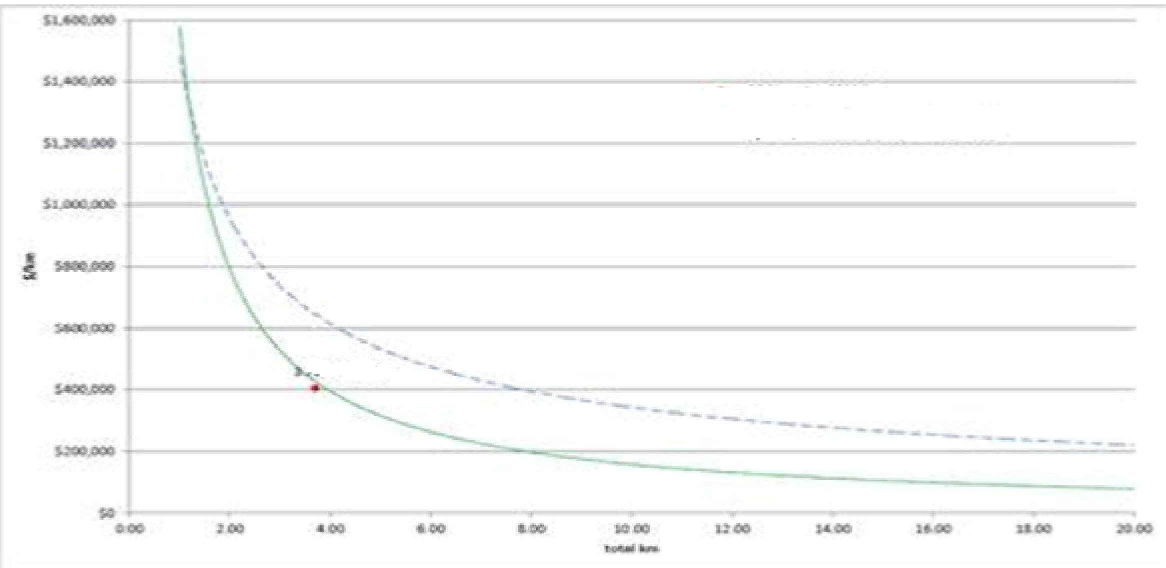

Figure 3 Unit rate demonstration of potential economies of scale[9]

Note: Dotted line represents 300mm excavation 0% ballast return, solid line represents 300mm excavation 70% ballast return

[8] Operations and Maintenance Report, Investigation and Benchmarking, Aurizon Network, Review Team 2012

[9] Operations and Maintenance Report, Investigation and Benchmarking, Aurizon Network 2012

1.5.3. Determining intervention levels

Traditionally, methods used to assess track ballast condition involved visual checks for evidence of fouling, pumping and water accumulation at ditches and shoulders. This method, however, can provide insufficient information to determine the condition and extent of fouling.

In addition to visual checks, the mass-based Fouling Index (FI) has generally been adopted throughout the world. The FI is defined as the percentage passing a 4.75mm sieve plus the percentage passing a 0.075mm sieve. However, the FI is only suitable if the fouling material has similar densities to the ballast particles. Coal which has a predominant density of approximately 0.9t/m^3 is significantly different from the density of ballast particles which have a density of approximately 2.7t/m^3. This means coal fines for the same mass as ballast can occupy three times the voids in the ballast profile, thereby reducing drainage significantly.

To combat this density variation the volume-based Percentage Void Contamination (PVC[10]) method was developed approximately 13 years ago[11] and used extensively in the CQCN. The results of a global benchmarking survey undertaken in 2008 concluded that CQCN were world leaders in the use of regular measurements of percent void contamination to plan ballast cleaning[12].

However, during 2005, several major derailments occurred in the BNSF US Class 1 railway at Powder River Basin. This increased the level of scrutiny and research globally into finding a better method of evaluation of the serviceability and proper function of the existing ballast layer, ballast strength and its deformation behaviour. The driver for this research was a need to be able to differentiate fouling as different percentages which not only identify the percentage of void contamination but also recognise the percentile extent of each of the fouling materials, such as plastic soil fines, mineral fillers, and mineral contaminants such as coal dust coming from coal trains. Although still ongoing, the research is helping to address concerns that coal fouling appears to create a greater degradation and derailment risk than other types of mineral fouling.

Hence growing concerns in relation to the impact of coal fouling coupled with rapidly increasing demand to haul greater coal tonnages during the recent resources boom, caused the industry to consider that an alternative approach better targeted to objectively compare granular sections (sub-1km) of track across the whole network was required. To this end, Aurizon Network trialled and now use Ground Penetrating Radar (GPR) technology to determine contamination levels.

To determine the ballast fouling rate and subsequently the required ballast undercutting cycles for a section of track or corridor based on the PVC results, Aurizon Network has applied a system of classification to PVC values (Figure 4). This categorisation assists in the understanding of the level of fouling and provides a basis for development of a forecast of when undercutting should take place. This category should be considered in conjunction with the time period since previous undercutting, any changes in traffic volume or type and any major environmental incidence such as flooding in forecasting decisions.

[10] The PVC percentage is calculated from the V1 (the void volume between re-compacted ballast particles) divided by V2 (the total volume of re-compacted fouling material passing a 9.5mm sieve). The samples for PVC tests are taken from the total depth of ballast. Therefore, V1 represents the void volume of the entire ballast layer. Different allowable limits of PVC have been applied for different track standards and ballast depths. In a concrete sleeper track with a 250 mm thickness of ballast, an allowable limit of PVC at 30% is used to specify a ballast-cleaning process considering a minimum requirement for the depth of clean ballast of 100 mm.

[11] Alternative Testing Method for the Measurement of Ballast Fouling: Percentage Void Contamination; Fieldman, Fran; Nissen, Darryl, CORE2002, IEAust Press

[12] UT3 Parallel Comparison Exercise, WorleyParsons for Queensland Rail 2008-09

PVC Category	Description	PVC range (%)
6	Clean	0 to <10
5	Moderately Clean	10 to <20
4	Moderately Fouled	20 to <30
3	Fouled	30 to <40
2	Highly Fouled	40 to <60
1	Severely fouled	>=60
0	Unavailable	n/a

Figure 4 PVC Categories

1.6. APPROPRIATE INTERVENTION THRESHOLD FOR CONTAMINATED TRACK

Several issues need to be considered when determining the appropriate intervention threshold for contaminated track.

Retention of moisture in any part of the ballast layer is undesirable, but, a certain level of retention can be tolerated without immediate adverse effects on either the formation material or track quality.

Research has shown that coal fines (and other contamination) tend to migrate towards the bottom of the ballast layer, gradually reducing the depth of clean ballast remaining beneath the sleepers.

Once contamination reaches a level of 100mm below the sleeper bottom, the rate of deterioration will begin to increase. Track geometry becomes increasingly difficult to manage within mandated standards once contamination exceeds the 100mm level (see Figure 5).

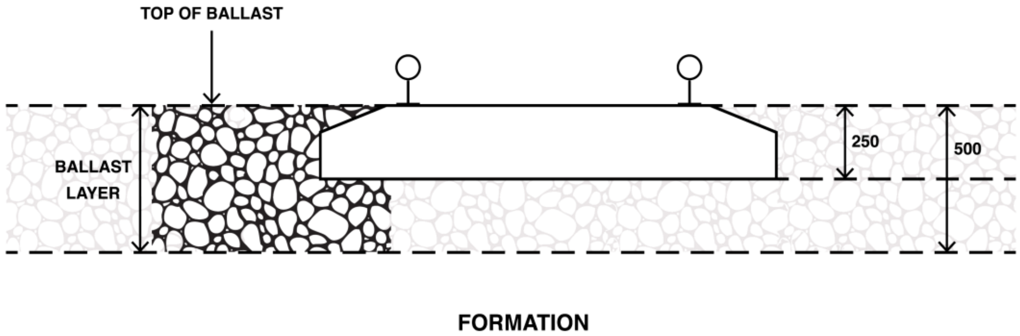

Figure 5 Demonstrating ballast depth (shoulders not shown)

When fouling reaches the underside of the sleepers (circa PVC = 50%, in concrete sleeper track with 250mm of ballast), the substructure starts to fail. In addition, the attrition will increase between foul ballast and sleeper, thereby creating a higher wear rate.

Research has shown that in order to maintain track stability and the safe operation of rail traffic a minimum clean ballast depth of 100mm below sleeper bottom (bsb) is required, thus reducing the allowable limit for PVC to 30%. This allowable limit will, however, vary with different track standards and ballast depths.

When 50% of the voids are filled, there is no longer any clean ballast below sleeper bottom and attrition accelerates dramatically. Broadly, international opinion appears to support the premise that ballast cleaning is deemed appropriate when 30% of the voids are filled with fines, and absolutely necessary when greater than 40% are filled[13].

Aurizon Network uses a 30% PVC value as the intervention level at which ballast undercutting becomes necessary and, in view of the points discussed above, the Review Team consider this reasonable.

It can be argued that the application of a blanket intervention threshold across the whole of the Aurizon Network, including yards and balloon loops, is not prudent as the tolerance to track defects will be different for a variety of traffic and specific operational requirements. However, against this, track stability is important for the safe running of trains in any location, and the international consensus is that 30% is a prudent intervention threshold for heavy haul railway systems across a system. One reason for this is that in yards, and balloon loops especially, there is typically a higher concentration of traffic than on the mainline sections. There is also the expectation the additional acceleration and braking required in such locations will encourage additional spillage of contaminants from various parts of bulk freight wagons such as hopper doors, vehicle bodies and bogie frames.

It is recognised by the Review Team that research is ongoing in this area, and methods for measuring contamination and consensus within the industry are continually being challenged. In consideration of current industry accepted best practice, however the Review Team considers the blanket application of this PVC intervention level of 30% across the CQCN is appropriate to ensure continuing track stability for all rail traffic. Having established 30% PVC as a reasonable intervention threshold, it is also prudent to prioritise undercutting works at areas where the need for reliable track geometry is at its greatest. This includes the mainline sections of track, and, where resources allow, yards and balloon loops.

[13] Track Geotechnology & Substructure Management, Selig et al, 1992, Modern Railway Track, Esveld C; 2001, amongst others

2. ASSESSMENT OF BALLAST UNDERCUTTING SCOPE

2.1. INTRODUCTION

To determine the undercutting scope, Aurizon Network deploys a different methodology for mainline, turnouts and underbridges. There are a number of reasons for this and these are summarised in this section.

For the FY2014 Aurizon Network proposed to use the actual achieved scope and costs both for mainline and turnout undercutting.

Based on its analysis, Aurizon Network stated in its public submission that the “proposed scope” for the FY2015 to FY2017 period would consist of:

- 420 kilometres of track (140 kilometres per year for 3 years, although Aurizon Network’s ballast cost model only identifies 402 kilometres over this period)
- A total of 169 turnouts.

This section will discuss:

- Aurizon Network’s current methodology for determining the proposed scope above
- The appropriateness of using GPR data as the basis for Aurizon Network’s proposed required scope
- The appropriateness of Aurizon Network’s methodology
- Issues arising from Aurizon Network’s methodological assumptions and concerns as noted by the QCA in the Consultant’s Terms of Reference.

However, before discussing the above this section will summarise the methodology used by Aurizon Network to develop the forecast undercutting scope for:

- mainline;
- turnouts; and
- underbridges.

2.1.1. Mainline

The Review Team understands there are four key tasks involved in developing the mainline ballast undercutting scope and a schedule of works. These are summarised in Figure 6 and detailed in full in Appendix 1.

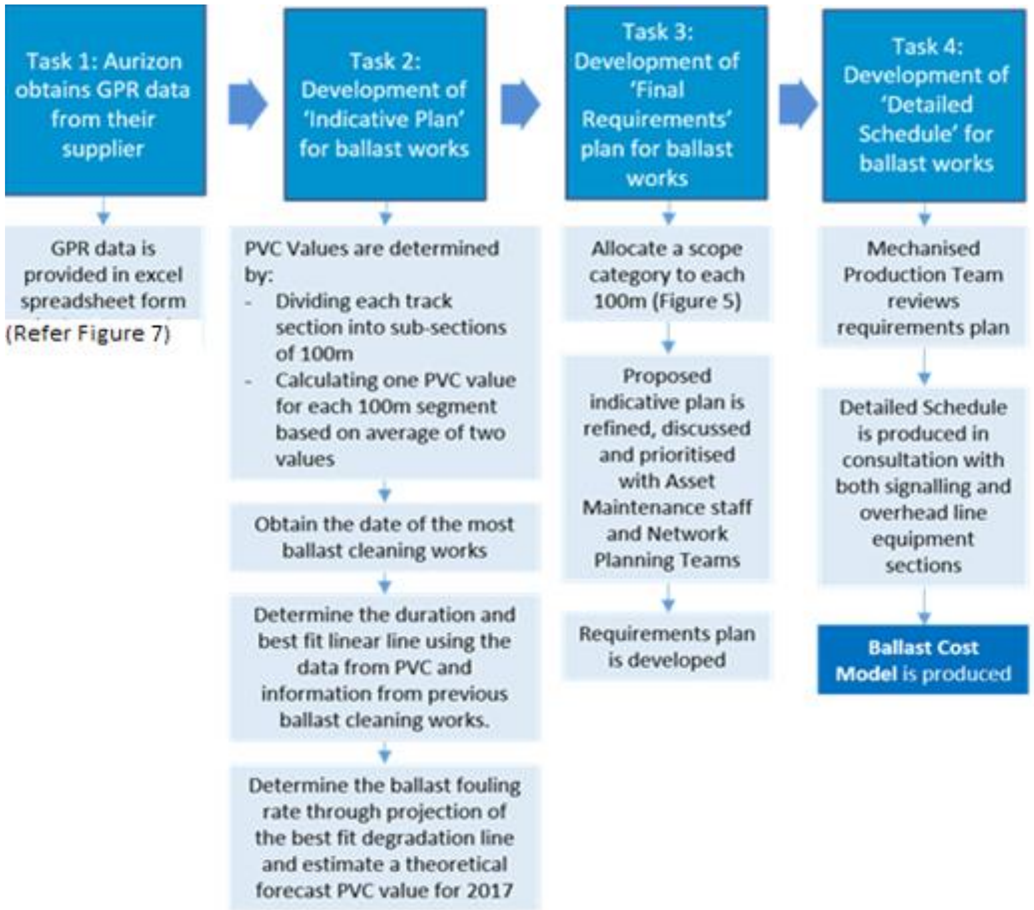

Figure 6 Aurizon Network's process for developing ballast undercutting scope and schedule of works

The primary task is to collect the GPR data and define the PVC values for each track section for each year that the data has been collected.

For the development of the mainline ballast undercutting scope for the FY2015 to FY2017 period, Aurizon Network has used the data from GPR runs undertaken in 2012 and 2014 in conjunction with relevant maintenance records of ballast undercutting works undertaken between the two measured runs.

PVC values for 100m segments were calculated from these two data sets, and then the projected degradation line used to estimate the forecast PVC value for FY2017. The projected line is derived from the calculated PVC points by using a linear extrapolation technique across the two data points. The forecast PVC value for the segment is then used to categorise the segment into one of four scope categories. Scope categories and the final requirements plan prior to development of the detailed schedule outline in Task 4 is summarised in Figure 8.

Although the Review Team considers the use of the two figures will add rigour to the projection estimate, it is noted where a negative figure was obtained from the accumulation of the FY2012 and FY2014 figures (that is, where the PVC value had decreased between those two years), the FY2012 figures are excluded.

In addition, if the FY2012 data is missing and there are no records of previous undercutting, the FY2017 forecast value is set to be equal to the FY2014 PVC value. Effectively, this approach assumes the PVC does not change for the track segment and there will be zero PVC growth.

The above methodology appears to be a logical approach, taking into account the developmental stage of the GPR data and the constraints imposed by the limited number of GPR data runs. However, the review of the methodology highlighted a number of concerns with the simple linear extrapolation approach, namely:

- The methodology does not take into account tonnage wear. It is reasonable to expect that the wear over the period is combined with tonnages to provide the unit fouling rate per year per Mnt of rail traffic.
- No acknowledgement is made of other works which may impact the condition, only previous undercutting works – although Aurizon Network stated these works were likely to be the reason for any recorded PVC "improvements". The Review Team considers it important to record and highlight where such works did take place (and where they did not). Where there are still high instances of such differences occurring, this process will reveal potential issues with calibration (or other matters).
- No allowance is made for expected decreases in fouling rates due to initiatives such as the coal veneering program.

Location Information					GPR PVC (ballast fouling index calibrated to PVC)					
Route Description	Track	KM	Dec.Lat	Dec.Long	Left		Right		Centre	
					Category	PVC Value	Category	PVC Value	Category	PVC Value
Biloela	Single	0.032	-24.229086	150.416020	5	20	5	18	2	48
Biloela	Single	0.037	-24.229128	150.416002	5	17	5	18	4	23
Biloela	Single	0.042	-24.229170	150.415985	5	16	5	14	4	27
Biloela	Single	0.047	-24.229212	150.415967	4	21	6	10	2	55
Biloela	Single	0.052	-24.229254	150.415950	5	13	6	7	3	39
Biloela	Single	0.057	-24.229295	150.415932	5	16	5	18	4	24
Biloela	Single	0.062	-24.229337	150.415915	3	37	0	-999	3	32
Biloela	Single	0.067	-24.229379	150.415897	2	47	0	-999	1	65
Biloela	Single	0.072	-24.229421	150.415880	5	19	0	-999	2	54
Biloela	Single	0.077	-24.229463	150.415863	4	22	0	-999	0	-999
Biloela	Single	0.082	-24.229505	150.415845	1	64	0	-999	0	-999
Biloela	Single	0.087	-24.229547	150.415828	3	39	0	-999	0	-999
Biloela	Single	0.092	-24.229589	150.415811	3	37	0	-999	0	-999
Biloela	Single	0.097	-24.229631	150.415794	2	54	0	-999	0	-999
Biloela	Single	0.102	-24.229672	150.415776	2	48	5	19	0	-999
Biloela	Single	0.107	-24.229714	150.415759	6	10	5	11	6	9
Biloela	Single	0.112	-24.229756	150.415741	6	9	6	9	6	8
Biloela	Single	0.117	-24.229797	150.415723	5	12	6	4	6	8
Biloela	Single	0.122	-24.229839	150.415705	5	10	6	4	6	6
Biloela	Single	0.127	-24.229881	150.415688	6	6	6	5	6	7

Figure 7 Extracted sample from spreadsheet of GPR Data (Refer Figure 2 PVC categories)

The omission of these factors raises questions in relation to the robustness of the forecasted rate of degradation.

