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AN EVALUATION OF A WARATAH HTH MODEL 234 FELLING AND TREE-LENGTH DELIMBING IN RADIATA PINE CLEARFELL

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ABSTRACT

A Waratah Hydraulic Tree Harvester (HTH) Model 234 (Waratah 234) was evaluated harvesting (felling, tree-length delimbing and "bunching") and tree-length delimbing and "bunching" of manually felled trees in a radiata pine clearfell operation in Tarawera Forest.

Estimated productivity for the Waratah 234 working with an average extracted tree size of 1.95m³ (45cm DBH):

- *Felling, tree-length delimbing and "bunching" was 51 trees - 100m³ per PMH*
- *Tree-length delimbing (butt-first) and "bunching" was 73 trees - 143m³ per PMH*
- *Tree-length delimbing (tip-first) and "bunching" was 70 trees - 137m³ per PMH.*

These productivity estimates assume a malformation level of 11.5% of total stems. Regression equations for fell and delimb time, delimb (butt-first) and delimb (tip-first) are given, together with all productive cycle element times.

Actual stump heights were observed to be higher and more variable than those associated with motor-manual felling in the same block. However, the effective stump height which includes unacceptable felling-related butt damage (usually removed as a sloven in manual operations) was lower.

Felling with the Waratah 234 significantly increased the probability of a tree not breaking. The average butt log length was increased by 4m, and the break diameter was reduced by 3cm when compared with manual felling.

The Waratah 234 enhanced the efficiency of following skidder extraction and manual processing at the skidsite through the "bunching" of tree-lengths and an improved standard of delimbing.

INTRODUCTION

Three Waratah 234s are currently operating in New Zealand forests. One is working as a processor in a ground-based operation (Evanson and Riddle, 1994); the others are in cable-based operations (Evanson, Riddle and Fraser, 1994). One of these was processing and the other was tree-length delimbing. One of the two machines has been used on an occasional basis for felling and tree-length delimbing, and has also been leased out to companies investigating the machine's potential for their operations.

Figure 1 - Waratah 234 harvesting in Tarawera Forest

Evaluations to date have highlighted the Waratah 234's delimbing capacity in a range of tree sizes, from 1.5m³ to 2.9m³.

Recent short trials have provided the opportunity to assess the Waratah 234 as both a "harvester" and a tree-length delimber/buncher for ground-based operations. This report details results from one such trial and comments on results from two previous evaluations. The report focuses on potential productivity and factors associated with and affecting productivity, including; tree size, malformation, stump height and breakage.

ACKNOWLEDGEMENTS

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THE WARATAH HYDRAULIC TREE HARVESTER MODEL 234

The Waratah 234, manufactured by Waratah Engineering Limited in Tokoroa, is a single-grip harvester head, designed specifically for radiata pine and is capable of felling and delimbing trees up to 70cm diameter. It weighs approximately 3.5 tonnes and requires a minimum 30 tonne excavator base carrier. The machine reported on in this study was mounted on a Hitachi EX300 excavator and is owned and operated by a Rotorua-based contractor, Keith Travers. The hydraulic chainsaw uses 0.404 pitch chain with a one metre bar. Trees are driven through the delimbing knives by three hydraulically powered spiked drive rollers. Feed speed is approximately 3.2 m/sec, and the theoretical feed power is 3 to 4 tonnes.

STUDY DETAILS

Location	Tarawera Forest Cpt.533
Species	Radiata Pine
Age (yrs)	27
Stocking (live, sph)	376
Malformation (%)	11.5
Av. Diameter (cm)	45
Av. Height (m)	39
Recoverable Vol./ha (m^3)	732
Av. Piece size (m^3)	1.95
Terrain	Flat
Soils	Free draining Volcanic ash-based scoria
Undergrowth	Light, mainly ferns and old windfalls
Weather	Fine

OPTIONS EVALUATED

(a) "Harvesting" - felling, tree-length delimbing and "bunching"

The area to be felled comprised an "island" about 100m square, surrounded by open cutover.

Work Method - The operator worked a swathe along the stand edge, felling trees predominantly into the stand forward of the machine (Figure 1). The operator preferred this technique as it crushed undergrowth and he believed it reduced overall tree breakage. Each tree was successively felled, delimbed on the right of the machine (for better visibility), and ejected. Tree-lengths were "bunched" in the form of a low continuous stack, which built up as the operation progressed. Sliding the logs along others enhanced delimbing.