Scope Category	Method	Total KM	Goonyella	Blackwater	Newlands	Moura
1.00	>30% PVC in 2014 GPR	320.3	147.1	137.0	24.1	12.1
2.00	<30% PVC in 2014 Forecast to be >30% by Jul 2017 Trended from 2012 GPR data to 2014 GPR data Have 2014 GPR 2012 GPR No undercutting between GPR runs	134.8	76.2	51.1	2.3	5.2
3.00	<30% PVC in 2014 Forecast to be >30% by Jul 2017 Trended from last undercut to 2014 GPR run Have 2014 GPR 2012 GPR Undercutting between GPR runs	12.7	7.7	4.9	0.1	-
4.00	<30% PVC in 2014 Forecast to be >30% by Jul 2017 Trended from last undercut to 2014 GPR run Have 2014 GPR No 2012 GPR Undercutting prior to 2014 GPR run	33.1	23.0	9.8	-	0.3
	Total	500.9	254.0	202.8	26.5	17.6

Figure 8 Scope categories

2.1.2. Turnouts

A key limitation in the use of GPR is that data cannot be collected in areas where metallic objects appear within the zone being explored by the radar pulse. This is because of radar echoes created by the effect of the metallic objects on the radar pulse. Turnouts, by their nature, introduce diverging rails (i.e. metallic objects) into the areas between the running rails of the main route and on the side of that route to which the turnout rails diverge.

Hence it is understood that, at a strategic level, Aurizon Network determines its required turnout scope using the National Strategic Asset Plan (NSAP) model. This model employs tonnage usage wear rates and design life of the asset to determine a strategic turnout undercutting scope.

The Review Team did not have access to the NSAP model. However, based on the GPR datasets provided by Aurizon Network, the review Team notes that 121 turnouts are identified as priority locations for ballast undercutting. To overcome the absence of GPR data (for the reasons discussed above) the PVC value of turnout ballast is extrapolated from the GPR values immediately either side of the turnout.

2.1.3. Underbridges

The Review Team notes that work on underbridges is not undertaken by the ballast undercutting team. Therefore, this work does not use the RM900 nor excavator undercutting machines and, accordingly, is not included in the 140km per annum undercutting commitment for the UT4 period.

Information received from Aurizon Network staff confirmed that in their December 2014 MAR response submission, ballast replacement on underbridges is not classed as undercutting work, as the track is necessarily removed before the re-ballasting work can be undertaken. Given this, the Review Team understands the underbridge task is not included in either the mainline RM900, or any other undercutting scope allowances and should therefore be treated as excluded from the submitted undercutting cost estimates.

2.1.4. Conclusion

In conclusion as the Review Team did not have access to the NSAP model and as the majority of the UT4 undercutting forecast has been calculated using GPR data and the tasks summarised in Figure 6, the following discusses the methodology as outlined in Figure 6.

2.2. RELIABILITY AND APPROPRIATE USE OF THE GPR DATA

2.2.1. Reliability

A considerable amount of work has been performed using GPR to assess railroad track substructure, especially in the past few years[14] . Numerous surveys have been conducted and the results have proved GPR to be a reasonably effective non-destructive inspection method for the assessment of railway ballast fouling. Laboratory fouling results and the GPR fouling index have been shown to correlate well – it has been found that the GPR method of providing an index to describe the condition of each section helps to effectively select the sections where ballast cleaning is required.[15]

2.2.2. Aurizon Network calibration

Aurizon Network have calibrated the GPR signals in terms of PVC values to measure ballast fouling levels. This was done due to a developed familiarity of the PVC method and a desire to continue measuring ballast fouling levels in terms of PVC[16]. The calibration was originally undertaken by identifying locations with a range of fouling levels in GPR from track sections then performing targeted PVC sampling in the same track sections. However this method did not provide the adequate distribution to enable full calibration to be achieved, and a “calibration track panel” was devised with a range of PVC values including:

- 11 sub-sections with mixtures of clean ballast and coal fines, with PVC values of 0% to 100%, increasing in 10% increments, representing typical coal fouling
- 3 sub-sections with mixtures of unscreenable and clean ballast (25%, 50% and 75% of unscreenable ballast representing degraded ballast)

This calibration track was then flooded with water to wash the fines to the base of the ballast layer, hence representing the typical accumulation of fines in the live operational setting. Tests with the GPR equipment were carried out before and after flooding.

2.2.3. Method of GPR data collection

The GPR equipment is mounted on a specially adapted rail vehicle and transmits short electromagnetic waves into the subsurface of the ballast layer recording and displaying the reflected energy as the vehicle travels along the track. By examination of the reflected radar waveforms an interpretation of the material and/or structure under investigation is able to be determined.[17] The radar waveforms are able to determine the level below sleeper bottom at which voids in the ballast layer have been clogged with contaminant fine particles.

In order to capture data across the whole width of corridor occupied by the track on which the vehicle is running three separate GPR units attached to the one rail vehicle are used. One captures data from the central area of the track, between the running rails, while the other two capture the condition of the ballast in the right and left hand shoulders on each side of track. The ‘raw’ data captured is supplied to Aurizon Network in a variety of formats including excel, kmz and pdf files before being converted, by Aurizon Network, into discrete 100m track lengths for planning of the annual ballast undercutting task.

2.2.4. Limitations

The Review Team consider that Aurizon Network’s use of GPR data has shown many advantages compared with traditional trial pit and PVC testing for assessment of ballast condition. However it is important to note that this technology still has a number of limitations which should be considered when applying the data to development of future ballast undercutting requirements.

[14] Al-Nuaimy et al., 2006; Kathage et. al., 2006; Keogh et al., 2006, Hyslip et al., 2005
[15] Inspection of Railway Ballast Quality, Silvast,et al, Finish Rail Administration
[16] Planning ballast cleaning using ballast fouling levels determined with ground-penetrating radar, Foun, Damien, CORE212
[17] Model track studies on fouled ballast using ground penetrating radar and multichannel analysis of surface wave; Journal of applied Geophysics, Anbazhagan et al

The main limitation is that to ensure high accuracy it is important that the GPR data collected is clean and without any significant noise. This is difficult in a railway environment where many sources of noise (e.g. rails, ties, and radio signals) are generated and may mask the ballast information in the GPR data[18].

In addition, research suggests that GPR surveys should be performed in the dry season if at all possible. Soil moisture, especially in high-clay soils, increases the radar attenuation rates, further limiting the radar performance[19]. This limitation potentially may cause some inconsistencies in readings in areas such as northern Queensland.

In addition, GPR will have a statistical error margin that should be factored into the analysis.

2.2.5. GPR analysis

The Review Team reviewed the reliability of the GPR data made available by Aurizon Network and their current GPR contractor, Zetica Rail. To ascertain reliability of the data overall a random sample of twelve individual sections of track were selected for detailed analysis. Each track section was 5km long, and the selection included sites from each of the four CQCN systems.

The review process analysed, from a geotechnical perspective, the information provided by Aurizon Network to confirm the reliability and appropriateness of the processed GPR data and included:

- correlation of rail line chainages detailed in the relevant GPR spreadsheets with eight ballast condition photographs provided for review in response to an RFI, and google maps where applicable;
- visual assessment of these photographs to estimate the extent of fouling;
- determination of whether the visual assessment and chainage data appeared to correctly correlate with the relevant GPR spreadsheets; and
- assessment of whether the data demonstrated that the undercutting works were required from a strategic perspective.

Further, for the 2012 and 2014 data, the review team replicated the procedure used by Aurizon Network to convert the raw (5 metre segment) data from the system spreadsheets they received from Zetica Rail into processed (100 metre segment) data. This work included:

- assembly of the raw PVC readings, taken at three points (Left, Centre and Right of track) at approximately 5 metre increments into three averaged 100 metre long segments. The segments contain all raw readings contained between two solid 100 metre integers - for example all readings contained between 5.100 kilometre through to 5.200 kilometre are averaged, as opposed to say 5.101 kilometre through to 5.201 kilometre; and
- comparison of the 100 metre long segments produced by the Review Team with the corresponding results produced by Aurizon Network, and production of an error rate showing the overall quantum of error between the two datasets within the same sample section.

In consideration of the Fouling Rate during the period between the capture of the 2012 and 2014, the Review Team repeated the procedure used by Aurizon Network to calculate a future fouling rate for the twelve sample sections. The Review Team compared the original Aurizon Network data with the newly calculated 100 metre segment GPR data and identified a number of errors with the initial dataset. The Review team then assessed whether the errors between the two datasets is likely to result in an over-estimate or under-estimate of the average fouling rate along the entire section. The issues and conclusions from this analysis are discussed below.

[18] Railroad Ballast Evaluation Using Ground-Penetrating Radar Leng, Zhen and AlQadi, Imad, Transport Research Board: Journal of the Transportation Research Board, 2010
[19] Ground Penetrating Radar (GPR) Usage and Limitations, by Lambert Dolphin

2.2.6. Issues identified

In summary, the Review Team consider that the use of GPR data is an appropriate input to the assessment for the determination of ballast condition and ballast undercutting scope. It is believed it provides more rigour in the determination of the ballast condition overall (e.g. over the whole corridor) as opposed to using traditional methods based upon only a limited number of trial holes combined with visual inspection.

However its limitations should also be emphasised.

The Review Team consider the use of the initial GPR PVC calibration track panel to obtain the preliminary data calibration set and categorisation reasonable. However in view of the limitations and developmental stage of the technology in the industry globally it is considered that it would have been prudent to continue field calibration (e.g. further field testing involving the identification of a range of fouling levels in the field and then performing targeted GPR followed by PVC sampling). Such ongoing calibration would provide information to further understand some of the abnormalities (for example improvements in ballast condition from 2012 to 2014 readings where no reparation work or other logical reason was evident) as well as give more confidence in the reliability of the categorisation and GPR data.

Additionally, GPR facilitates the ability to combine historic maintenance and performance data with material characteristics, operational and environmental factors, to gain a greater understanding of the maintenance task in order to be able to achieve cost benefits such as:

- Reduction in interventions
- Targeted prioritisation and delineation of the extent of remedial works required
- Efficient deployment of ballast

However it is considered by the review team that by not including contributing factors in the analysis many of the benefits to be gained from the deployment of GPR will not be achieved.

It is noted that Aurizon Network has stated that operational and other factors will be combined and considered with the GPR results when NAMS[20] is developed. However, it is believed that considerably more statistical analysis can and should be carried out in the meantime using statistical software such as Excel, as this would enable Aurizon Network to commence gaining from efficiencies in using GPR sooner and also ensure rigour in the methodology and application of these factors before needing to input the correct fields and variables into the NAMS system.

2.3. Reliability and Appropriateness of Methodology Applied in Developing Scope

The Review Team examined the current ballast scope development process from receipt of the GPR data to the development of the cost model, and identified any key issues through:

- review and analysis of key spreadsheets used by Aurizon Network to develop the ballast undercutting scope and schedule of works;
- direct discussions with Aurizon Network staff responsible for developing the ballast scope model and the ballast cost model (which includes a schedule of works); and
- feedback from requests for information from Aurizon Network.

A number of areas were identified where there are issues with the current approach to developing the scope of ballast undercutting works. These have been defined in terms of: data reliability and consistency, methodological issues, and engineering issues.

2.3.1. Data reliability and consistency issues

The Review Team identified three data reliability and consistency issues and these are discussed below.

[20] Network Asset Management System

Data reliability and consistency issue 1: The PVC calculated values (100 metre segments) do not always match the underlying GPR data.

As previously discussed, the GPR data that Aurizon Network receives from its suppliers is received in four spreadsheets and the PVC values are calculated at 5 metre intervals. Aurizon Network then converts this into 100 metre segments in a separate spreadsheet[21]

On review of the data it was found that the average PVC values calculated by the Review Team from the "raw" GPR data did not always match the underlying GPR data when the 100 metre segments were recalculated using Aurizon Network's methodology (outlined above). Figure 9 and Figure 10 provide examples of the inconsistencies found ('Difference' columns). Aurizon Network has stated that the final GPR datasets were not analysed, instead a hybrid of draft and final data was used.

Additionally, the Review Team's preliminary review of Aurizon Network's PVC calculations identified that approximately 1.5 per cent of the PVC values were greater than 100 per cent. This would appear to be metre

that the method outlined in calculation of the volume of voids in average sample of ballast means that PVC values in excess of 100% are possible. Aurizon Network has stated that for the 2014 data sets the final "raw" dataset has been capped and will be capped in future calculations. Subsequently the Review Team capped the PVC results at 100% for both the recalculated 2012 and 2014 GPR datasets to correct this matter.

If this issue is understood and taken into account whilst interpolating the data, this fact in itself is not a major issue, however for the purposes of statistical calculation it is recommended that Aurizon Network continue to cap the "raw" datasets at 100% for future calculations.

[21] AllSystemsGPRDataandUndercuttingHistory(2015-05-20) – Final.xls.

SYSTEM	LINE	TRACK	START KM	END KM	Aurizon analysis PVC (LEFT)	Aurizon analysis PVC (CENTRE)	Aurizon analysis PVC (RIGHT)	Marsden Jacob analysis PVC (LEFT) TOTAL	Marsden Jacob analysis PVC (CENTRE) TOTAL	Marsden Jacob analysis PVC (RIGHT)	Difference PVC (LEFT)	Difference PVC (CENTRE)	Difference PVC (RIGHT)
Moura	Callide	Single	0.200	0.300	18.7	21.5	4.6	7.5	8.5	9.0	**-11.15**	**-12.96**	**4.44**
Moura	Callide	Single	0.300	0.400	13.2	18.1	5.4	12.1	14.3	39.0	**-1.07**	**-3.76**	**33.60**
Moura	Callide	Single	0.400	0.500	5.7	15.2	4.3	3.3	10.8	7.7	**-2.45**	**-4.40**	**3.45**
Moura	Callide	Single	0.500	0.600	10.7	14.1	4.4	2.1	10.8	4.9	**-8.60**	**-3.30**	**0.50**
Moura	Callide	Single	0.600	0.700	36.3	13.8	10.0	3.3	4.7	9.4	**-33.05**	**-9.10**	**-0.60**
Moura	Callide	Single	0.700	0.800	7.1	10.4	4.2	13.3	4.7	49.9	**6.15**	**-5.70**	**45.70**
Moura	Callide	Single	0.800	0.900	5.2	11.3	2.9	24.5	8.1	25.7	**19.25**	**-3.20**	**22.75**
Moura	Callide	Single	0.900	1.000	6.9	16.4	2.8	17.2	19.3	27.6	**10.30**	**2.95**	**24.80**
Moura	Callide	Single	1.000	1.100	4.2	11.2	3.6	8.6	9.4	12.3	**4.40**	**-1.85**	**8.75**
Moura	Callide	Single	1.100	1.200	5.2	9.3	3.5	21.8	15.3	18.4	**16.56**	**6.03**	**14.93**
Moura	Callide	Single	1.200	1.300	5.6	6.1	4.0	5.8	13.6	17.4	**0.20**	**7.55**	**13.45**
Moura	Moura	SINGLE	1.800	1.900	16.6	70.7	9.0	16.6	57.3	9.0	0.00	**-13.42**	0.00
Moura	Moura	SINGLE	1.900	2.000	11.3	21.8	4.4	11.3	21.8	4.4	0.00	0.00	0.00
Moura	Moura	SINGLE	2.000	2.100	31.9	65.5	14.3	27.6	44.9	14.3	**-4.35**	**-20.60**	0.00
Moura	Moura	SINGLE	2.100	2.200	45.9	121.9	31.2	45.9	79.6	31.2	0.00	**-42.35**	0.00
Moura	Moura	SINGLE	2.200	2.300	43.6	156.2	51.1	43.6	95.6	48.6	0.00	**-60.60**	**-2.50**
Moura	Moura	SINGLE	2.300	2.400	70.6	92.6	69.9	57.7	69.6	58.3	**-12.93**	**-23.06**	**-11.60**
Moura	Moura	SINGLE	2.400	2.500	65.1	58.2	32.6	51.5	45.7	32.6	**-13.55**	**-12.50**	0.00
Moura	Moura	SINGLE	2.500	2.600	60.1	95.6	17.9	48.9	68.8	17.9	**-11.14**	**-26.81**	0.00
Moura	Moura	SINGLE	2.600	2.700	52.8	26.5	14.1	47.3	26.5	14.1	**-5.55**	0.00	0.00
Moura	Moura	SINGLE	2.700	2.800	5	19	4	5.15	19.45	3.60	0.00	0.00	0.00
Moura	Moura	SINGLE	2.800	2.900	4	23	3	3.95	22.55	3.40	0.00	0.00	0.00
Moura	Moura	SINGLE	2.900	3.000	6	21	4	5.85	20.85	4.00	0.00	**-0.40**	0.00
Moura	Moura	SINGLE	3.000	3.100	5	12	3	5.35	12.00	3.20	0.00	0.00	0.00
Moura	Moura	SINGLE	3.100	3.200	5	15	6	5.11	15.44	5.78	0.00	0.00	0.00
Moura	Moura	SINGLE	3.200	3.300	4	12	4	4.10	12.15	3.75	0.00	0.00	0.00
Moura	Moura	SINGLE	3.300	3.400	6	14	4	5.70	14.45	4.15	0.00	0.00	0.00
Moura	Moura	SINGLE	3.400	3.500	7	21	3	7.10	21.40	3.30	0.00	0.00	0.00
Moura	Moura	SINGLE	3.500	3.600	5	16	3	4.90	16.30	2.90	0.00	0.00	0.00
Moura	Moura	SINGLE	3.600	3.700	38	13	13	35.47	12.60	13.31	**-2.53**	0.00	0.00
Moura	Moura	SINGLE	3.700	3.800	11	15	6	10.85	15.45	6.10	0.00	0.00	0.00
Moura	Moura	SINGLE	3.800	3.900	10	9	3	10.30	8.90	3.05	0.00	0.00	0.00
Moura	Moura	SINGLE	3.900	4.000	42	109	30	41.70	71.50	27.79	0.00	**-37.50**	**-2.21**
Moura	Moura	SINGLE	4.000	4.100	11	36	13	10.67	36.29	12.89	0.00	0.00	0.00
Moura	Moura	SINGLE	4.100	4.200	12	21	6	11.58	20.84	6.47	0.00	0.00	0.00
Moura	Moura	SINGLE	4.200	4.300	7	15	5	7.10	15.30	4.50	0.00	0.00	0.00
Moura	Moura	SINGLE	4.300	4.400	9	10	3	8.95	9.89	3.16	0.00	0.00	0.00
Moura	Moura	SINGLE	4.400	4.500	11	17	2	11.32	16.74	2.37	0.00	0.00	0.00
Moura	Moura	SINGLE	4.500	4.600	7	12	2	6.75	11.90	2.35	0.00	0.00	0.00
Moura	Moura	SINGLE	4.600	4.700	9	22	3	9.05	21.74	2.84	0.00	0.00	0.00

Figure 9 Moura system comparison analysis

SYSTEM	LINE	TRACK	START KM	END KM	Aurizon analysis PVC (LEFT)	Aurizon analysis PVC (CENTRE)	Aurizon analysis PVC (RIGHT)	Marsden Jacob analysis PVC (LEFT) TOTAL	Marsden Jacob analysis PVC (CENTRE) TOTAL	Marsden Jacob analysis PVC (RIGHT)	Difference PVC (LEFT)	Difference PVC (CENTRE)	Difference PVC (RIGHT)
Blackwater	Callemondah	No5Arrival	10.700	10.800	3.6	6.3	6.3	3.6	6.3	5.8	0.00	0.00	**-0.57**
Blackwater	Callemondah	No5Arrival	10.800	10.900	4.0	5.4	5.4	3.1	5.4	4.5	**-0.86**	0.00	**-0.93**
Blackwater	Callemondah	No5Arrival	10.900	11.000	3.5	5.0	5.0	3.5	5.0	6.1	0.00	0.00	**1.15**
Blackwater	Callemondah	No5Arrival	11.000	11.100	4.8	7.8	7.8	4.8	7.8	5.8	0.00	0.00	**-2.00**
Blackwater	Callemondah	No5Arrival	11.100	11.200	4.2	5.7	5.7	4.2	5.7	3.8	**0.00**	0.00	**-1.86**
Blackwater	Callemondah	No5Arrival	11.200	11.300	7.4	16.8	16.8	7.4	16.8	6.6	0.00	0.00	**-10.15**
Blackwater	Callemondah	No5Arrival	11.300	11.400	6.6	32.5	32.5	6.6	32.5	11.1	0.00	0.00	**-21.40**
Blackwater	Callemondah	No5Arrival	11.400	11.500	7.2	14.9	14.9	7.2	14.9	5.3	0.00	0.00	**-9.60**
Blackwater	Callemondah	No5Arrival	11.500	11.600	4.7	6.7	6.7	4.7	6.7	4.6	0.00	0.00	**-2.15**
Blackwater	Callemondah	No5Arrival	11.600	11.700	3.2	5.6	5.6	3.2	5.6	4.5	**0.00**	0.00	**-1.13**
Blackwater	Callemondah	No5Arrival	11.700	11.800	3.1	6.5	6.5	3.1	6.1	4.6	0.00	**-0.45**	**-1.95**
Blackwater	Callemondah	No5Arrival	11.800	11.900	3.4	6.9	6.9	3.4	6.9	4.1	**-0.01**	**-0.04**	**-2.80**
Blackwater	Callemondah	No5Arrival	11.900	12.000	2.9	7.8	7.8	2.9	7.8	4.5	0.00	0.00	**-3.25**
Blackwater	Callemondah	No5Arrival	12.000	12.100	3.5	8.4	8.4	3.1	8.4	4.9	**-0.45**	0.00	**-3.50**
Blackwater	Callemondah	No5Arrival	12.100	12.200	2.9	4.3	4.3	2.8	4.3	4.9	**-0.09**	0.00	**0.57**
Blackwater	Callemondah	No5Arrival	12.200	12.300	12.9	18.2	18.2	12.9	18.2	7.6	**0.00**	0.00	**-10.58**
Blackwater	Callemondah	No5Arrival	12.300	12.400	47.4	56.2	56.2	34.2	41.2	32.6	**-13.18**	**-15.00**	**-23.55**
Blackwater	Callemondah	No5Arrival	12.400	12.500	6.7	17.2	17.2	6.7	17.2	10.1	**0.00**	**0.00**	**-7.07**
Blackwater	Callemondah	No5Arrival	12.500	12.600	18.4	52.4	52.4	18.4	45.4	48.8	0.00	**-7.00**	**-3.57**
Blackwater	Callemondah	No5Arrival	12.600	12.700	14.9	5.0	5.0	14.9	35.6	34.3	0.00	**30.59**	**29.25**
Blackwater	Callemondah	No5Arrival	12.700	12.800	19.6	42.3	42.3	19.1	32.0	47.0	**-0.56**	**-10.26**	**4.69**
Blackwater	Callemondah	No5Arrival	12.800	12.900	14.0	37.0	37.0	14.0	36.4	69.5	0.00	**-0.63**	**32.53**
Blackwater	Central	raghBalloonL	0.000	0.100	6.4	16.6	16.6	6.4	16.1	16.9	**0.00**	**-0.53**	**0.35**
Blackwater	Central	raghBalloonL	0.100	0.200	8.7	24.8	24.8	8.7	24.8	13.9	0.00	0.00	**-10.90**
Blackwater	Central	raghBalloonL	0.200	0.300	1.7	3.6	3.6	1.7	3.6	1.9	0.00	0.00	**-1.70**
Blackwater	Central	raghBalloonL	0.300	0.400	9.4	17.6	17.6	9.4	17.6	8.3	0.00	0.00	**-9.25**
Blackwater	Central	raghBalloonL	0.400	0.500	1.7	12.0	12.0	10.7	12.0	11.0	**9.00**	0.00	**-0.95**
Blackwater	Central	raghBalloonL	0.500	0.600	7.9	1.6	1.6	7.9	10.6	10.1	**-0.04**	**9.00**	**8.52**
Blackwater	Central	raghBalloonL	0.600	0.700	5.0	1.8	1.8	5.0	10.8	7.4	0.00	**9.00**	**5.68**
Blackwater	Central	raghBalloonL	0.700	0.800	3.0	5.9	5.9	3.0	5.9	4.7	0.00	0.00	**-1.25**
Blackwater	Central	raghBalloonL	0.800	0.900	3.4	6.3	6.3	3.4	6.3	4.5	0.00	0.00	**-1.80**
Blackwater	Central	raghBalloonL	0.900	1.000	4.2	8.6	8.6	4.2	8.6	6.8	0.00	0.00	**-1.80**
Blackwater	Central	raghBalloonL	1.000	1.100	2.9	4.5	4.5	2.9	4.5	3.9	0.00	0.00	**-0.55**
Blackwater	Central	raghBalloonL	1.100	1.200	4.7	6.6	6.6	4.7	6.6	5.1	0.00	0.00	**-1.55**

Figure 10 Blackwater system comparison analysis

Re-estimation of PVC values

In view of the above, the Review Team re-calculated the PVC values to assess the impact on the development process of the indicative plan for ballast works of the inconsistencies identified. This was achieved by applying a set of pivot tables and formula driven calculations to recreate Task 2: Development of 'Indicative Plan' for ballast works.

The Review Team re-estimated the ballast undercutting scope using both 2012 and 2014 GPR data and noted that this reduced the overall number of 100 metre sections of track with a PVC value greater than or equal to 30 per cent, with most of the reduction in the scope category 1. Overall, the re-estimation reduced the ballast scope from 500.9 to 421.0 kilometres of track ('The Review Team estimated scope').

The re-estimated scope also resulted in a significant change in the 100m sections of track that are identified as fitting into one of the four scope categories. As a result the Review Team finds that:

- 698 sections of 100 metre track (69.8 kilometres) are now at or over the 30% PVC threshold that previously were not. (This equates to 20% of the sections previously identified by Aurizon Network); and
- 1436 sections of 100 metre track (143.6 kilometres) are now less than the 30% PVC threshold (This equates to 42% of the sections previously identified by Aurizon Network).

These figures represent a significant change from the previous Aurizon Network calculations.

Most critically, this analysis also finds that a significant number of 100m track segments were incorrectly 'prioritised' for ballast undercutting works. Equally a number of track sections were inappropriately excluded from the initial scope analysis because they incorrectly fell below the 30% PVC threshold.

It was beyond the scope of this review to undertake a full audit of the segments in the cost modelling as compared to the GPR modelling but, to illustrate the extent of the issue and prioritise any further attention required, the Review Team examined the number of 100m track sections, for which the average PVC has either fallen below or reached the threshold across the original Aurizon Network PVC as compared to the Review Team's recalculated PVC values. This analysis concluded that the Blackwater system is the worst affected (Table 3), with over eight per cent of 100m track sections having changed from above to below the threshold or vice versa. The Moura system is the second most affected with 2 percent of track segments and the Goonyella and Newlands systems are lower again at 0.6 percent and 0.4 percent, respectively.

Table 2 Re-estimated ballast scope

Scope category	Aurizon scope	The Review Team estimated scope	Difference (km)	Difference %)
1.0	320.3	274.8	-45.5	-14%
2.0	134.8	92.1	-42.7	-32%
3.0	12.7	17.5	4.8	38%
	33.1	36.6	3.5	11%
Total	**500.9**	**421.0**	**-79.9**	**-16%**

Table 3 Re-estimated ballast scope

System	Change in 100m segments (%)
Blackwater	**8.2%**
Goonyella	**0.6%**
Moura	**2.0%**
Newlands	**0.4%**

Data reliability and consistency issue 2 - The 2012 and 2014 GPR data sets do not appear to be comparable.

There is large amount of data that does not logically correlate across the 2012 and 2014 GPR datasets. This can be illustrated with reference to both:

- 100m segments that have not had works after 2012; and
- 100m segments that have had works after 2012.

Significant PVC reductions for segments where ballast undercutting works have not been undertaken

To illustrate those segments of track that have had not works after 2012, The Review Team found that approximately:

- 333.8km (3338 sections of 100m track) or 37 per cent of the total number of 100m lengths has a PVC value that has fallen from 2012 to 2014; and
- 115.3km (1153 sections of 100m track) or 13 per cent had a PVC value fall by greater than 10 percentage PVC points (Figure 11).

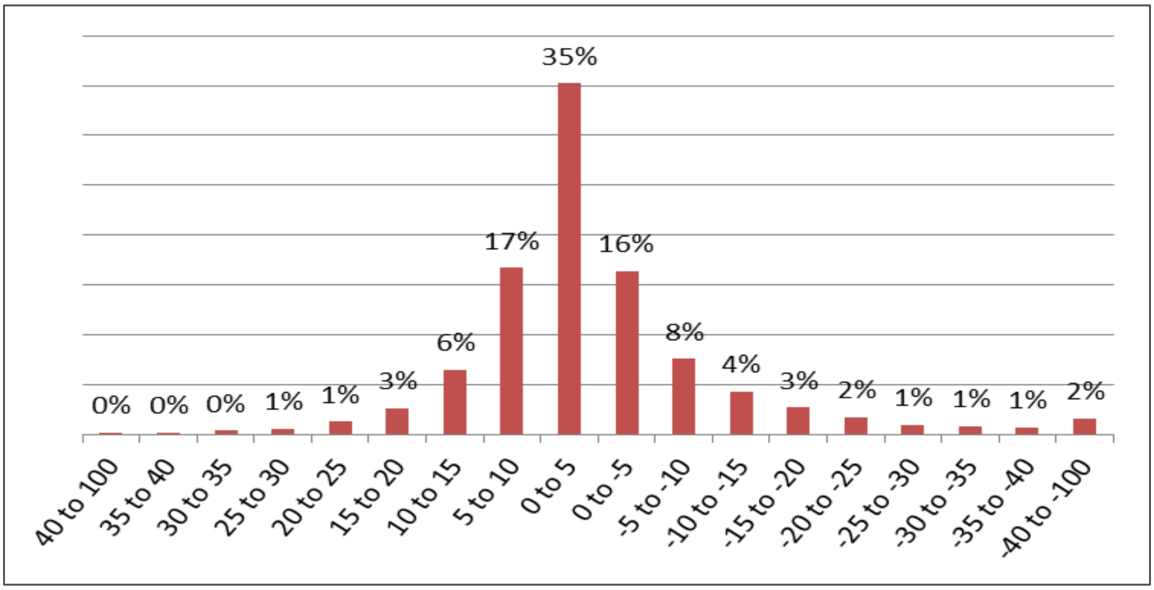

Figure 11 Change in PVC from 2012 to 2014 no ballast undercutting works after 2012 (n=10,105, all rail systems)

The Review Team acknowledges that there are a number of reparation works, which if carried out on the track will improve conditions and affect the GPR result. Aurizon Network have stated such works are inclusive of formation renewal, resurfacing and stoneblowing and other civil works and as such, are generally one of the main reasons such dramatic changes occur.

The results from Figure 11 demonstrate the importance of taking into account all reparation and other maintenance works which may any impact on the resultant projection of ballast degradation. It is apparent that these works potentially have a significant effect on the GPR result and subsequently may skew the resultant projection for the development of the ballast undercutting scope.

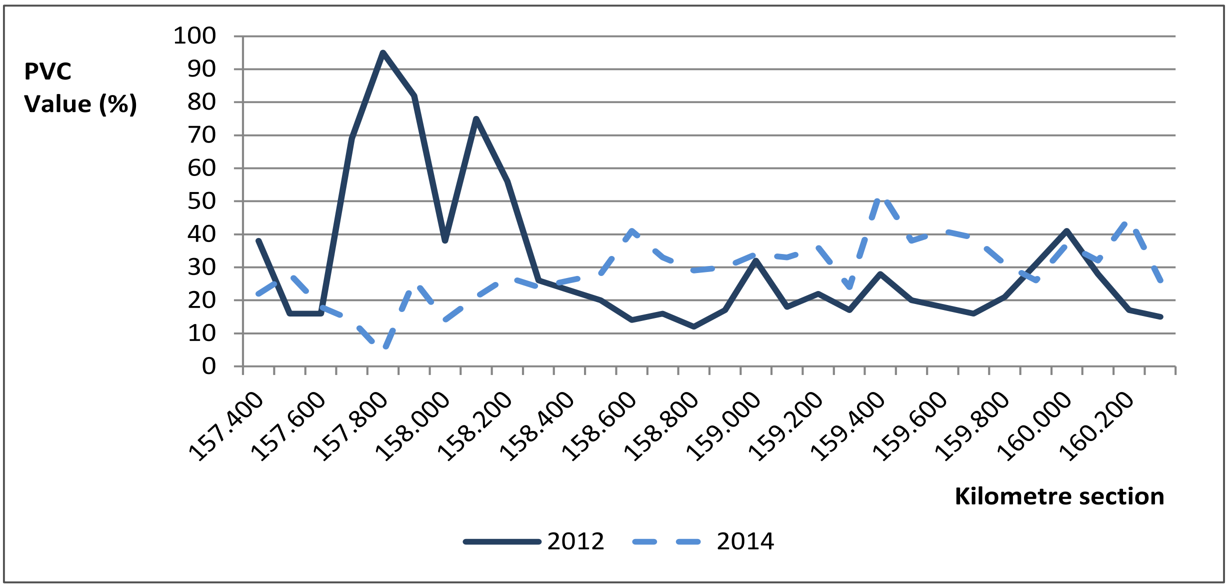

Figure 12 Comparison of PVC values for 2012 and 2014 where there no ballast undercutting works after 2012 for a section of Goonyella track (n=30)

Significant PVC increases for segments where ballast undercutting works have been undertaken

For those segments of track that have had works undertaken since 2012, The Review Team found that approximately 257km of track (28 per cent of the total number of 100m lengths) had a PVC value that has increased from 2012 to 2014 (Figure 13). This is an unexpected result as if works have been undertaken on a segment of track it seems counter-intuitive that there would be a subsequent increase in the PVC value.

An example of this issue is illustrated in Figure 14 for a 3km section of Goonyella track. This shows that, from the data provided for review for ballast undercutting works, there are a number of 100m segments where the PVC values are, and in some cases significantly, greater in 2014 than in 2012 and yet work was undertaken on these segments between 2012 and 2014.

The Review Team has used 2012 GPR data to verify the 2012 PVC data. This analysis confirmed the 2012 PVC values for the 3km section of Goonyella track. As such, the Review Team believes there are a number of possible sources of these unexpected results:

- GPR machine calibration differences between 2012 and 2014 GPR data collection projects
- Other works are being undertaken (such as an annual significant asset renewals programme and resurfacing and stone blowing, wet weather events or deeper-seated maintenance intervention) are reducing the PVC rate and thus reducing the ballast undercutting scope
- Noise or other affecting the GPR readings either 2012 or 2014
- Differences in the degree and moisture content of ballast fouling; or
- Differences in the GPR antenna frequency

All the above have been assessed to potentially have an impact on GPR quality data[22].

Aurizon Network has advised the Review Team that the same methodology was applied both in 2012 and 2014, however due to the developmental stage of the technology, it is noted that there are no guidelines or standards in terms of antenna use or error margins to take into account for different climate conditions. The Review Team can confirm that this is the case for this particular section of Goonyella track. However, we note that the same issues that we have identified with the 2014 data exist for the 2012 data for other systems and track sections (see above).

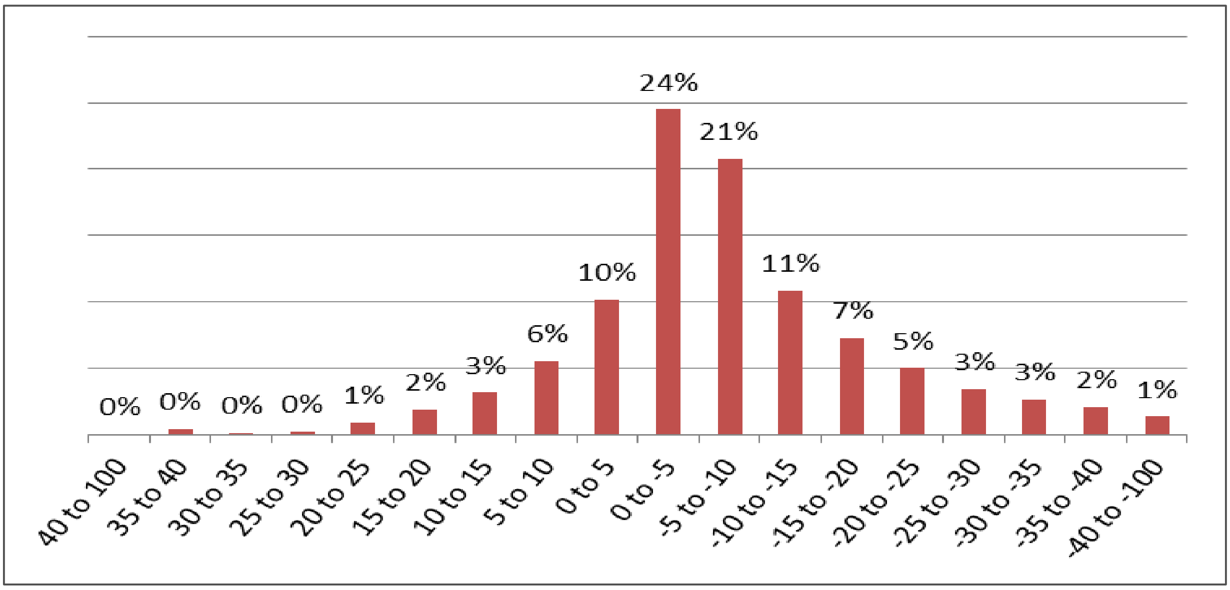

Figure 13 Change in PVC from 2012 – 2014; with ballast undercutting works between 2012 and 2014 (n=1866, all rail systems)

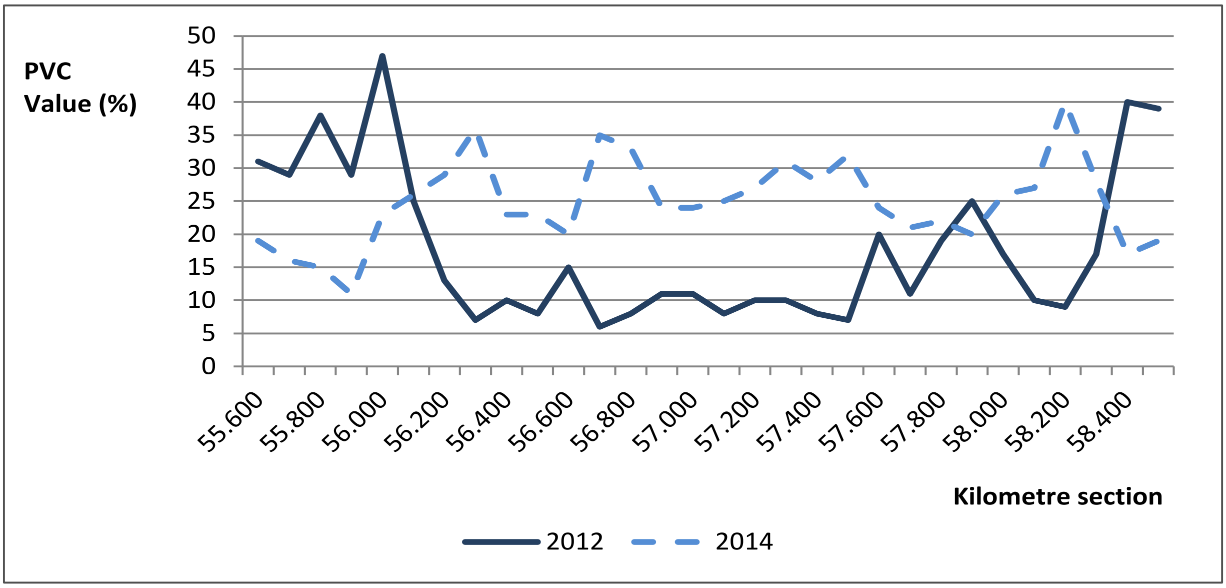

Figure 14 Comparison of PVC values for 2012 and 2014 with ballast undercutting works after 2012 for a section Goonyella track (n=30)

22 Non-destructive assessment of rail track condition using ground penetrating radar. Su et al, University of Wollogong, 2011

Data reliability and consistency issue 3: The forecast PVC values for 2017 do not consistently apply the change in values between 2012 and 2014.