(b) Tree-length delimbing butt first and "bunching" manually felled trees

The area planned to test this option comprised a road-edge strip approximately 400m long by 25m wide. Trees were manually felled with most slovens cut, prior to the study. Some large, heavy limbed trees occurred adjacent to the road.

Figure 2 - Waratah 234 tree length delimbing in Tarawera Forest

Work Method - The operator approached from the butt-end, reaching and delimbing as many trees as possible from one location (Figure 2). Trees were delimbed and ejected on to low continuous stacks as above. Slovens, if they occurred, were cut prior to delimbing.

(c) Tree-length delimbing tip first and "bunching" manually felled trees

Observed in the above block, but from the opposite end.

Work Method - Effectively identical to option B except that the trees were handled and delimbed in the reverse direction. Prior to delimbing the head was cut to give a clean SED below the break which helped ensure the tip did not dig in or break during delimbing.

Note: The operator has extensive experience with both excavator operation and the use of the smaller Waratah 230 harvester. He had been operating the Waratah 234 as a tree-length delimber for some six months prior to the trial, and had used it as a harvester intermittently.

STUDY METHOD

Prior to felling, all trees involved in the study were measured for DBH and colour coded at breast height (1.4m) into seven diameter classes covering the range of diameters present.

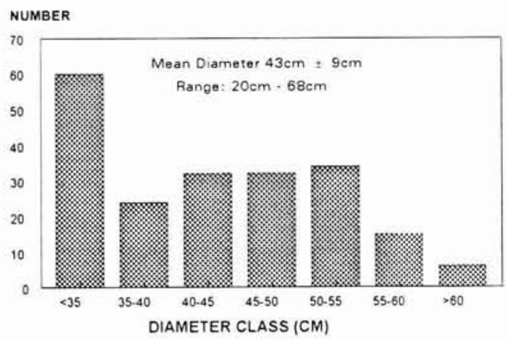
The Waratah 234 and operator were only available for two days, of which approximately 65% was spent operating in a "delimbing only mode" and 35% in a "harvesting mode". Continuous time study using a "Husky Hunter" was carried out on the Waratah 234 for defined elements of the work cycle in all three modes of operation. Diameter class and tree form (rated as "normal" or "malformed"), were recorded against the time to handle individual trees. Tree volumes were later estimated using MARVL data. All delays were measured.

Actual stump height, effective stump height (including felling-related butt damage/slovens), butt log length and first break diameter were measured on a sample of trees for both manual and mechanised felling, for later comparison.

RESULTS AND DISCUSSION

"Harvesting" Option

Figure 3 - Harvested trees



The Waratah 234 was timed to fell, tree-length delimb and "bunch" a total of 203 trees. A diameter distribution of the harvested trees is shown in Figure 3. Only four large trees (2%), were felled using the "double cut" method, to reduce possible felling related butt damage.

The operator preferred to fell trees into the stand where possible, as it crushed the undergrowth and slowed the speed at which the tree hit the ground. This technique resulted in 4% of standing trees being pushed down (uprooted in the loose soils), breakage in 3% of standing trees (generally smaller diameter stems), and was the principal cause of breakage of 2% of trees being felled during the study. Observation suggests that this technique was not a cause of increased stem breakage and may well have reduced breakage overall.

It is possible that broken pieces within the stand may contribute to higher stumps, where they lie against the butts of trees subsequently felled, and time is not taken to move them aside prior to felling. Also, the operator noted that trees were harder to drive through the delimber when effectively unbroken, especially larger trees.

A breakdown of the productive cycle time for all 203 trees is shown in Table 1.

An average of two trees were felled per "move" (Range 1 to 5). Some limited movement was associated with getting the tree down through the stand during felling, or to aid delimbing or "bunching".

Delimbing times from harvesting and delimbing-only operation cannot be combined, as the fell/delimb elements during harvesting merge at their interface, and delimbing is required along a longer butt log length (+4m), due to reduced felling breakage.

There was no need to cut slovens after felling.

"Other work", includes reconnaissance, felling non-merchantable stems, stacking/ restacking for improved skidder extraction, and delimbing merchantable top pieces.