The key method used to forecast PVC values for 2017 is to add an additional value to the value for 2014 based on the estimated annual average increase in PVC value from 1 June 2012 (the timing of the 2012 GPR data) to 1 July 2014 (the timing of the 2014 GPR data) multiplied by the number of years difference between the forecast data (1 July 2017) and the 2014 GPR data (1 July 2014). Thus a linear extrapolation is being used.

However, this additional value only applies if there is an increase in the PVC value between 2012 and 2014. If, however, there is a reduction in PVC value, the delta figure is set to zero and thereby ignoring (at least) the statistical error margin of the GPR surveying. This has the effect of upwardly biasing the forecast PVC values for 2017 since if the additional value is negative the 2014 PVC value is applied as the forecast value. This is an important consideration as any equipment has a statistical error count. Any associated analysis therefore needs to include both the positive and negative delta values otherwise the statistical error count is not correctly incorporated into the overall data set.

The Review Team notes that approximately 530km of track (or approximately 44 per cent) of PVC values estimated using this method exclude the additional value because the change in the PVC value from 2012 to 2014 is negative.

Fortunately, in this instance, the use of the Review Team's re-estimated PVC values showed that if the negative values were included into the forecast calculations it would not change the ballast scope from the previously the Review Team's revised reduced re-estimated value of 421.0km.

2.3.2. Methodological issues

The Review Team has identified four data reliability and consistency issues which are discussed below:

Methodological issue 1 - The PVC value for each 100m could be calculated in alternative ways, which would materially change the result.

The traditional method used by Aurizon Network to estimate the PVC value for 100m of track uses an average of two values: the PVC value from the centre of the track (over 100m) and maximum of the left or right shoulder PVC values (over the same 100m).

However, there are alternative approaches that may provide insights into the PVC level for 100 metres track segments. These include:

- use of the centre PVC value (only) - under the current measure, ballast fouling issues on the centre of the track could be concealed if the centre PVC value is high and the left and right PVC values are low; and
- use of the right and left PVC values by themselves since these will indicate whether there are issues on the shoulders of the track. Moreover, under the current measure, ballast fouling issues on the left and right of the track could be concealed if the centre PVC value is low and the left or right PVC value is high.

These measures could be considered in addition to Aurizon Network's measure to provide additional insights into the extent of ballast fouling and subsequent prioritisation. Aurizon Network commented that they would like to undertake additional analysis of the PVC data, but they have been constrained by computational power and statistical knowledge. To this end they are investing in a new system that will support additional analysis of the data. The Review Team is of the opinion that considerably more analysis of the GPR data could be undertaken using Microsoft Excel and other statistical software while also maintaining analytical transparency and flexibility. Equally, the new system needs to be designed in a manner that facilitates independent review by the QCA.

As an example, the Review Team has estimated the ballast scope, based on the recalculated 2014 data, using a range of alternative methods in Table 4. This illustrates that alternative approaches will deliver varying results. A key result from this analysis is that the PVC method using only centre track data generates more than 550 kilometres of track requiring ballast works over the UT4 period.

Table 4 Alternative methods to calculate PVC for each 100 metres

Method	Estimated ballast scope (kilometres)
Current Aurizon Network method	500.9
The Review Team re-estimated using Aurizon Network method	421.0
The Review Team re-estimated using only PVC centre data	525.8
The Review Team re-estimated using only PVC right data	274.0
The Review Team re-estimated using only PVC left data	245.9

Each of the metrics gathered is important for the overall stability of the track, given the dual roles of the ballast in supporting and spreading the vertical loads applied by passing rail traffic, and withholding lateral loads applied by the same traffic, especially on curved track, or by elements of the track geometry alone, by holding the sleepers in the correct alignment.

Notwithstanding this, Aurizon Network stated that the most important metric is the ballast condition data gathered by the central GPR unit, positioned between the running rails, as this is the section of ballast normally carrying the maximum applied loads. This is considered to be a reasonable position to adopt, and the contiguous nature of the ballast is such that the current process for defining the overall PVC index for each 100m length of track is also considered reasonable.

Methodological issue 2 - The PVC value for each of the left, centre and right track could be calculated in alternative ways, which would materially change the result.

The PVC for 100 metre segments for each of left, centre and right is currently calculated based on an average of 20 data points of 5 metres length (that is, 100 metres in length).

There are alternative methods that could be used in addition to this measure to provide further insights into where there are localised pockets of high fouling that are not highlighted in a measure that involves averaging 20 data points. This could include alternative measures of the PVC value such as:

- the maximum of 20 data points across the 100 metres;
- the average of the highest five or ten data points across the 100 metres; and
- a rolling analysis method[23] of grouping 20 data points. At present the 100 metre segments are rigidly fixed based on each 100 metres starting at 0 metres (i.e. they increase by 0-95 metres, 100 to 195 metres etc.) An alternative would be to continually vary this (e.g. 0-95 metres, 5-100 metres, 10-105 metres, etc.) to assess the most appropriate set of 100 metres segments to target for ballast works.

As an example, using the Review Team's PVC re-estimation model and applying the maximum of 20 data points it was estimated that the number of 100 metre sections of track that are greater than 30 per cent PVC in the Blackwater system increases from 159.3 to 416.0 kilometres – which confirms that the ballast undercutting scope is highly sensitive to this assumption

[23] Note – A rolling analysis method is a statistical technique that can be used to assess the consistency of a model's results and involves computing parameter estimates over a rolling window of a fixed size in this case 100 metre segment lengths. It is distinct from a rolling average analysis.

This highlights that in developing a ballast plan, it would be worthwhile for Aurizon Network to consider a variety of measures that might all ultimately be considered to identify the highest priority areas. Coupled with the application of local knowledge this could significantly enhance the scoping exercise.

The Review Team notes that these techniques are likely to increase the ballast undercutting scope (kilometres), but potentially also create savings by optimising redistribution and reducing the number of interventions during the life of the ballast. While this would increase the cost it would also reduce the extent of any contingent liability that could be present if the ballast under-cutting scope is under-estimated. Aurizon Network have stated that they are currently seeking to incorporate field variables to the initial data-driven strategic scope, however the priority is to primarily build the foundation database with reliable condition data such as that obtained from GPR survey.

Methodological issue 3 - The PVC values for each 5 metres could be calculated in alternative ways, materially altering the results.

As previously discussed, the PVC value for each five metre segment of track is an average of 100 traces, with each trace at a 5 centimetre interval.

The Review Team has not been provided access to the 5 centimetre data as this was not provided to Aurizon Network by its suppliers, but we note that there may be alternative ways to calculate the 5 metre data which are similar to what is described for the 100 metre sections in methodological issue 2 above, and as above the results could be highly sensitive to these results.

We also note that the GPR presumably has a statistical error margin that should be factored in the PVC calculations. At this stage this statistical error has not been factored into the PVC scope analysis.

Methodological issue 4 - Inconsistent and upwardly biased techniques are being used to forecast PVC values for 2017.

Our review of the calculations found that various methods are used to forecast PVC values for 2017, in particular:

- where data exists for 2012 and 2014, a linear interpolation between the two PVC values for each year is made to estimate the annual average increase in PVC value. However, as noted previously, this annual average increase is only taken into account if ballast condition has deteriorated, if PVC values improve then only the 2012 data is used and a straight line degradation is assumed, and any reductions of PVC are excluded in the proposed scope development. As discussed above, as this occurs for a significant proportion of the dataset, the Review Team considers that this approach potentially means there is a material upward bias
- where there is no data for either 2012 or 2014, a variety of forecasting methods appear to be used to estimate the forecast PVC for 2017. For example, if 2012 data is missing, the forecast value is based on the additional value being equal to the value of PVC in 2014 divided by the number of years since the last time the ballast was cleaned. Alternatively, if 2012 data is missing, it could be set to equal to the 2014 PVC value estimated in the first step discussed above.

There is potential for improved forecasting methods to be applied where there is no data for either 2012 or 2014, particularly if a robust method can be applied to estimate deterioration of ballast. This is apart from issues associated with a variety of methods being applied where there is no data for either 2012 or 2014.

However, before forecasts can be developed with any confidence, the data consistency and comparability issues that exist between the 2012 and 2014 GPR data must be resolved.

2.3.3. Engineering issues

It should be noted that, in addition to ballast undercutting, there are a number of works which potentially will impact the PVC data in the proceeding measuring run. In this context these activities include:

- Full depth ballast renewal[24]
- Sleeper renewal (full depth v partial depth decided on a case by case basis)
- Culvert renewal (excluding sleeving of culverts
- Formation renewal
- Bridge ballast renewal (including renewal beyond the splay set)
- Turnout renewal (full depth v partial depth decided on a case by case basis)
- Level crossing renewals
- Partial depth ballast renewal
- Rail renewal
- Mud hole rectification
- Wet weather events

It was beyond the scope of the Review Team to attempt to collate and compare the data associated with these activities to establish the exact effect of these factors, and Aurizon Network have stated that currently it has not been collated in a method facilitating the usage for this purpose. Considering the material effect these factors could have on the magnitude of the overall undercutting task the Review Team consider that, similar to the consideration of when previous ballast undercutting works were undertaken, these factors should be considered when estimating the overall estimation of degradation for the purpose of scope development.

Nevertheless the percentage delta figures noted above indicate that either other activities or variables are impacting the GPR data set or there are issues with the calibration.

An example of this issue is illustrated in Figure 13 for a 3 kilometre section of Goonyella track. This shows that there are a number of 100 metre segments where the PVC values are greater in 2012 than in 2014 and yet the spreadsheet provided by Aurizon Network states that no RM900-based undercutting work was undertaken on these segments between 2012 and 2014. In some cases the reductions are quite substantial.

Of particular concern is that this issue occurs for such a reasonably large portion of the GPR data, indicating either unreliability of the data or that the analysis has to, in some way, extend to take into account some of these factors, or at least provide a theoretical impact index to be applied to the projected degradation assumptions used for the development of scope. Not taking these factors into account is considered to significantly undermine the robustness of the dataset for the purposes of future forecasting.

2.3.4. External factors

In addition to the issues outlined in above it should be noted that the methods currently employed by Aurizon Network to forecast increases in PVC does not allow for any variations in the traffic task or operational management strategies such as the Coal Loss Management program.

Coal Loss Management

In July 2007 an Environmental Evaluation Notice was served on QR Network under the provision of Section 323 of the Environmental Protection Act, 1994. Due to this, steps were taken to reduce coal loss, including the installation of chemical treatment stations at 11 priority mine site loading facilities to create

[24] For an estimate of the kilometres completed please refer to Aurizon Network Annual Cost Maintenance Report 2013 – 2014, located at www.aurizon.com.au/network/reports-and-qca

a thin veneer on the top of the loaded product coal to reduce the number of fines available for deposition along the corridor.

In addition Aurizon Network has installed, at key locations on the system, equipment which sends a beam across the top of wagons travelling at main line speeds. The intensity of the retuned beam is a measure of the quantity of coal dust in the air immediately above each passing wagon, with procedures being in place to reduce emissions from trains where the dust levels exceed acceptable limits. Shown below is the coal dust detection equipment installed at Mindi on the Goonyella system (Figure 15).

Figure 15 Coal dust detection equipment at Mindi on the Goonyella system

The intention of these measures is to significantly reduce the quantity of coal fines deposited along the corridor.

It is understood that some of the facilities described above may have been installed or commissioned during FY13. Even if they had been installed ahead of this time, however, they may not have been operating at full efficiency at the time of the 2012 GPR data collection run. If so, that could mean that the delta increase in fouling between the 2012 and 2014 data collection runs is not truly linear, thereby overstating the PVC which might be calculated by forward extrapolation to FY17.

Variations in Tonnage Carried

Whilst it is acknowledged that Aurizon Network do not currently consider past or projected tonnages in consideration of forecast PVC values, and that they intend to move to a position where this will be done, it should be noted that straight line extrapolation is only truly valid in a situation where there is no fluctuation in the tonnages being carried on the system. Any reduction in tonnages would mean that the predicted PVC values would be overstated, while an increase in tonnes carried would potentially see them being understated.

It is anticipated that the Network Asset Management System (NAMS) which has been developed by Aurizon Network will be able to address some of the variations in degradation caused by fluctuating traffic tasks.

2.4. BALLAST CATEGORISATION

The Review Team's intention was to examine the amount of ballast deterioration with reference to the Aurizon Network analysis of 2012 and 2014 data sets (and possibly 2010 and 2011 data sets) and whether there were alternative categorisations of different line sections that may improve the estimation of ballast scope. This was expected to be particularly relevant for future years by considering alternative deterioration rates for different categories of track.

However, the Aurizon Network approach to estimating PVC's to some degree alleviates the need for categorisation since their analysis (and the Review Team's revised PVC analysis) estimates PVC values for each 5 metre and then 100 metre section of track. This 'bottom up' approach is theoretically preferable to a 'top down' categorisation approach assuming that the data is robust. It is also considered preferable from a practical perspective, assuming there is no reason to question the robustness of the 2012 and 2014 raw GPR data sets.

Comparison of PVC by Category

To illustrate the comparison by category the Review Team have analysed the rates of changes across the categories 1 - 4 in Aurizon Network's PVC model. The categories of track that the Review Team have analysed in Table 5 and Table 6 are the only ones possible from the data provided by Aurizon Network. The Review Team do not have comparable 2012 and 2014 data sets for passing loops or non- mainline track. Considering the comparability issues with 2012 and 2014 data, a useful objective for future work would be to attempt to develop a data set at this level of categorisation which:

- factors in works not currently classified as ballast undercutting but which reduce the PVC rate; and
- logically explains changes in PVC values in the absence of undercutting works.

The analysis of the rates of change in PVC across the whole of Aurizon Network's rail track (Table 5) and by category illustrates that there is not a consistent upward or downward trend in PVC across the systems. There are also some track segments in which the rate of PVC has reduced considerably even though there has been no ballast undercutting work on these sections of track (Table 6).

The Review Team acknowledges that Aurizon Network is currently reviewing methods of factoring in the most critical contributing factors in the analysis of rates of change in PVC for forecasting purposes. However, it is of note that the analysis raises important questions around the robustness of the current set of data, considering that it does not have these factors included. The analysis undeniably supports the importance of factoring at least the most predominant of the contribution factors and/or the calibration of the GPR devices and the subsequent calculation of PVC values as the phenomenon is sufficiently large as to rule out the other possible contributing factors discussed above.

Table 5 Re-estimated ballast scope – all tracks using 2012 and 2014 data

Rail system and section	Average PVC change 2012 to 2014 (PVC percentage points)	Average PVC change 2012 to 2014 (%)	Number of observations (based on 100m segments)
Blackwater Central Down	2.26	18%	886
Blackwater Central SINGLE	0.64	4%	460
Blackwater Central UP	-2.40	-16%	1415
Blackwater Gregory SINGLE	2.07	10%	717
Blackwater NCL Down	1.14	9%	561
Blackwater NCL UP	-2.10	-15%	559
Goonyella Main Down	-4.26	-17%	1446
Goonyella Main SINGLE	-2.01	-9%	362

Rail system and section	Average PVC change 2012 to 2014 (PVC percentage points)	Average PVC change 2012 to 2014 (%)	Number of observations (based on 100m segments)
Goonyella Main UP	-0.12	-1%	1618
Goonyella Oaky Creek SINGLE	No 2012 data available		
Moura SINGLE	0.70	7%	1647
Newlands Main SINGLE	-5.32	-36%	1025
Total	**-1.08**	**-6.55%**	**10696**

Table 6 Re-estimated ballast scope – track where there was no works between 2012 and 2014

Rail system and section	Average PVC change 2012 to 2014 (percentage points)	Average PVC change 2012 to 2014 (%)	Number of observations
Blackwater Central Down	2.23	17%	602
Blackwater Central SINGLE	0.64	4%	460
Blackwater Central UP	-1.69	-11%	1167
Blackwater Gregory SINGLE	2.12	11%	710
Blackwater NCL Down	2.02	15%	448
Blackwater NCL UP	-1.68	-12%	346
Goonyella Main Down	-3.04	-13%	1233
Goonyella Main SINGLE	-2.01	-9%	362
Goonyella Main UP	0.79	4%	1195
Goonyella Oaky Creek SINGLE	No 2012 data available		
Moura SINGLE	0.85	8%	1637
Newlands Main SINGLE	-3.58	-28%	855
Total	**-0.41**	**-2.58%**	**9015**

2.5. Aurizon Network's ability to deliver the required scope

For mainline work Aurizon Network currently have one undercutting machine, the RM900, and this is understood to be coming to the end of its useful life.

The required scope task for the period FY15 to FY17 varies according to the source data used, as shown:

- GPR data capture: 500.9km
- Review Reworked Data Capture: 421.0km
- Cost model 'Detailed Plan' output: 402.2km

The Review Team understand that Aurizon Network has committed to deliver 140 standardised[25] km of ballast undercutting for each of these years, giving a total deliverable of 420 standardised km over the

[25] "standardised" track is defined as standard 300mm depth linear kilometre

remaining UT4 period, compared with variously reported actual delivered figures of 103.80km[26], or 118km[27].