Table 1 - Productive cycle time - harvesting

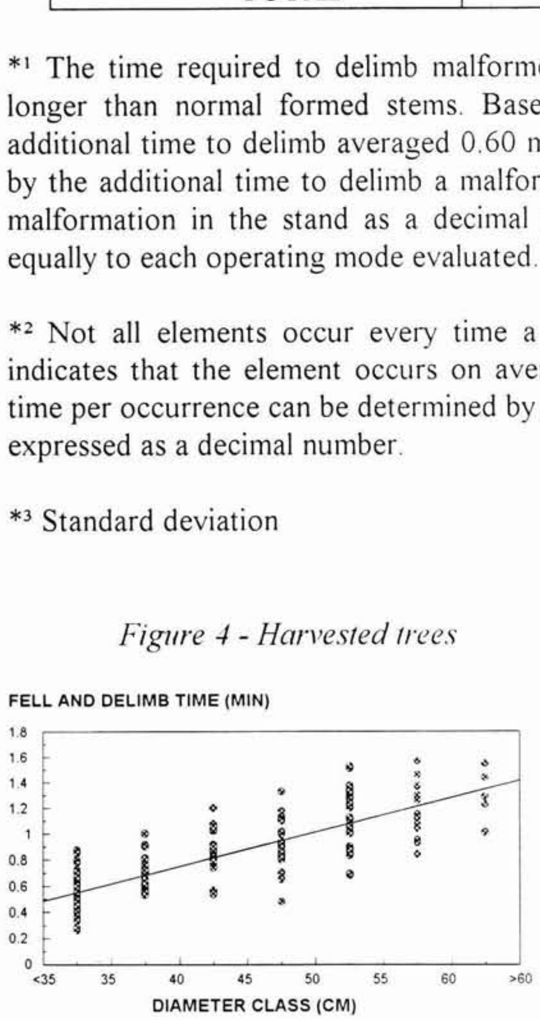
Element / Operation	Frequency *2	Av. Time / Cycle (min)	%
Move	49%	0.12	10
Clear	8%	0.02	2
Fell + Delimb (43cm)	100%	0.84 ± 0.30 *3	74
Malformation Allowance *1	11.5%	0.07	6
Other Work	29%	0.09	8
TOTAL		1.14	100

*1 The time required to delimb malformed trees varies considerably and takes significantly longer than normal formed stems. Based on a total sample of 56 malformed trees, the additional time to delimb averaged 0.60 minute. The "malformation allowance" is determined by the additional time to delimb a malformed stem (0.60 min), multiplied by the percentage malformation in the stand as a decimal number (0.115). This allowance has been applied equally to each operating mode evaluated.

*2 Not all elements occur every time a tree is felled and delimbed: a frequency of 50% indicates that the element occurs on average, once every two cycles. The average element time per occurrence can be determined by dividing the average time per cycle by the frequency expressed as a decimal number.

*3 Standard deviation

Figure 4 - Harvested trees



Fell + delimb time (min) = 0.0266 x DBH (cm) - 0.3105 r2 = 0.65

Picking up and processing "top pieces" required 34% of "other" time shown in Table 1. In number, they equalled 6.4% of butt logs (13 pieces), and took an average 0.46 minute ±0.24, to flush cut one end and delimb.

Fewer top pieces were delimbed while harvesting, than when tree-length delimbing following manual felling. This supports the fact that mechanised felling as observed during this study reduced stem breakage.

Five trees (2.5%), were observed to break during delimbing. They were of average size, one clearly the result of malformation.

This evaluation shows an improvement of approximately 10% over a previous evaluation by Forestry Corporation of New Zealand Limited (FCNZ), and is mainly due to improved operator performance with increased experience between the two evaluations.

Felling-related butt damage and stem breakage

A sample of 50 trees felled by the Waratah 234 and 50 trees manually felled were measured to compare differences in felling-related butt damage and stem breakage. The results are summarised in Table 2.

Table 2 - Felling-related butt damage and stem breakage

Feature	Manual Felling	Waratah 234 Felling
DBH (cm)	47 ± 12 *[1]	44 ± 12
Actual Stump Height (cm)	18 ± 4	23 ± 12
Sloven	9 ± 7	0
Effective Stump Height (cm)	26 ± 12	23 ± 12
Butt Log Length (m)	25.7 ± 4.0	29.9 ± 4.5
SED (cm)	22 ± 7	19 ± 5
Relative Break Diameter	0.45	0.40
Probability of not Breaking	12%	24+%

*[1] Standard deviation

Note: Trees were regarded as unbroken if the first break occured at a stem diameter of less than 10cm SED.

Actual stump height for the mechanised felling is higher, and remains as a solid block, possibly an added hindrance to following operations on site. No significant relationship was found between tree size and stump height for the mechanised felling. Effective stump height, includes a sloven to remove felling-related butt damage (draw wood, scarf face, splitting or slabbing), becomes similar if not higher for manual felling. Minor slabbing occurred on 18% of the mechanically felled butts but seldom exceeded 25mm depth and was judged acceptable by the forest owner. This slabbing generally occured on larger butts, and may be contributed to by heavy lean, wind or blunt saw chain.

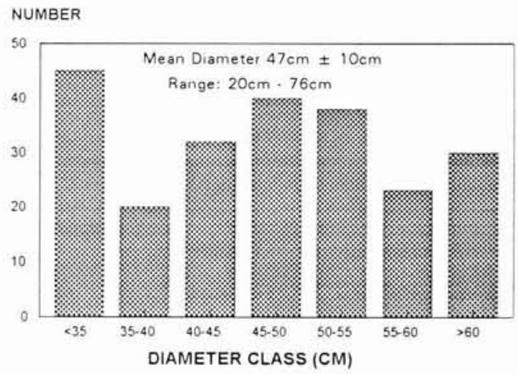
A previous evaluation of the Waratah 234 by FCNZ reported a similar stump height, and reduced stem breakage (butt log length increased by an average 2.2m and break diameter reduced by 5cm).

Note : In all situations the operator can have a considerable influence on the damage and breakage patterns occurring.

Delimbing Butt-First Option

The Waratah 234 was timed to delimb a total of 228 manually felled tree-lengths, beginning from the butt-end. A diameter distribution of the delimbed trees is shown in Figure 5.

Figure 5 - Trees delimbed butt-first



The manual fallers usually cut the sloven off the butt when they felled the tree. Manual fallers are in a better position to assess the felling-related butt damage, than a machine operator, and slovens can therefore be kept to a minimum size. The Waratah 234 was only observed cutting slovens on 20 occasions. The average observed time was 0.12 minute ± 0.03. Time for cutting slovens has been excluded from all productivity analysis in this report.

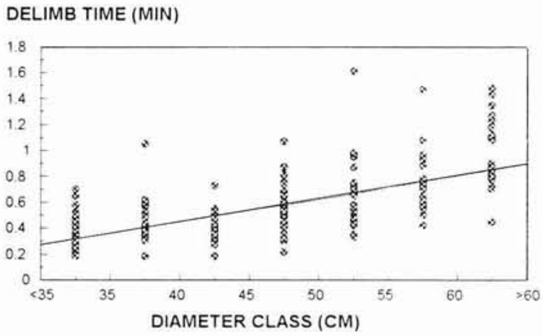
A breakdown of the productive cycle time for all 228 tree-lengths is shown in Table 3.

Table 3 - Productive cycle time - delimbing butt-first

Element / Operation	Frequency *2	Av. Time / Cycle (min)	%
Move	46%	0.11	13
Delimb (47cm)	100%	0.56 ± 0.27 *3	67
Malformation Allowance *1	11.5%	0.07	8
Other Work	28%	0.10	12
TOTAL		0.84	100

*1 *2 *3 Refer to Table 1

Figure 6 - Trees delimbed butt-first



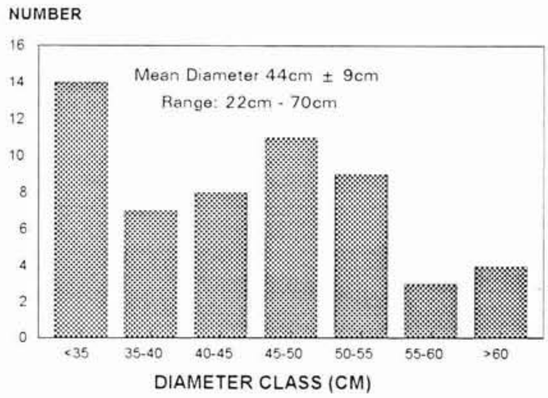
Delimb time (min) = 0.0178 x DBH (cm) - 0.2630 r2 = 0.41