In addition achievement of the 140km per annum output was dependent upon a number of changes to the way Aurizon Network delivered the works[28], including:

- revised rostering of staff;
- procurement of additional spoil wagons; and
- procurement of an additional, smaller, undercutting machine.

Following discussion with Aurizon Network staff the Review Team understand that revised staff rostering was implemented in FY15 and that additional spoil wagons became available for use with the RM900 undercutter. However on analysis of the Aurizon Network cost model it is apparent that that these additional ballast spoil wagons only became available late in FY15. Hence, although it is believed that the additional wagons will provide them with greater capacity in the future, the timing of their arrival would not significantly affect their capacity to achieve the proposed 140km of standardised track during FY15.

Further, the Review Team understands that Aurizon Network delivered 152km of standardised mainline undercutting work (124km actual track) during FY15. Extrapolation of these figures over the remaining UT4 period suggests that in standardised terms Aurizon Network is able to complete the annual target 140km standardised task. Consideration of the actual km of track undercut, however, suggests that Aurizon Network do not currently have the capability to deliver the 402.2km outputs shown in the cost model information discussed in the meeting held on 27th July 2015 with QCA and Aurizon Network staff or the recalculated mainline undercutting task of 421.0km within the UT4 period.

Against this it is understood that Aurizon Network are proposing to make good this shortfall by the use of hired in excavator undercutting resources. While this may enable delivery of the required undercutting task it does not deliver the output in the same efficient manner as the RM900 machine. Inefficiencies associated with the use of excavator undercutters include:

- inability to screen the used ballast to return suitable material to the track; and
- need to transport replacement ballast to site by road rather than rail due to the comparatively small quantities involved. This method of delivery carries a cost premium.

In addition to this shortfall the Review Team also express concern in relation to the evident backlog of ballast undercutting which has been prevalent over the UT3 period.

[26] Aurizon Network Ballast Cost Model for 2014
[27] Aurizon Network powerpoint presentation BallastScopeDevelopment_RB_April_2015.pptx, Slide 4 of 11
[28] Aurizon Network powerpoint presentation BallastScopeDevelopment_RB_April_2015.pptx, Slide 4 of 11

3. ASSESSMENT OF BALLAST UNDERCUTTING COSTS

3.1. INTRODUCTION

The following section comprises a high level review of Aurizon Network's forecast ballast undercutting costs over the proposed UT4 period. The review aims to assess the reasonableness of the costs submitted by checking the rigour around the cost model developed, and consistency with unit rate historical costs and industry expectations.

All material used for this review and referenced in this section is publicly available or was provided to the Review Team by Aurizon Network and/or QCA, and consists of data from;

- public documents relating to Aurizon Network maintenance;
- information reports undertaken for Aurizon Network;
- Aurizon Networks Annual Maintenance cost reports to the QCA; and
- historical data from earlier undertakings.

3.1.1. Aurizon Network current scope costs

Initially it is worth noting that the Aurizon Network's forecast scope differs significantly for UT4 from that in UT3 or previous undertakings. In particular Aurizon Network has developed the scope, as discussed previously, on the results of GPR data as opposed to traditional methods based on traffic tonnage and trial pit results. Overall this should result in a more defined and robust scope, however as has been noted previously, the methodology is still in development, and will probably not provide full efficiencies until another robust set of financial year GPR data is obtained.

Table 7 shows that Aurizon Network is forecasting a significant rise in costs for the ballast undercutting task in FY15 with a subsequent rise the following year. The FY14 data in this table has been normalised by the Review Team so that 'pooled' costs are treated more consistently across the four financial years.

Table 7 Current Aurizon Network scope

Current Plan ($ Nominal)	FY14* Actual	FY15	FY16	FY17
C01 + C14 - Mechanised Ballast Undercutting	43,153,811	54,278,016	63,960,493	67,366,679
GPR Costs	1,200,000	1,200,000	1,200,000	1,200,000
C03 + C13 -Turnouts	5,589,777	6,048,407	6,178,728	6,694,473
C02 - Other Ballast Undercutting	4,616,411	4,723,179	4,900,792	5,178,787
Total ballast undercutting costs	**54,560,000**	**66,249,602**	**76,240,013**	**80,439,939**
Mainline Scope (km)	**117.82**	**129.21**	**133.00**	**140**
Turnout Scope (unit)	**41**	**54**	**57**	**58**
Unit cost/km	**366,272**	**420,069**	**480,906**	**481,191**
Percentage change (year on year)		**13%**	**13%**	**0%**

Unit cost/turnout	**136,336**	**112,008**	**108,399**	**115,422**
Percentage change (year on year)		**-22%**	**-3%**	**6%**

As can be seen from Table 7 overall ballast undercutting costs will increase from around the actual FY14 costs of $54.6M to $80.4M in FY17. Although this increase is also accompanied by an upward trending in scope over the period, the relationship is not linear and it is noted that there is a significant unit cost rise for mainline ballast undercutting unit rates per kilometre.

This increase is forecasted despite the introduction and implementation of a number of technologies and systems which Aurizon Network states are being implemented to improve overall efficiencies and potentially reduce costs of future ballast undercutting such as:

- GPR measurement, as discussed previously in this report, to enhance the accuracy of determination of ballast condition;
- implementation of NAMS or "SMART systems which will enable improved GPR data interrogation and management to occur along with the integration of other data streams" enabling targeted prioritisation and greater efficiencies in resource allocation; and
- coal loss management programs such as the veneering to reduce the coal loss coming from the coal surface in wagons.

Although it is acknowledged that the benefits of these programs will probably not be fully effective until future years, it would seem logical that some of these benefits should be taken into account for FY16 and FY17 year forecasting. Especially the coal loss management programs, which effectively should be slowing down the rate of expected fouling due to reduction in coal surface loss from wagons, which accounted for "80% of the coal" spillage[29].

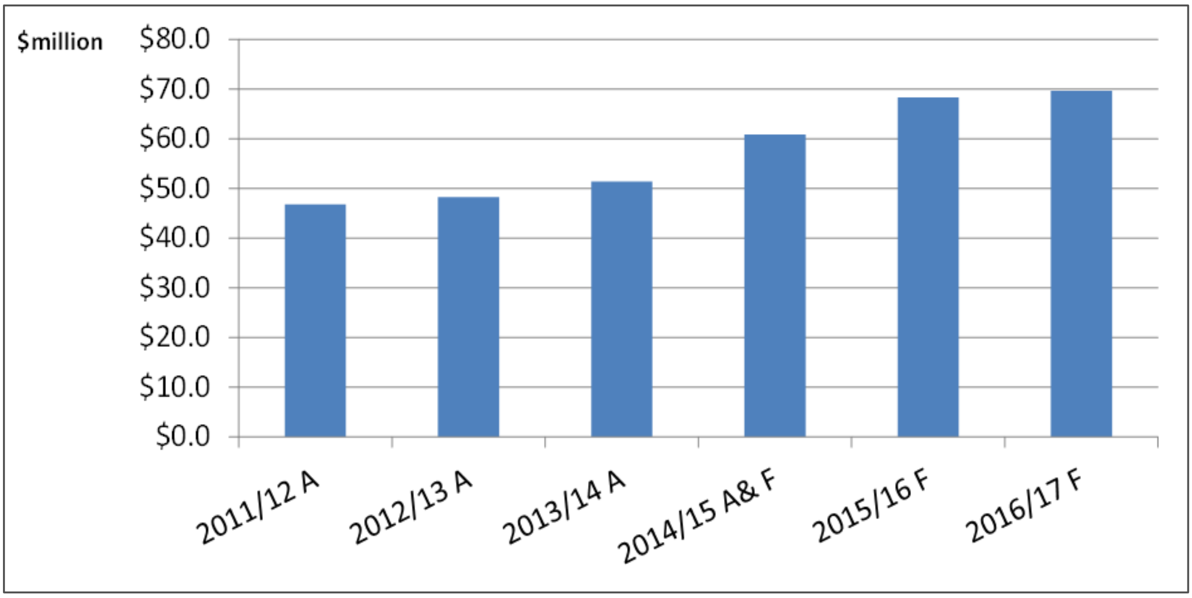

Figure 16 Ballast undercutting costs (2012)[30]

[29] Connell Hatch report – Aurizon network 2010 submission re coal dust emissions

[30] Source: The 2011/12 and 2012/13 costs are from Aurizon Network's Response to the QCA's draft decision on the MAR in Aurizon Network's 2014 DAU, page 136. The 2013/14 A and 2014/15 Actual and Forecast, 2015/16 F and 2016/17 F are

3.1.2. Overall ballast cost trend analysis

The Review Team's analysis shows that overall ballast undercutting costs have increased from around $47 million in FY12 to around $70 million in FY17 (Figure 16), in 2012 dollars. The Review Team acknowledges, and has confirmed with in discussions with Aurizon Network that a number of issues can affect the cost of ballast undercutting, including climatic conditions and market factors that affect rail access. However the Review Team still maintains that despite these issues the initiatives being implemented should result in at least some stabilisation of the overall costs, and specifically some improvements in the operational unit rate per kilometre for the ballast undercutting task.

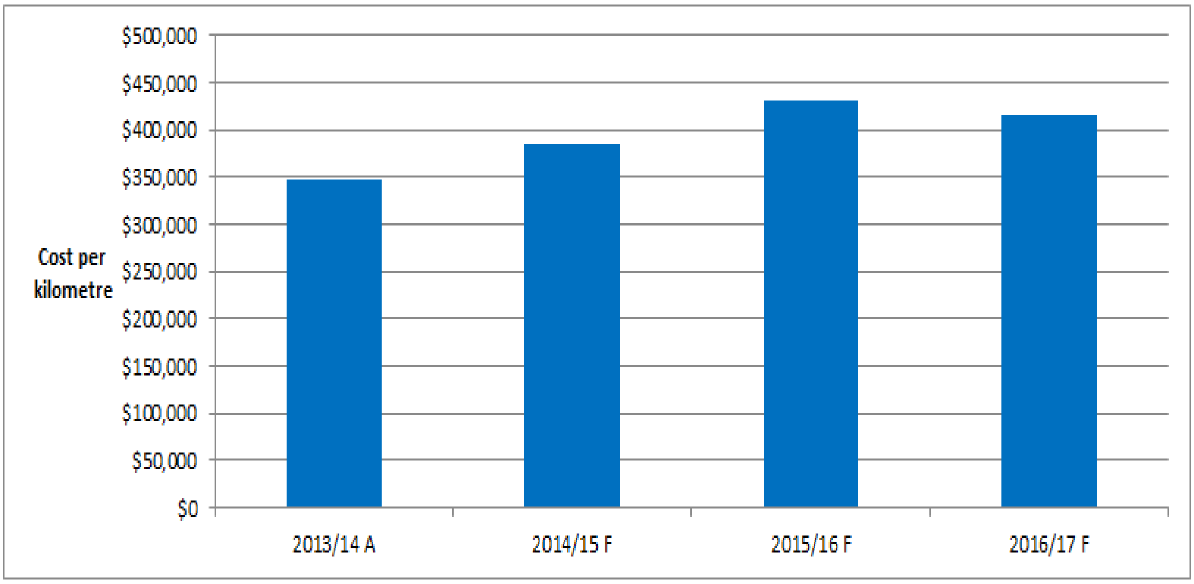

Figure 17 Ballast undercutting costs per kilometre (2012 dollars) for mainline only[31]

Moreover, the Review Team notes that while there is some inaccuracy in its estimated overall ballast undercutting cost per kilometre (because it has been necessary to estimate turnout kilometres in order to estimate the overall volume of ballast being managed), the analysis shows ballast undercutting costs are slightly trending upward over the period FY14 to FY17.

In particular, there is a slight increase in overall per kilometre ballast costs over the forecast period FY15 to FY17. A key driver of this is the increase in ballast undercutting works (as measured in kilometres) – see Figure 18. This and other key drivers are examined in more detail in Section 3.2.2.

from Aurizon Network's ballast cost model. The 2012/13 costs were adjusted by actual maintenance cost index (MCI) figures sourced from section 6, Aurizon Network Annual Maintenance Cost Report, 2012/13.

[31] Source: The analysis of Aurizon Network's ballast cost model. Ballast undercutting kilometres represent total kilometres (mainline and loops including both RM900 and excavator machines).

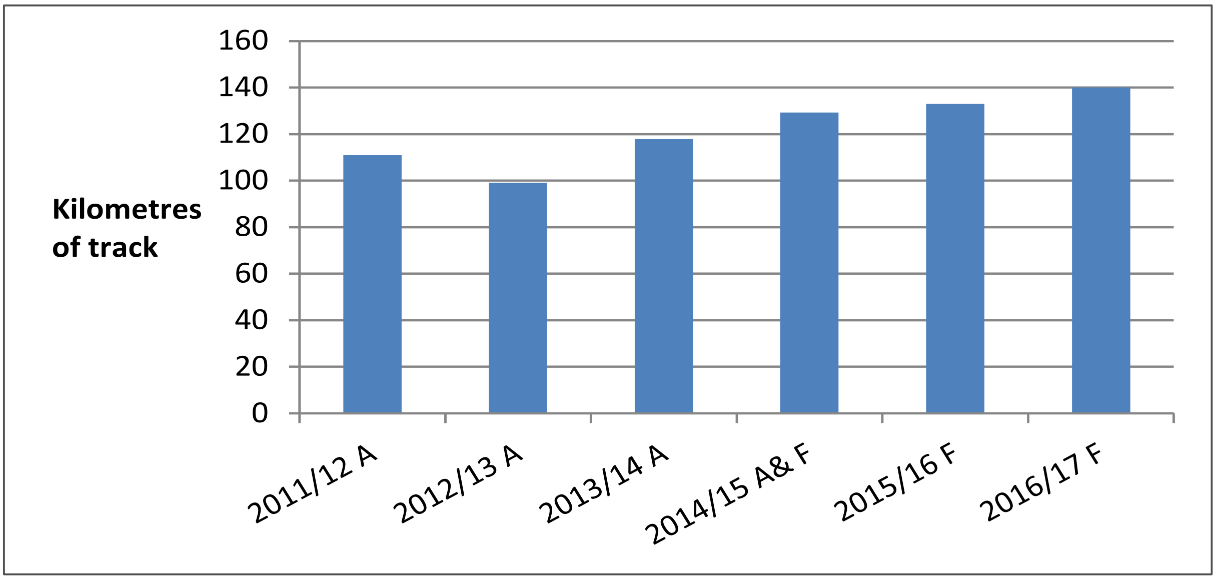

Figure 18 Ballast undercutting kilometres (mainline and excavator)

3.1.3. Assessment methodology

To attempt to understand the reasons for this significant increase in costs shown in the Aurizon Network cost model the Review Team applied a three tiered approach. This approach included:

- a review of the Aurizon Network cost model;
- a comparative review with actual Aurizon Network historic costs for similar works; and
- an independent cost build-up of operational unit rate costs for ballast undercutting

The objective of this three tiered approach was to understand whether the reasoning behind the increases could be justified through either economic review, organisational historic pricing or from industry benchmarking.

The following section summarises the Review Team's findings obtained from each approach.

3.2. Analysis of Aurizon Network's ballast undercutting cost model

This section presents the results of The Review Team's analysis of Aurizon Network's ballast undercutting cost modelling. The Review Team has examined a range of ballast-cost issues, including:

- Ballast cost trend analysis: whether there are material changes in overall ballast costs over time which could indicate the UT4 ballast scope costs are higher than what could be expected given the amount of works that are planned to be undertaken.
- Ballast cost modelling and key cost drivers: whether future ballast costs estimated by Aurizon Network are internally consistent with operational and supply chain objectives and whether there are any significant changes in key assumptions over the forecast period.
- Turnout and other cost modelling.
- Fixed and variable Cost splits.

The Review Team has focussed on: analysing trends and how costs link to works; reviewing the internal inconsistency of modelling; and examining if there are significant changes in the assumptions.

3.2.1. Information sources

The Review Team examined the key issues with ballast costs through reviewing the following documentation, some of which relates to the UT3 period:

- Aurizon Network's ballast cost model provided for review[32];
- Aurizon Network's submission to the QCA[33]; and
- Aurizon Network's Maintenance Cost report[34].

The Review Team has undertaken separate analysis of the turnout cost model. This is also discussed below.

3.2.2. Ballast cost modelling and key assumptions

The Review Team's analysis of the ballast cost model has focused on the:

- total calculations for each year. This involves examining how total costs have been calculated based on adding up costs from each of the cost types, including allocating 'pool' costs to one of: machine ballast undercutting; excavator ballast undercutting; and turnout ballast undercutting.
- drivers of costs for the top three cost categories (by value) for mechanised (RM900) and excavator ballast undercutting.

Total cost calculations

The Review Team analysed the cost model spreadsheet that Aurizon Network provided[35], and considered the formulae within the model.

The Review Team's analysis has revealed the total calculations for FY14 year appear to be calculated incorrectly since the allocation of pool costs is linked to the cells for FY17. It appears that the formulae in cells for 2013/14 were inadvertently copied across from 2016/17. With this correction, the total machine ballast costs (in nominal dollars and including the costs of the GPR machine) are estimated to be $42.0 million each year instead of $43.4 million. This is a reduction of $1.4 million.

Drivers of costs for the top three cost categories (by value) for mechanised and excavator ballast undercutting

Our analysis of the detailed costs illustrate that the top three cost categories (in order of cost value) for ballast undercutting costs for combined mechanised and excavator ballast costs are (Table 8):

- **hire charges.** These are external labour costs incurred by Aurizon Network to undertake both undertake mechanised and excavator ballast works.
- **ballast raw materials.** These are the costs of raw materials used to replace fouled ballast.
- **labour charges.** These are Aurizon Network's labour costs and are allocated only to mechanised ballast undercutting costs.

We have undertaken an analysis of these three cost categories to focus our review on the most significant costs.