On average 2.2 trees were delimbed per "move" (Range 1 to 6). The "delimbing" time includes picking up the tree, removing the branches and "bunching" on to distinct, continuous low stacks. "Other work" time was again dominated by time taken to handle broken top pieces. These equalled 13% of butt logs (29 pieces), and took 0.40 minute ± 0.24 to flush cut one end and delimb. This made up 55% of all "other work", an increase over that recorded for harvesting due to the increased breakage measured for manual felling.

Delimbing Tip-First Option

The Waratah 234 was timed to delimb a total of 56 manually felled tree-lengths, beginning from the small/top end. A diameter distribution of the delimbed trees is shown in Figure 7.

Figure 7 - Trees delimbed tip-first



A breakdown of the productive cycle time for all 56 tree-lengths is shown in Table 4.

On average 1.9 trees are delimbed per "move" (Range: 1 to 5). When delimbing from the tip-first, most small-ends are cross-cut flush prior to delimbing. As with butt-first delimbing the trees are left on distinct, continuous low stacks. Also, "other work" time was again dominated by time taken to handle broken top pieces. These equalled 21% of butt logs (12 pieces), and took 0.40 minute ± 0.24 to flush cut one end and delimb. This made up 66% of all "other work". Additional breakage occurred at the small-end when delimbing tip-first.

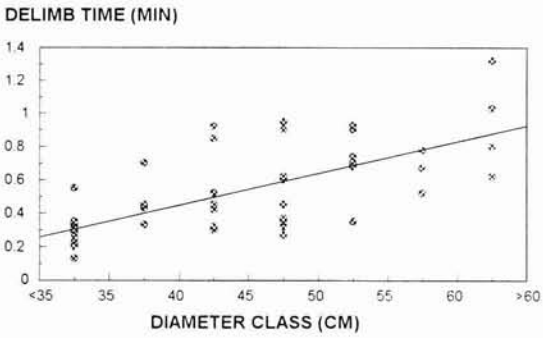
Occasionally trees were jammed under others to be delimbed. This slowed delimbing times, contributed to breakage and log surface damage. Improved felling layout could minimise this problem.

Table 4 - Productive cycle time - delimbing tip-first

Element / Operation	Frequency *2	Av. Time / Cycle (min)	%
Move	54%	0.11	13
Delimb *1 (44cm)	100%	0.53 ± 0.27 *3	63
Malformation Allowance *1	11.5%	0.07	8
Other Work	32%	0.13	16
TOTAL		0.84	100

*1 *2 *3 Refer to Table 1

Figure 8 - Trees delimbed tip-first



Delimb time (min) = 0.0191 x DBH (cm) - 0.3150 $r2 = 0.48$

During delimbing, from either end, tree-lengths occasionally became stuck, either buried in the limbed log pile or up against obstacles on the ground. This was not a significant problem because most trees slid cleanly across the ground or more usually along the continuous stack of delimbed trees. The Waratah 234 has the ability to turn and move logs around as it works.

These two delimbing only options indicate a performance about 11% above that reported in a previous FCNZ evaluation under similar conditions. A further study by Tony Evanson in June 1994 (unpublished) with a sample of 157 merchantable tree-lengths averaging $2.1m^3$, closely supports the results reported here.

DELIMBING QUALITY

A sample of 50 trees (25 delimbed butt-first and 25 delimbed tip-first), were assessed by Tasman Forestry Limited staff, to determine the proportion of branches trimmed flush, and the number of residual branch stubs, in a range of length classes. This assessment is summarised in Table 5.

There was no significant relationship between tree size and delimbing quality. There were minor incidences of knife-slicing damage along the stem, and infrequent occurrences where the spiked

Table 5 - Delimbing assessment - branch numbers

Delimbed Tip-First				Delimbed Butt-First			
Flush	<10cm	10-20cm	>20cm	Flush	<10cm	10-20cm	>20cm
683	110	24	17	651	149	14	10
82%	13%	3%	2%	79%	18%	2%	1%

rollers had dug into the stem, churning out a "spaghetti-like" mass of wood fibre. Also, some branches were pulled or torn from the stem, leaving characteristic impacts, which although eye-catching were not thought to be serious, nor were they measured in any greater detail during this study.