Table 8 Ballast undercutting costs for cost types

Cost category	2016/17 F	% of total cost (2017)	Cumulative % of total cost (2017)	% Change from 2013/14 to 2016/17
Hire Charges	$12,437,955	18%	18%	52%
Ballast raw materials	$11,612,720	17%	36%	55%

[32] UT_DD_Ballast Response Submission Final v2a – Unprotected – Submitted 130815.xls
[33] Response to the QCA's Draft Decision on Aurizon Network's 2014 Draft Access Undertaking – Maximum Allowable Revenue, dated 19 December 2014
[34] Aurizon Network Annual Maintenance Cost Report, 2012/13, produced in December 2013
[35] UT_DD_Ballast Response Submission Final v2a – Unprotected – Submitted 130815.xls

Cost category	2016/17 F	% of total cost (2017)	Cumulative % of total cost (2017)	% Change from 2013/14 to 2016/17
Labour	$11,509,632	17%	53%	16%
On-track vehicles	$8,583,377	13%	66%	126%
Internal Charges	$5,502,533	8%	74%	77%
Freight	$5,269,811	8%	82%	23%
Depreciation - machines	$2,900,790	4%	86%	333%
Trade Service	$2,549,537	4%	90%	257%
Travel and accommodation	$2,251,007	3%	93%	-5%
Overtime	$1,620,460	2%	95%	48%
Vehicles	$909,460	1%	97%	19%
Depreciation - other	$556,159	1%	98%	14%
Professional Services	$489,036	1%	98%	173%
Intercompany charges	$444,890	1%	99%	1197%
General Supplies	$292,945	0%	99%	18%
Other Expenses	$190,114	0%	100%	1%
Freight & Postage	$110,112	0%	100%	-59%
Utilities	$76,265	0%	100%	20%
Other consumables	$53,899	0%	100%	31%
Repairs and Mtce	$47,034	0%	100%	-27%
Employee Expenses	$18,921	0%	100%	59%
Other Track Components	$15,625	0%	100%	n.a.
Infra Mtce & Mats	$9,902	0%	100%	84%
Computer	$1,289	0%	100%	-26%
Energy & fuel	$86,791	0%	100%	36%
Total	**$67,366,679**			

The Review Team analysis of the key drivers of the costs for the three cost categories has revealed that the costs are influenced by a combination of an increase in ballast kilometres and unit costs. Table 9 illustrates the two main drivers of costs for each of the three categories (hire charges, ballast raw materials and labour), which in most cases explains all of the increase in costs. Note that we have only included changes in cost drivers for 2014/15 where there is information available.

While we have not assessed the reasonableness of the unit rates, we can draw some conclusions from the changes in unit rates over time:

- **unit hire rates.** The hire rates per shift (mechanised and excavator) increase at XX[36] per cent per year with the overall average unit rate increasing above this in 2015/16 because higher shift cost rates are being used since ballast works are either further out on line sections or more ballast work is required to replace the existing ballast on the targeted line sections.
- **ballast cost materials.** The ballast cost materials are directly related to the cost of sourcing materials from different quarries and the amount of ballast works (in terms of kilometres of track).
- **unit labour rates.** The increases for labour are driven by the change in wage rates in the recent 2015 enterprise bargaining agreement.

Therefore, the increase in unit rates for these three cost categories is either the: agreed wage rates under the 2015 enterprise bargaining agreement; the amount of ballast works required; or the nature of the ballast work (e.g. location and screenability). We did not find any internal model inconsistencies in the way that the costs were developed for these cost categories, noting that we have not checked every spreadsheet cell in the calculations.

However, one area that may require further examination is the changes that occur from 2014/15 to 2016/17 in the sourcing of ballast materials. Aurizon Network's model assumes that there is a large shift from sourcing of materials from quarries to on-site sourcing (

Table 10). This is a significant outcome since the cost of on-site sourcing is between 11 and 45 per cent higher than from the quarries used by Aurizon Network.

This change has a material impact on the cost of ballast material costs which we estimate to be around $1 million[37] for each of 2015/16 and 2016/17. The Review Team initially interpreted this as the transport task being managed by Aurizon Network rather than the quarry operator. However, this is contradicted by the freight ballast costs for the on-site category also increasing by a similar proportion. On this basis, Aurizon Network should query the reasonableness of the change in sourcing patterns.

In addition, the Review Team notes that the labour costs have increased significantly because Aurizon Network is using more labour hire and contractors to make up for the reduction in permanent FTE of 10. Labour hire and contractors will provide increasing flexibility, but this strategy is not considered efficient as it is materially increasing the unit cost rate. Also, the labour and overtime costs would increase significantly under Aurizon Network's proposal (16 per cent from FY14 to FY17). This appears to contradict Aurizon Network's assertion that the increase in external costs is driven by the permanent reduction in FTE.

[36] This is commercially sensitive information that would impact on commercial negotiations with suppliers.

[37] Cost increases from on-site sourcing are FY16 ($992,574) and FY17 ($1,166,529)

Table 9 Three top cost categories: cost drivers, based on ballast cost model

Cost category	Key drivers	2014/15	2015/16	2016/17	Cumulative
Hire rates					
Actual hire charges cost increases			13%	7%	**21%**
	Change in average hire rates		10%	2%	12%
	Change in ballast kilometres (machine and excavator)		3%	5%	8%
	Total		13%	8%	**21%**
Ballast cost materials					
Actual ballast cost material increases			20%	7%	**28%**
	Change in cost of ballast raw materials		15%	1%	16%
	Change in ballast kilometres (machine and excavator)		3%	5%	8%
	Total		18%	7%	**26%**
Labour					
Actual labour cost increases		31%	2%	2%	**37%**
	Change in wages as per enterprise bargaining agreement	4%	4%	4%	12%
	Change in ballast kilometres (machine and excavator)	10%	3%	5%	19%
	Total	14%	7%	9%	**34%**

Table 10 Sourcing of ballast raw materials (% of total), based on ballast cost model

Cost category	2014/15 A& F	2015/16 F	2016/17 F
Waitara	43%	16%	16%
Hatfield	5%	9%	9%
Yarwun	8%	17%	17%
Blackwater	21%	6%	6%
Midgee	0%	0%	0%
Westwood	3%	0%	0%
On Site	19%	52%	51%
Total	**100%**	**100%**	**100%**

3.2.3. Turnout cost modelling

The turnout undercutting unit rate falls from $136,336 in FY14 to $108,399 in FY16 (Nominal $) and from $129,022 to $97,635 in FY12 dollars. Considering the scope of the works involved in undercutting turnouts, the Review Team considers the unit rate reasonable.

The key reason that the unit rate appears to be higher in FY14 is that internal charges being applied to turnouts in that year are higher than in subsequent financial years. However, it is noteworthy that across

FY14 and FY15 the total internal cost (across turnouts and mainline) is relatively stable at $6 million and $6.2 million, respectively.

In terms of specific turnout ballast undercutting costs, our analysis revealed that the increase in turnout costs from FY14 to FY17 (Figure 19) is consistent with the change in kilometres of turnout track kilometres as the cost per kilometre is relatively stable over this period once we exclude internal charges.

Figure 19 Summary of turnout costs

The exclusion of internal charges is important to compare across years since the method of allocating internal charges to turnouts for FY14 actual costs is different to the forecast years (FY15 to FY17). This is because the forecast years costs are allocated using a 'bottom up' costing approach (i.e. with reference to the actual number of forecast turnouts and its impact on internal charges – for example, signalling costs and its labour shift requirements based on the number of turnout ballast works) whereas the FY14 actual costs are allocated using a simple 'top down' cost allocation approach.

There are numerous potential explanations for this change in internal charge attribution, including the varying track closure costs arising from location of and access to the worksite.

Internal charges as specified in the UT4 ballast cost model (which is based on GPR data rather than the volumetric analysis undertaken previously) average over 40% of the total turnout ballast cost. However, beneficially, from (Figure 19), it can be seen that the absolute and proportional internal cost has decreased over the period FY15 to FY17 when compared to FY14 as a result of the change in methodology.

In their assessment of CQCN asset condition for the basis of UT4, Evans & Peck identified that there was a significant backlog of turnouts on the system which "were still in service but book life expired". From these some 100 turnouts needed replacement in 2008-due to being life expired[38]. Evans & Peck assessment identified that to reach a "relative steady state some 40 to 50 turnouts" will require "some sort of asset renewal" or major reparation each year over the next five years (from 2012). The report does not provide reasons for the backlog identified however this identified lag[39] appears to have been a historical issue for Aurizon Network in relation to ballast undercutting works.

The review team acknowledge that book life differs from service life and that the service life in turnouts, with careful monitoring and maintenance, can extend significantly over the book life. However one notes that when this occurs ongoing maintenance is critical to mitigate any operational risks arising from obsolete or life expired equipment. In consideration the issue identified by Evans & Peck the Review

[38] Refer Fig 13 Technical Expert Report , CQCN Asset Maintenance and Renewals, Evans & Peck
[39] "Ballast undercutting requirements lag 6 to 7 years behind". Refer QR Network Access Undertaking, Assessment of Operating and Maintenance costs for UT3, GHD

Team consider the continual shortfall on delivery of turnout undercutting delivered by Aurizon Network to be a concern (refer Figure 20).

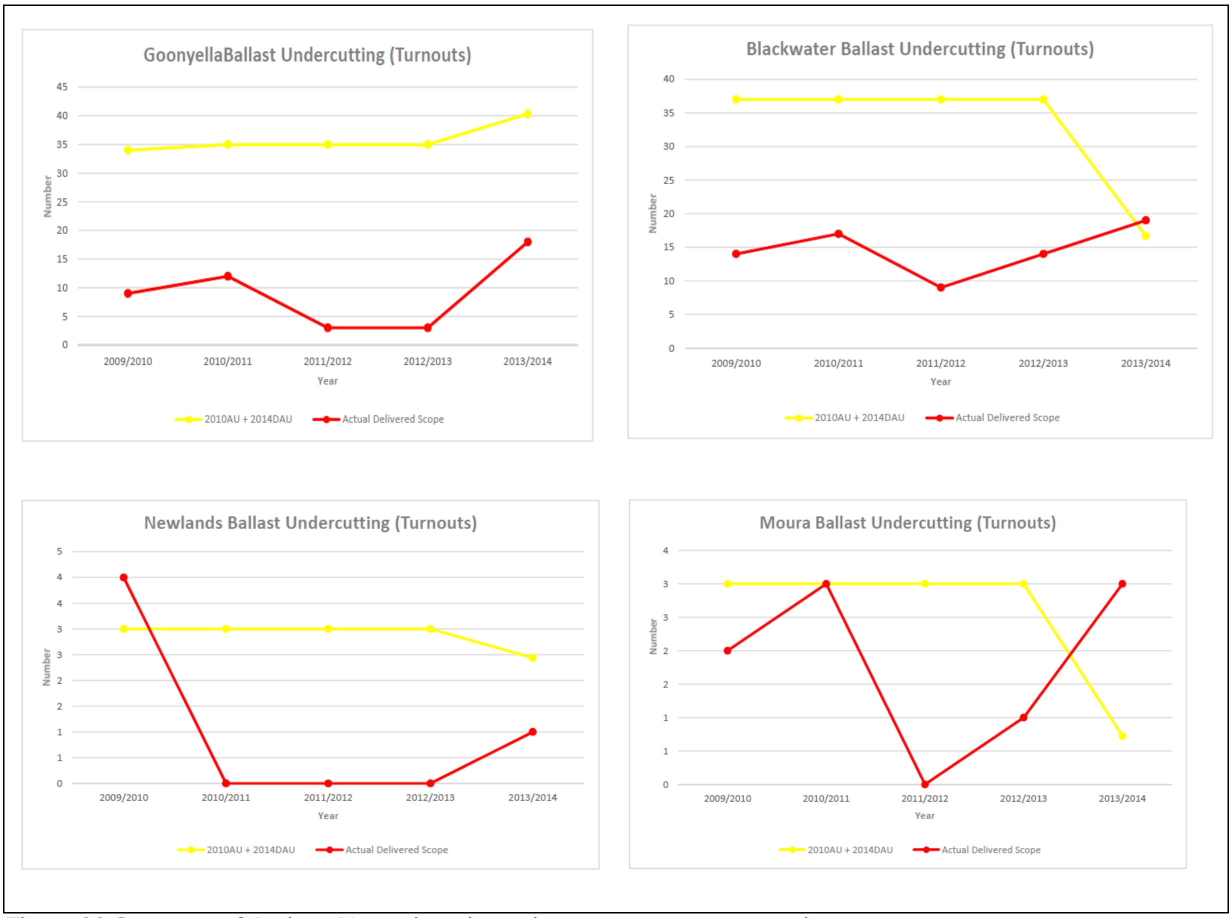

Figure 20 Summary of Aurizon Network undercutting program versus actual

This highlights that significant works were undelivered in relation to turnout undercutting over the UT3 period. As customers would have already paid for this work and as it is reasonable to assume that this undelivered scope has now been included in the proposed UT4 scope, one questions whether the forecast cost reflects “double-counting” in relation to the fact that potentially a percentage of the turnout undercutting costs reflected in the UT4 forecast have been allocated already in previous years scope.

The Review Team further notes an inconsistency in the proposed number of turnouts included in the Aurizon Network submission, 236 turnouts as compared to 210 in the cost model.

Aurizon Network has submitted (slightly lowered) tonnage estimates for the UT4 period than was originally estimated during the time of publication of the Evans and Peck report (2012). Unlike the development of scope for the mainline undercutting, Aurizon Network has stated that the development of the turnout scope is still dependent on tonnage. Although a decrease in operations may not see a sharp decrease in costs immediately due to fact that costs are not that variable and the evident lag, an overall decrease over the period would be expected.

In consideration of the significant shortfall (under-delivery) in turnout undercutting that has previously been claimed, the Review Team considers that although the scope going forward is likely to be reasonable in view of the overall condition of turnouts on the system, a reduction in the turnout undercutting costs would be appropriate. This review project has identified that QCA has two options to reduce turnout scope cost:

Option 1: Reject all turnout undercutting scope cost because the under-delivered scope, over the UT3 period, is broadly equivalent to the proposed turnout undercutting scope for UT4; or

Option 2: Agree to a reduced scope, in this case the Review Team notes that the GPR analysis identifies that 121 turnouts have elevated PVC levels (see Section 2.1.2). This would reduce the undercutting works by 48 turnouts over the UT4 period which in turn would reduce the scope cost by around $2 million over the UT4 period. This appears to represent a reasonable compromise position to support works to maintain track integrity while also reducing the incidence of customers paying twice for turnout works.

3.2.4. Fixed and variable cost splits

Aurizon Network has advised that since re-submission of the 2014 DAU the mix of fixed and variable costs has changed, primarily due to the change in procurement strategy of the off-track solution from purchasing to procurement through a lease arrangement (AN MAR response, 19 December 2014, Pg. 133). This has altered the fixed and variable split from the original April 2013 submission and Aurizon Network state that the fixed/variable cost split is 44%/56% for ballast undercutting.

Figure 21 is derived from the Aurizon Network cost model and presents operational, plant maintenance and overhead costs. In the first column, the Review Team identifies the variable and fixed costs associated with the Ballast undercutting task. This indicates that the average (real) variable cost over the FY14 to FY17 period is marginally higher at around 60-61% of the cost base.

Current Plan FY12$: FY14 - FY17

MCI	1.057	1.083	1.110	1.145
Kms/Turnouts	C01	C14	C13	Total
Blackwater	219.98	28.34	98.00	248.32
Moura	10.00	4.65	14.00	14.65
Goonyella	172.25	42.40	91.00	214.65
Newlands	27.86	14.55	7.00	42.41
TOTAL FY14	**430.09**	**89.94**	**210.00**	**520.03**

	Operational costs	C01	C14	C13	Pool	TOTAL
variable	Ballast	25,628,237	9,814,955	2,868,500	-	38,311,692
variable	Freight	16,784,389	-	-	-	16,784,389
variable	Internal Charges	11,418,074	6,018,923	8,593,126	-	26,030,123
variable	Hire Charges	11,350,786	27,162,391	9,225,015	-	47,738,192
fixed	Trade Service	6,740,566	-	138,190	802,877	7,681,633
fixed	Labour	30,427,225	-	138,190	9,462,360	40,027,775
variable	Overtime	4,283,836	-	6,910	1,233,159	5,523,905
	Total Operational Costs	**106,633,113**	**42,996,268**	**20,969,931**	**11,498,397**	**182,097,709**
	Operational Costs per km/turnout	**247,933**	**478,043**	**99,857**		
			1.928117551			

	Plant Maintenance Costs	C01	C14	C13	Pool	TOTAL
fixed	On Track Vehicles	22,875,749	25,583	25,583	-	22,926,915
	1.59	301,121	478,328	99,979		

	Overhead Costs	C01	C14	C13	Pool	TOTAL
variable	Travel and accommodation	6,000,973	-	144,924	2,232,305	8,378,202
fixed	Depreciation - machines	6,772,647	121,810	121,810	-	7,016,267
fixed	Depreciation - other	-	-	-	2,196,070	2,196,070
fixed	Employee Expenses	-	-	-	68,337	68,337
fixed	Utilities	-	-	-	293,322	293,322
fixed	Other Track Compnents	-	-	-	45,410	45,410
fixed	Professional Services	858,801	-	-	635,667	1,494,468
fixed	Vehicles	-	-	-	3,503,529	3,503,529
fixed	Freight & Postage	-	-	-	620,622	620,622
fixed	Repairs and Mtce	-	-	-	209,210	209,210
fixed	Infra Mtce & Mats	-	-	-	34,840	34,840
fixed	Computer	-	-	-	5,705	5,705
fixed	General Supplies	-	-	-	1,131,521	1,131,521
fixed	Intercompany charges	1,176,099	-	-	38,587	1,214,685
variable	Energy & fuel	-	-	-	(323,967) -	323,967
fixed	Other consumables	-	-	-	202,973	202,973
fized	Other Expenses	-	-	-	764,550	764,550
	Total Overhead Costs	**14,808,520**	**121,810**	**266,733**	**11,658,682**	**26,855,745**
	TOTAL	**144,317,382**	**43,143,661**	**21,262,247**	**23,157,079**	**231,880,369**

Figure 21 Fixed/variable cost[40]

[40] Source: UT4 DD Ballast Response Submission Final v2a

> Our review of the model has found that the following reductions are recommended to the cost model:
>
> - Total cost error – a reduction of $1.4 million
> - On-site ballast sourcing – a total reduction of around $1 million for each of 2015/16 and 2016/17
> - Turnouts excess scoping and under-delivery – a total reduction of around $2 million

3.3. AURIZON NETWORK HISTORIC COSTS

3.3.1. Historical mainline undercutting costs

Figure 23 below shows historic unit mainline ballast cleaning costs compared to scope, with a projection of expected costs throughout the UT4 period. As can be seen from the graph there is some fluctuation the unit rate figure, with expected costs for FY16 and FY17 being similar to, or in excess of the unit costs incurred in FY13, while costs for FY14 and FY15 are less.

It is noted from the Aurizon Network Annual Maintenance Cost Report that FY13 was a particularly difficult year due to the adverse weather conditions and consequent flooding suffered in the Central Queensland area. Against this, the report states that works in FY14 were, on average, undertaken on sections of track where there was less ballast fouling and therefor had a reduced requirement for fresh ballast, thus reducing the unit rate.

The same report also states that more heavily fouled sections will be tackled once the additional spoil wagons procured for use with the RM900 mainline undercutting machine become operational. Arrival of these wagons is noted as being due from the end of calendar year 2014, and this corresponds with information received from members of Aurizon Network staff.

The Review Team note, however that if this is the case, one would expect corresponding decreased in unit costing due to the efficiencies gained through the additional wagons, otherwise what would be the reason for deferring this work and potentially increasing operational risks if the final unit cost was to remain the same or increase.

Therefore, from the graphs and the information provided by Aurizon Network on the report, it is observed that:

- Higher unit costs for mainline ballast undercutting are synonymous with “bad weather” or higher contamination,
- Lower unit cost rates for are synonymous with ballast undercutting in sections of track where there is less fouling

This is due to two main factors; the reduced requirement for fresh ballast, and the increased efficiently of the ballast undercutting machine (i.e. production rate can range significantly with depth and level of contamination of the site)[41].

Furthermore the maintenance report provides the following average rates of loss recorded from ballast undercutting works:

- 2011/12 – average loss 49%
- 2012/13 – average loss 48%
- 2013/14 – average loss 26%

[41] Both of the above align with the analysis undertaken and shown in Figure 3 Unit rate demonstration of potential economies of scale

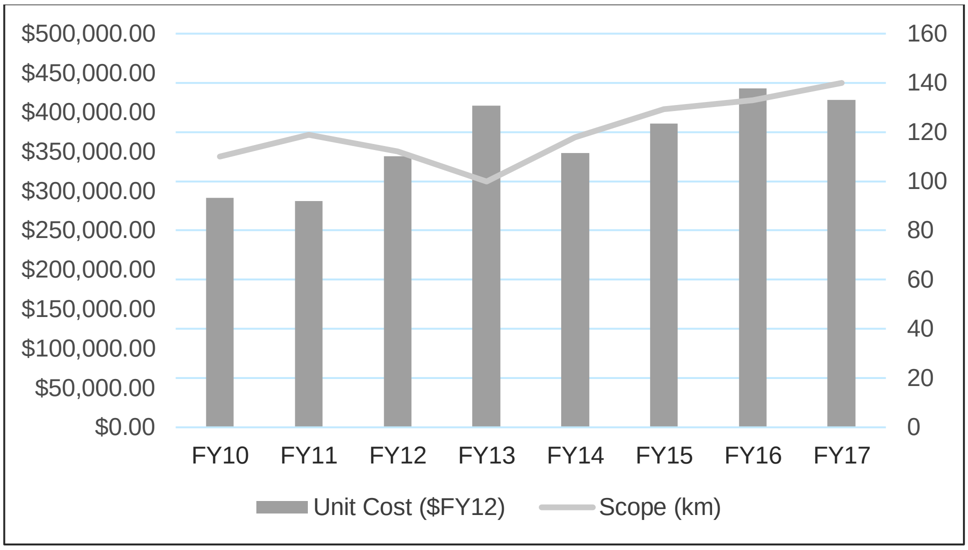

Figure 22 Mainline historic ballast undercutting costs compared with scope

From the reasoning sited above it is considered valid to deduct that the future forecast figures for FY16 and FY17 appear to be based upon an expectation that undercutting will be occurring at highly contaminated sites in the future, or in adverse climatic conditions. The Review Team have based this assumption on the fact that unit costs appear to align with costs experienced with the adverse climatic conditions in FY13, where it is stated that many of the sites had little ballast return due to high contaminates and clay within the ballast.

This would indicate that the work that is occurring may be a catch up for the previous periods.

3.3.2. Historical turnout undercutting costs

Figure 24 below shows unit costs for turnouts over the period from FY10 - FY17. This graph shows the unit cost to be more stable than that for mainline works, although the annual scope fluctuates considerably over the review period.

It is noted by Evans and Peck[42] that many of the turnouts within the Central Queensland Coal Network were past their book life. As such significant intervention was likely to be required to maintain the reliability of the system. In particular it was noted that around 200 turnouts needed replacement in the next few years, with an intensive but achievable programme being the replacement of 30-40 turnouts per year.

Intervention of this type involves a significant financial investment in the system, at a time when there is pressure on the market price of coal.

Information obtained from the Aurizon Network Annual Maintenance Cost Report 2013-2014 indicates a general underachievement of planned turnout undercutting scope throughout the period from FY10 to FY14. The actual scope achieved is shown in Figure 24 but this is considerably less than the planned works indicated in the Maintenance Cost Report.

Given the Aurizon Network expectation of a ballast life of ballast 5 – 7 years sustained under delivery of this nature means that many turnouts are currently likely also to be located on life expired ballast meaning, in turn, that the condition of the overall turnout asset in likely to deteriorate further, making the undercutting of each location more challenging and therefore expensive than might otherwise be the case.

It is noted from the graph that the costs for FY14 are particularly high but, as discussed previously, this is understood to be due to the treatment of internal charges within that period. Considering unit costs for the other years it is noted that works in FY12 generated a high unit cost with very little output delivered.

[42] Condition Based Assessment, 2013

Although the reason for this is unclear the Review Team that the unit rates proposed by Aurizon Network for the remaining UT4 period are reasonable.

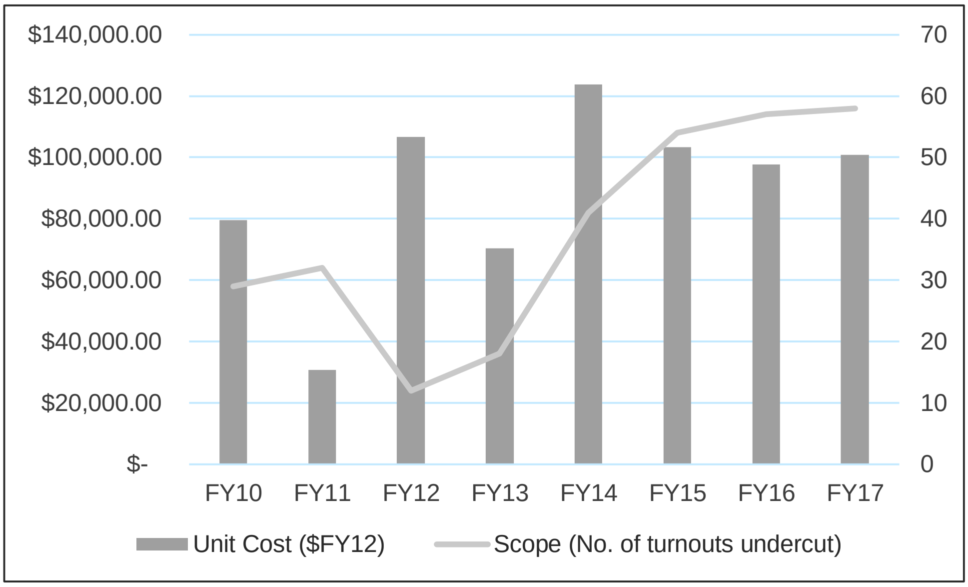

Figure 23 Turnouts - historic unit cost compared with scope

Our review of actual historic costs, although not being able to provide us with a rigorous method of deduction has indicated that:

- some of the works occurring appear to be catch up for underperformance of undercutting works in previous periods.
- the average unit rate cost for mainline ballast undercutting appears to be based on an average obtained when the majority of sites are highly contaminated.

3.4. INDEPENDENT COST ESTIMATING

3.4.1. Mainline costs

To assess the reasonableness of the forecast cost, the Review Team developed a high-level cost estimate for mainline undercutting undertaken by an Automated Ballast Cleaning machine. The estimate was based on industry rates and included:

- Off-site overheads of 20% and margin of 10%.
- Full ownership costs for all capital equipment including spares, repairs, depreciation, and escalation on replacement and finance costs.
- Full rail system maintenance and not localised sections of work, which requires single mobilisation costs and include relatively short lengths of track.

Table 11 shows the independent cost estimate in comparison with Aurizon Network's forecast costs per kilometre. The Review Team's processes and assumptions for estimating the build-up are described in Appendix B[43].

While the Review Team has used its professional judgement in the development of this estimate, it should be noted that the issues considered may not be exhaustive. Further, while the costs used are considered to be reasonable they have not been cross checked with current industry rates. Notwithstanding this, the purpose of developing this estimate with independent and objective reasoning was to assess whether the rates used by Aurizon Network are reasonable and this objective has been achieved.

Table 11 Estimated cost build up ballast undercutting

The Review Team Forecast (Mainline RM900 only)					
	Blackwater	Goonyella	Moura	Newlands	Average
Cost	$286,511	$287,870	$286,872	$277,235	$284,622
Total/average costs based upon full length maintenance repair of the network, continuously working through shifts and excludes isolated/minor lengths of repair					
Estimates allow for continuous operation of ballast cleaning machine throughout shift at worksite					
Includes Off Site Overheads of 20% and Margin of 10%					

Table 12 Aurizon Network's cost model (Nominal $)

Aurizon Network Forecast (Mainline RM900 only)					
	FY14[1]	FY15	FY16	FY17	Average
Cost	$345,434	$397,836	$471,316	$461,612	$419,050

Note: 1. FY14 has been normalised, so that pooled expenses are treated more consistently across the four FYs.

Note 2. Table only includes mainline RM900 only, hence unit rate figure differs from Table 7 detailing Aurizon current scope as these unit rates include mainline RM900 and excavator costs.

The Review Team's estimates are most comparable with Aurizon Network ballast undercutting costs for the mainline in FY 2014. However, Aurizon Network's forecast costs in subsequent financial years are significantly higher. Based on the cost build up, the Review Team considers the expected industry range

[43] Revised upon base information source: Operations and Maintenance Report, Investigation and benchmarking, Aurizon Network 2012

for these types of works would be in the $280,000 - $340,000 range, which indicates that Aurizon Network's forecast unit rates are particularly high. One explanation for this is that the median has crept to the higher rates due to deterioration of conditions or a higher contamination than previously anticipated.

It has been discussed previously how high rates of deterioration and inefficiencies in planning can cause significant increases in unit rate costs. This sensitivity of the unit rate becomes concerning when considered against Aurizon Network's historic evidence of annual deficits in actual against programmed ballast cleaning programs[44]. Each time there is a shortfall in the program, the percentage of ballast in the field with over the maximum 30% PVC voids will increase, hence increasing the amount of ballast that needs to be undercut. This also increases the level of contamination and subsequently decreasing the return originally expected on the ballast. This in turn will result in a higher unit cost rate and it is suspected that this may be the reason for the increased unit rate costs proposed.

The Review Team recommends the unit rate per kilometre be accepted as what is reasonably considered as an average expected cost resulting from a program of undercutting undertaken for a contamination rate of 30% PVC with a reasonable percentage of high cost sites. From the information provided from Aurizon Network this is deduced to be in line with average unit rates obtained in FY12 and FY14 rather than FY13, which as stated by Aurizon Network was an exceptionally difficult year.

The Review Team also notes that Aurizon Network has under-delivered on the previously approved undercutting scope (see Figure 24). This potentially indicates that some of the UT4 works may be catch up works for the previous works. As previously discussed for turnouts, the Review Team questions why customers should pay twice for the underperformance on mainline ballast undercutting.

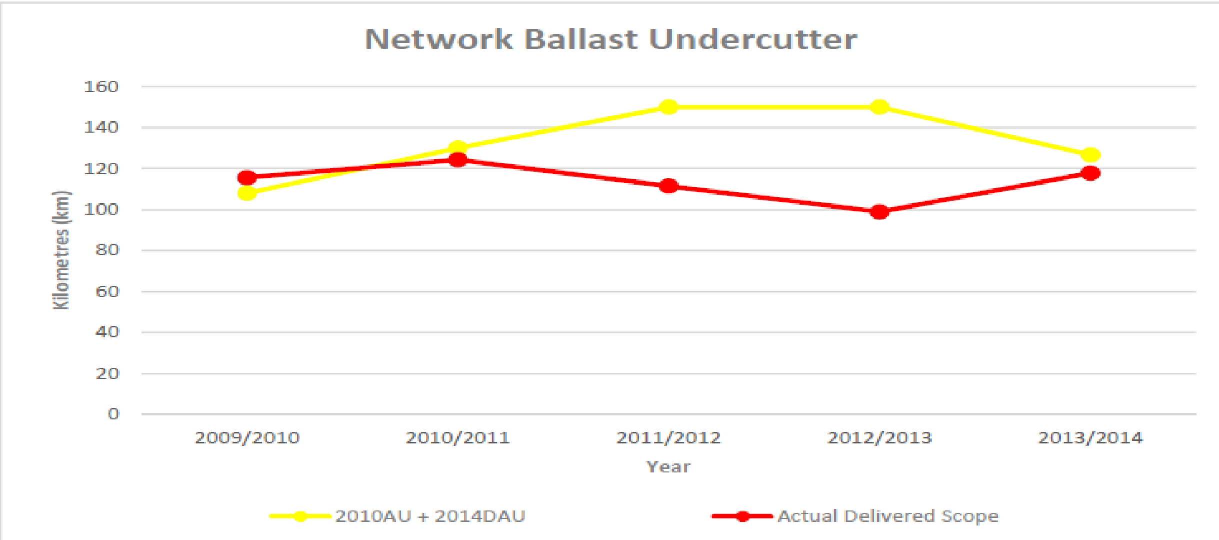

Figure 24 Aurizon Network ballast undercutter - Aurizon Network Annual Maintenance Cost Report Financial Year 2014

It is noted that ballast scope and overall scope costs are very sensitive to changes in the PVC threshold (Figure 25). A key issue for ballast scope planning works, and to potentially mitigate the liability risks associated with operational risks, is that it may be best, on a risk and benefit-cost basis, to focus first on those sections of track that have the highest PVC levels. Under Aurizon Network's current approach there is no further categorisation of those sections of track that are over the 30 per cent PVC threshold. However, it may more optimal to place a higher priority on the 256 kilometres of track with PVC values greater than 40 per cent compared to those in the 30 to 40 per cent range. Aurizon Network should consider applying this type of approach in conjunction with appropriate risk and high level benefit-cost considerations.

[44] Refer Aurizon Maintenance Cost Report Financial Year 2014 and Cost Report FY2012-13

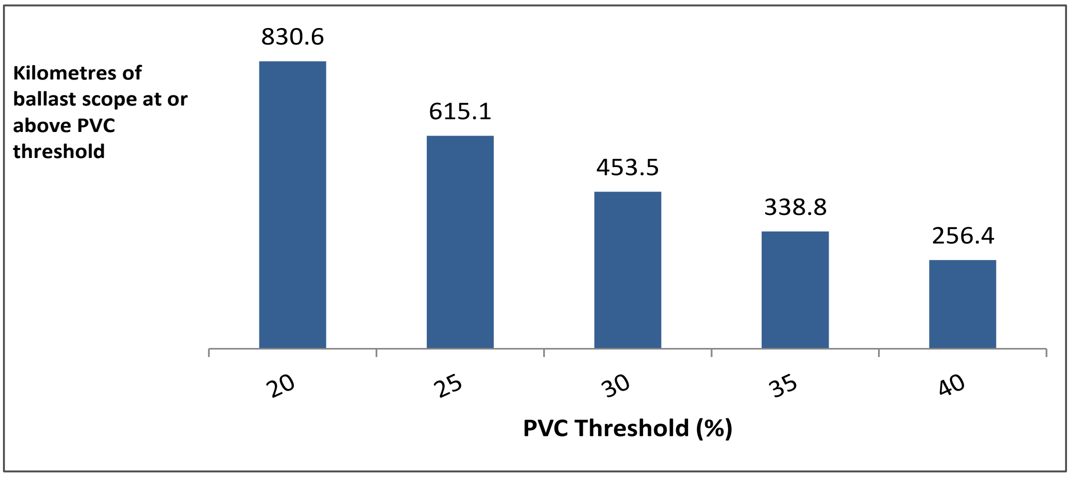

Figure 25 Ballast scope kilometres with different PVC threshold levels

> Based upon our independent cost estimate, the historical actual figures and the efficiency graph based upon the range of Aurizon Network actual figures, the Review Team consider a mainline cost per kilometre reduction is appropriate. A figure of $400,000 is therefore suggested as a reasonable compromise which includes the calculated figures from our analysis and allows a contingency for "climatic conditions and market factors that affect rail access".
>
> It should be noted that this is not a benchmark value, because a detailed benchmarking study has not been undertaken. Rather it is a cost estimate based on the analysis undertaken in this review project.

4. KEY FINDINGS

Ballast fouling significantly impacts the maintenance task. However, improvements from coal loss management expenditure should be impacting the rate of fouling in the UT4 period.

Ballast undercutting as a result of fouling, mainly from airborne coal particles, has been shown to be a significant maintenance task. It is consuming approximately 25 – 30% of Aurizon Network's maintenance budget. In recent years, Aurizon Network has spent considerable amounts on mitigation measures such as the coal veneering program. Early indications are that the amount of airborne emissions has been reduced[45] yet this observation has not been accounted for in the interpolation of GPR data moving forward to determine forecast PVC's and thus the ballast undercutting scope. Not considering the impact of mitigation programs may result in overestimating the increase in PVC over certain sections, which may result in these sections being prioritised over other sections with greater contamination.

Increased forecast unit rates potentially align with historic under delivery of scope

Increased unit forecast rates for ballast undercutting may be a result of historic significant under delivery of scope (see Figure 24[46]). Backlog increases the ballast fouling rate and therefore increases costs of ballast undercutting these sections due to higher contamination.

Not only does an under delivery of scope increase the costs of ballast undercutting due to increasing contamination, PVC's in the order of 35 to 45% potentially increase Aurizon Network's contingent liability and operational risks. As a key issue for ballast scope planning works, and to potentially mitigate the operational risks associated, is that it may be best, on a risk and benefit-cost basis, to focus first on those sections of track that have the highest PVC levels. Under Aurizon Network's current approach there is no further categorisation of those sections of track that are over the 30 per cent PVC threshold. The Review Team recommend that Aurizon Network should consider applying this type of approach in conjunction with appropriate risk and high level benefit-cost considerations.

In addition, the Review Team questions why Aurizon Network's customers should pay twice for the underperformance of prior years' ballast undercutting programs. It would appear more efficient for the QCA to approve a conservative ballast scope with Aurizon Network then being required to seek approval if the undercutting team is justifiably (both in terms of capability and necessity) able to exceed the approved scope and can demonstrate that customers have not previously paid for these works.

Reliance on GPR standalone data raised concerns about the integrity of the methodology

The simplified averaging of two points obtained from 2012 and 2014 GPR data may theoretically be sufficient to provide a projected estimate of a ballast fouling rate per year. However, wear and deterioration rates are also a function of tonnage and environmental factors. Not including these factors in the calculation of projected ballast fouling may result in overestimating or underestimating the actual scope. The Review Team considers that these should be taken into account when projecting fouling rates in future forecasting.

Inconsistencies in GPR readings between 2012 and 2014

Although it is considered that the use of GPR is more efficient than using traditional methods, it is also recognised that the technology deployment in Queensland is still relatively new and as such inconsistencies should not be ignored. The Review Team believe that some of the inconsistencies identified between 2012 and 2014 data readings may indicate either calibration issues which need to be addressed and refined or specific environmental or other factors which may be influencing the collection or interpretation of the GPR data. The Review Team acknowledge and accept that some of these differences will be due to other maintenance and renewal tasks being undertaken, however this should be recorded accordingly so that a greater overall understanding can be obtained in relation to the variables and intricacies of GPR ballast condition determination. This is important when considering that the data is being relied upon specifically to confirm the future scope to 2017.

[45] Aurizon Network Technical Expert Report, Review Team 2013

[46] Annual Maintenance Report Financial Years 2012-13 and 2014

The unit cost per km for mainline undercutting increases significantly (in both nominal and real terms) across the project period.