The spiked rollers loosen and remove a considerable amount of bark (not measured), and leave many shallow spike penetration holes in the wood of the stem. The real significance of the latter effect has yet to be determined. Overseas research (The Forest Authority, 1992) suggests that spike penetration into the wood increases the speed and severity of sap stain invasion.

IMPACT ON FOLLOWING ACTIVITIES

The "bunching" carried out by the Waratah 234 as it delimbs, improves the load accumulation time for the winch skidder extraction, particularly when extracting tree-lengths head first, as it is easier to get the strops around the stem. Also, tree-lengths delimbed by the Waratah 234 were noticeably easier to pull by the skidder than the usual manually delimbed stems.This is attributed to the higher standard of branch removal and the loosening and removal of significant amounts of bark.

The higher standard of branch removal on stems arriving at the landing, improves log marking and processing. A quick tidy-up of a few stubs by a skidworker may be required on the landing.

UTILISATION AND DELAYS

Due to the short duration of this evaluation, delays (operational, personal and mechanical), have not been included with the results. However, past experience to date suggests that the Waratah 234 is mechanically reliable and that high levels of utilisation are achievable.

It is important to appreciate that when operated as a"harvester", there will be a significant increase in mechanical delay associated with the felling head, primarily the saw bar and chain, plus an increase in repair and maintenance costs. This time and cost may be temporarily increased by an inexperienced operator. When delimbing only, problems associated with the saw bar and chain are minimal.

POTENTIAL PRODUCTIVITY/COST ESTIMATE

All productivity estimates are based on data collected during this study, and they assume a similar site and stocking to that observed. The productive machine hours (PMH) per day have been reduced by 15 minutes when operating as a "harvester", to allow for additional repair and maintenance associated with the felling head (saw bar and chain).

Daily costs of $1,290 and $1,230 have been determined for the Waratah 234 operating in a "harvesting" mode or "delimbing-only" mode respectively. These costs are derived from the LIRO costing procedure and assume a new price of $660,000, an 8,000 hour life and 1530 operating hours/year. These costs include profit at 10% and a machine operator at $150/day, but do not include a share of overheads or crew transport.

The contractor estimated that his fallers could fell and delimb 60 trees/day or delimb-only 90 trees/day, in similar stand conditions to the study. For an average tree size of 45cm DBH/1.96m^3, costs for manual felling and delimbing would be about $1.70/m^3 and for delimbing-only about $1.14/m^3. In an unconstrained situation, the Waratah 234 appears to be around 21% and 18% more expensive than manual methods, for "harvesting" or "delimbing-only" respectively. However, advantages including improved safety, reduced felling breakage (when harvesting), and possible

Table 6 - Potential productivity cost estimate

OPTION	AVERAGE EXTRACTED TREE SIZE		
	42cm / 1.66m³	45cm / 1.96m³	48cm / 2.26m³
Harvesting:			
Trees / PMH	55	51	48
m^3 / PMH	91	100	108
m^3 / Day (6.25PMH)	571	625	678
\$ / m^3	\$2.26	\$2.06	\$1.90
Delimbing Butt-first:			
Trees / PMH	78	73	69
m^3 / PMH	129	143	156
m^3 / Day (6.5PMH)	842	930	1014
\$ / m^3	\$1.46	\$1.32	\$1.21
Delimbing Tip-first:			
Trees / PMH	75	70	66
m^3 / PMH	124	137	149
m^3 / Day (6.5PMH)	809	892	970
\$ / m^3	\$1.52	\$1.38	\$1.27

Note: High levels of production at a relatively low cost are clearly possible. However, the ability to manage the potential unconstrained production is unlikely in many situations and any constraint imposed will have a significant increase in production cost.

improvements to extraction and skidwork performance should be considered. Any further perceived inequality between mechanised and manual options could be addressed by a limited increase in the Waratah 234's operating hours per day.

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The costs stated in this report have been derived using LIRO costing procedures. They are an indicative estimate only and do not necessarily represent the actual costs for this operation.

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