There are two main contributors to this cost increase:

- Escalating internal charges. Aurizon Network commented this had happened because contract and hire staff are expected to cost more than the full-time staff that have been let go. The Review Team understands contract staff are supposed to offer more flexibility than full-time staff. However, if the contract workforce materially increases costs without a corresponding increase in benefits to Aurizon Network, then this change does not appear to be prudent.
- On-track vehicle maintenance costs increase because additional equipment is required to complete the increasing number of kilometres that need to be undercut. This change appears to be prudent.

Aurizon Network's ballast-related expenses increase significantly across the UT4 period.

There are two key issues arise from this:

- On-site sourcing of ballast is increasing the cost of ballast by around $1 million in FY 16 and FY 17. This is not considered prudent, because ballast can be accessed considerably more cheaply through other means. Accordingly, the Review Team considers Aurizon Network should improve its planning to access ballast in a least cost manner.
- A significant volume of new ballast is required for the sites that are being cleaned by the RM900, despite the fact this equipment is able to screen and clean ballast. The Review Team understands that the age of the RM900 is a key contributor to this issue. Given the age of the RM900, the Review Team recommends Aurizon Network undertake a total cost of ownership analysis of continuing to use the RM900 relative to procuring a replacement equivalent machine (or multiple smaller machines). Changing to newer machines could facilitate cleaning of more ballast with elevated PVC levels, and reduce fleet maintenance costs and expected ballast costs.

Underlying Scope / Cost Recommendation (Aurizon Network's unit costs)

The Review Team identified the following underlying required changes and recommendations to Aurizon Network scope and unit costs:

- Cost increases from on-site sourcing in FY16 ($992,574) and FY 17 ($1,166,529) should be removed.
- Cost for GPR capture in FY 15 should be removed as these works are not being undertaken.
- The number of Turnouts should be reduced from 169 to 121 due to previous period shortfall.

The impact of these changes on the scope and unit costs is presented in the following table.

Table 13 Impact of proposed changes on scope and unit costs

(Nominal $)	FY14 Actual	FY15	FY16	FY17	Total
C01 + C14 - Mechanised Ballast Undercutting	43,153,814	54,277,115	62,967,919	66,200,150	**226,598,998**
GPR Costs	1,200,000	0	1,200,000	1,200,000	**3,600,000**
C03 + C13 -Turnouts	5,589,777	5,082,093	5,191,594	5,624,942	**21,488,406**
C02 - Other Ballast Undercutting	4,616,411	4,723,179	4,900,792	5,178,787	**19,419,169**
Underbridges	0	0	0	0	0
Total Ballast Undercutting Costs	**54,560,002**	**64,082,388**	**74,260,305**	**78,203,879**	**271,106,573**

Source: Review Team analysis

Underlying Scope / Cost Recommendation (Mainline unit cost constrained to $400,000 per kilometre in $FY15 and escalated by MCI thereafter)

Furthermore, the results of the comparative review of historic trends and independent cost build up indicates that the underlying scope/cost recommendation for the mainline unit cost could be constrained to $400,000 per kilometre in $FY15 and escalated by MCI thereafter (see Table 14).

Table 14 Impact of unit cost reduction

(Nominal $)	FY14 Actual	FY15	FY16	FY17	Total
C01 + C14 - Mechanised Ballast Undercutting	43,153,811	51,684,880	54,530,000	58,909,502	**208,278,193**
GPR Costs	1,200,000	0	1,200,000	1,200,000	**3,600,000**
C03 + C13 -Turnouts	5,589,777	5,082,094	5,191,594	5,624,942	**21,488,407**
C02 - Other Ballast Undercutting	4,616,411	4,723,179	4,900,792	5,178,787	**19,419,169**
Underbridges	0	0	0	0	0
Total Ballast Undercutting Costs	**54,560,000**	**61,490,152**	**65,822,386**	**70,913,231**	**252,785,769**

Source: Review Team analysis

Note: To avoid double counting the proposed cost reduction for on-site sourcing (see Table13) has been removed from the C01 cost estimate.

Appendix 1 Breakdown of Aurizon Network methodology for calculation of proposed undercutting scope

Using the GPR data, Aurizon Network undertakes a strategic exercise to develop an 'indicative plan' which identifies sections of track for ballast undercutting works, in three key steps (summarised below). This is undertaken in a spreadsheet called *AllSystemsGPRDataandUndercuttingHistory(2015-05-20) – Final.xls*. The Review Team has identified three key steps in this process.

FIRST STEP: Estimate PVC values for 2014

Aurizon Network estimates PVC values for 2014 by:

- defining 100 metre segments of track (which start at 0.0 to 0.09 kilometres and then increase in 100 metres thereafter – 0.1 to 0.19 kilometres, 0.2 to 0.29 kilometres etc.); and
- calculating one PVC value for each 100 metre segment based on an average of two values. The first value is a simple average of 20 data points (1 data point for each 5 metres) for the centre ballast over the 100 metres. The second value is the maximum of two values: the average of the 20 data points for the left ballast and the average of the 20 data points for the right ballast.

The averaging of 20 data points excludes those data points for which PVC could not be calculated (e.g. there was an interfering, metallic above-surface structure on that part of the track).

SECOND STEP: Estimate a forecast PVC value for 2017

Aurizon Network estimates forecast PVC values for 2017 with reference to 2012 and 2014 PVC values to calculate the average annual rate of fouling for each segment. The 2014 values are used from the first step discussed above. The 2012 100 metre length segment values were provided in Aurizon Network's spreadsheet and Aurizon Network has informed us that the same methodology was used to generate the 2012 data as was used for the 2014 data. Despite this the Review Team did note that there were differences in nomenclature for some locations, and these have now been regularised between the two data sets.

Where data exists for both 2012 and 2014, the forecast PVC value for 2017 is set equal to the 2014 PVC value plus an additional value. This additional value is the estimated annual average increase in PVC value from around 1 June 2012 (the timing of the 2012 GPR run) to around 1 July 2014 (the timing of the 2014 GPR run) multiplied by the number of years difference between the forecast data (1 July 2017) and the 2014 GPR data (1 July 2014). However, importantly, the Review Team notes that only positive values (where PVC has increased between 2012 and 2014) are used to estimate the forecast PVC value for 2017 and reductions are excluded.

Where there is no data for either 2012 or 2014, alternative forecasting methods appear to be used to estimate the forecast PVC for 2017. For example:

- if 2012 data is missing, the forecast value is based on the additional value being equal to the value of PVC in 2014 divided by the number of years since the last time the ballast was cleaned (which may or may not be after 1 June 2012); alternatively,
- if 2012 data is missing and where no records of previous undercutting exist it is set to be equal to the 2014 PVC value estimated in the first step discussed above. This means that there is a flat PVC growth assumption for this data.

Where undercutting has been undertaken between the 2012 and 2014 GPR data collection runs, or where only 2014 GPR data is available the rate of fouling is calculated using the fouling accumulated since the date when that track was last undercut, and the PVC value for 2017 extrapolated by using this rate added to the 2104 data.

THIRD STEP: Allocate a scope category to each 100 metre segment

Each 100 metre segment is assigned a scope category based on whether it fits into one of the categories in Table "Scope Categories" below. A 100 metre segment is not assigned a scope category if it does not fit into any of the four scope categories.

Scope categories

Scope Category	Method	Total KM	Goonyella	Blackwater	Newlands	Moura
1.00	>30% PVC in 2014 GPR	320.3	147.1	137.0	24.1	12.1
2.00	<30% PVC in 2014 Forecast to be >30% by Jul 2017 Trended from 2012 GPR data to 2014 GPR data Have 2014 GPR 2012 GPR No undercutting between GPR runs	134.8	76.2	51.1	2.3	5.2
3.00	<30% PVC in 2014 Forecast to be >30% by Jul 2017 Trended from last undercut to 2014 GPR run Have 2014 GPR 2012 GPR Undercutting between GPR runs	12.7	7.7	4.9	0.1	-
4.00	<30% PVC in 2014 Forecast to be >30% by Jul 2017 Trended from last undercut to 2014 GPR run Have 2014 GPR No 2012 GPR Undercutting prior to 2014 GPR run	33.1	23.0	9.8	-	0.3
	Total	500.9	254.0	202.8	26.5	17.6

Task 3: Development of ‘Final Requirements’ plan for ballast works

Once the indicative plan has been developed it is discussed, refined and prioritised with the District-based engineers, Asset Maintenance Track Inspectors and Network Planning Teams. From this a ‘penultimate plan’ is developed and issued for final comments. Once final comments are received, the plan is updated to produce a ‘final requirements plan’.

Please note that a copy of the final requirements plan has not been provided by Aurizon Network so it could not be reviewed.

Task 4: Development of ‘Detailed Schedule’ for ballast works

The ‘final requirements plan’ is provided to the Mechanised Production team within Aurizon Network. This team reviews the ‘final requirements plan’ and undertakes detailed planning activities in which they review the requirements and align to both signalling and overhead line equipment sections to ensure that disruption to revenue traffic is minimised. The “final output” is a detailed schedule which provides site-specific data broken down on a day-to-day delivery basis.

The ballast cost model is then developed on the back of the “Detailed Schedule”. The ballast cost model provided to the Review Team contains a detailed schedule from 2014/15 to 2016/17.

Appendix 2 Assumptions for Review Team estimated cost build up

In order to provide a comparison of Aurizon Network forecast costs for ballast undercutting, the Review Team has carried out comparable first principles estimates based upon current capital costs and market prices.

The following process and assumptions form the basis of our estimate and were applied to the estimating build-up. These have been developed from our professional experience and previous benchmark exercises

The table below summarises the considerations.

Item	Aspect	Assumptions
1	Major equipment	Ownership costs, maintenance costs, service life and depreciation were all allowed for, assumptions made on professional judgement and experience
2	Plant and Vehicles	Current industry rates were obtained and used in the cost estimates.
3	Crews	Crew sizes were based on equipment manufacturer literature and cross checked against professional experience of estimators
4	Consumables	Consumables were included. Detailed costs and consumption rates based on benchmarked figures
5	Mobilisation and travel	Actual historical mobilisation and travel patterns were used in the cost build up. These were obtained from professional experience doing similar works
6	Production rates	Costs were calculated for a range of productivities. These were generally related to access constraints.
7	Possession and site access	Empirical historical access and possession regimes were used. .
8	Overheads and margin	20% offsite overheads and 10% margins has been allowed for.

Rail Maintenance Machinery

General Approach

The Review Team selection of Maintenance Machinery, for inclusion within the estimate, has been based upon equipment similar to current or future planned Aurizon Network equipment identified within various Aurizon Network's reports.

The capital costs and machinery details have been obtained from appropriate manufacturers in Australia and where capital costs have not been available, the cost assumptions are detailed in the body of the estimate.

Productivity including operating speed and crew sizes have been made from observations of similar machinery performing the selected three maintenance tasks.

The following table provides a summary of the capital costs, production rates and crew sizes which are discussed further in the following sections.

Ballast Undercutter (General)

Item	Unit	Ballast Cleaning Machine
Capital Cost	$	$68,420,000
Manufactures Operating Lifetime	years	17
Estimate Write Off	years	8.5
Engine Power	kW	1400
Travel Speed	km/h	80
Operating Speed	km/h	0.3
Crew Required	no	40
Daily Crew Cost	$/day	$40,790

Ownership and Repair Costs

Full ownership and repair costs for the Rail Maintenance Machinery and Equipment components identified in the estimate include:

- Capital Costs
    - Actual capital costs have been used
- The following assumptions are included in the Review Team estimate:
    - An average working period of 200 days (shifts) per year, at 10 hours per day
    - Operating life has been assumed as between 15 and 17 years with no allowance for major repairs or rebuilds during the life of the equipment.[47] The following tables provide the base data for equipment write off and utilisation per year.

Equipment Write Off

Item	Write-off Period	Working Days per Year
Ballast Cleaning Machine (BCM)	15-17 years	200

BCM Ownership, Repair and Maintenance costs have been estimated at a yearly percentage of the acquisition cost applied at a daily rate as per the following table.

Ownership Factors

[47] http://wiki.iricen.gov.in/doku/lib/exe/fetch.php?media=old_journals_published_by_iricen:pw_march_2005.pdf ; http://nfrlyconstruction.org/nfrcon/rail/weblink/29.05.06-REVISED%20CODAL%20LIFE%20OF%20ASSETS.htm ; http://www.indianrailways.gov.in/railwayboard/uploads/directorate/cis/downloads/rba_25-20060001.pdf

Item	Repair and Parts Replacement	Labour	Overhaul, Major Repairs, Parts Replacement, etc.	Depreciation	Replacement Cost Escalation	Interest on Investment	Insurance, Storage, etc.	Total Ownership Expense	Daily Costs
	%	%	%	%	%	%	%	%	%
Ballast Cleaning Machine	7.5	5.0	12.5	11.8	7.0	7.1	4.5	42.9	**0.21432**

Notes:

- Annual Repairs and Parts replacement includes allowances for any Ground Engaging Tools (Cutting teeth, tines etc.)
- Depreciation has been based upon 50% of usable life with no allowance for major refurbishment
- No residual or resale value has been allowed
- No specific costs identified for equipment stabling other than an annual allowance
- Escalation on machinery replacement is included
- Finance costs are included **BCM Machinery Operating Costs**

The operating costs of the BCM has been estimated along the following principles:

- Travel speed
  - Maximum travel speed of 80km/hr
  - An average travel speed of 60% of the maximum indicated travel speed adopted to account for acceleration, coasting and braking when locomotives are travelling between sites
- Operating speed
  - Where a range was provided (e.g. progress of 0.1 – 0.3 km/hr) the average production rate has been adopted in the estimate and further factored for operating inefficiencies and waiting time on the tracks
  - Where a maximum operating speed has been indicated, an assumption has been made depending on the type of machinery and the type of work being performed to allocate a reduced average operating speed
- Engine power output
  - Engine power output has been identified for each type of machine and power utilisation allocated for the following scenarios:
  - Travelling between sites under power of locomotive only
  - Machinery operating performing operating activities
- Engine power has been used for the calculation of diesel consumption as follows;
  - Fuel consumption (L/hr) = Engine output (kW) x 0.1818 L/hr (fuel burn) x % engine utilisation
  - The utilisation factor has been estimated based on assumptions of operating loads and specific performance expectations for each vehicle's activities.

Maintenance Crew

Requirements for Maintenance Activity / Machinery

The crew manning levels required for operation of maintenance machinery and other maintenance activities have been estimated primarily from observation of similar equipment in operational conditions from web based research.

The Review Team estimate build-ups provide detail of crew manning levels for each type of equipment including Operators, Labour, TPO's and supervising staff.

Crew Costs

The rates for crew costs are included in the estimate as follows:

Crew Costs

Item	Unit	Labour/ TPOs	Skilled Labourer	Train Operator	Site Manager	Engineer
Accommodation	$/day	$150	$150	$150	$150	$150
FIFO allowance	$/week	$200	$200	$200	$200	$200
Hourly rate	$/hour	$90	$95	$110	$140	$160

Accommodation is based on current daily rates for third party provided camp accommodation

FIFO allowance has been based on an average cost of $400 per roster (roster 10 + 4) and allows for a mix of local travel and a mix of FIFO

Labour hourly rates reflect current market labour costs inclusive of all on-costs, insurance, superannuation, and overtime penalties, etc.

Consumables

Ballast

The quantity of ballast has been calculated using a ballast density[48] of 1.9 t/m^3 based upon a single track volume of 2.2 m^3/m plus a 10% wastage or loss allowance. The supply of ballast has been based upon a rate of $37.00 t delivered into stockpile by road haulage.

Diesel

The cost of diesel has been based upon a current market rate of $1.26 /L (less 10% GST) and has been included for maintenance machinery and general vehicles, allowing for the fuel rebate in accordance with current ATO allowances as follows;

- Hi-rail maintenance vehicles running on the rail track has been calculated at - $0.38 /L
- Maintenance equipment along the side of the rail tracks has been calculated at - $0.19 /L.

Fuel burn for track maintenance equipment has been calculated based upon the maximum engine power output (kW) and factored for power utilisation. Fuel costs for utes, light trucks etc. has been included in the daily rate.

Lubricants and other consumables

An allowance of 10% of the cost of diesel has been included for all maintenance machinery or costs of lubricants, grease and similar consumables.

[48] http://www.artc.com.au/library/Booz%20Allen%20final%20report%20May%202001.pdf

Water

This has been developed from the assumption of 4 washers operating at 150 L/hr to clean fouled ballast during operation.

The purchase cost of water has been allowed at $3.50 /kl ex. storage tanks adjacent to the rail corridor.

Crew Vehicles

Track Maintenance Crew vehicles (utes and light trucks) are included in the estimate on the basis of an average of four crew members per vehicle. The estimate has been based upon external hire vehicles on the assumption that the cost of a hire would be comparable to the ownership expense for the vehicles:

- Utes based on long-term 4WD hire rate of $107 /day + GST[49]
- Fuel included based upon the following:
    - Consumption rate at 15 l /100 km
    - An average travel distance of 30,000 km/yr.

Ballast spoil removal

A disposal rate of $20 /t has been allowed in the estimate for loading of ballast spoil and removal off site to a suitable tip (within 50 km).

Front End Loader (FEL)

The FEL has been used in calculations for the loading of hoppers with clean ballast at ballast sidings in the Ballast Undercutting cycle.

- In consideration of the large ballast capacities required for maintenance activities, the FEL's selected were those with a 4 t bucket capacity
    - A single ballast loading cycle (one bucket from siding to hopper) has been estimated at 25 seconds, resulting in an approximate cycle time to load each 104 t hopper of 13 minutes
    - To reduce the loading time of ballast hoppers attached to the ballast cleaning machine, and thereby maximise the ballast undercutting operating time, it has been assumed 3 FELs may be used at ballast sidings
- A wet hire rate of $1,800 /day has been used based on current market rates (inclusive of operator and fuel).

Offsite overheads and margin

The following mark-up factors have been allowed in the estimate:

- Offsite overheads - 20% of direct costs (allows for non-attendant staff, management, office requirements, etc.)
- Margin - 10% of direct costs.

Production Assumptions

Network Travelling Distances

Assumptions had to be made to calculate the effective distances travelled by the maintenance machinery between:

- Ballast sidings / holding yards and worksites
- Worksites and spoil disposal sites.

The following average distances have been assumed based on number of mines along networks, proximities to major towns, etc.

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[49] http://www.vistahire.com.au

Travel Distances

Average Travel Distance	Moura	Blackwater	Newlands	Goonyella
Ballast siding / holding yard to Worksite	11.4 km	17.6 km	15.8 km	7.7 km
Worksite to Spoil unloading site	22.8 km	35.2 km	31.7 km	15.4 km

- The number of ballast sidings / holdings yards along each network have been assumed to be similar to the number of mines along the network
  - The average distance between worksites and ballast sidings / holding yards has been taken as half the distance between ballast sidings
- The number of spoil unloading sites have been assumed to be half as frequent as the ballast sidings along each network
  - The average distance between worksites and spoil unloading sites has been taken as half the distance between ballast sidings
- An approximate average progress is used to account for differences in distance that the maintenance machinery must travel to and from the worksite throughout the maintenance operation.