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Reducing Landing Earthworks Through Computer Aided Design

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Forest Engineering Honours Project 2023
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Executive Summary

The aim of this study was to establish whether an equivalent landing surface area could have been constructed, moving fewer cubic metres of earth for a series of case study landings in steep terrain. To achieve this, new landings were designed in RoadEng and compared to the originals using the average cut depth (m). This information could be useful for the forest industry as companies may want to know whether committing more resources to detailed landing design prior to construction can achieve an equivalent landing area using less earth material. Presently, forest companies utilizing RoadEng are primarily concerned with road design, with landing design being considered a niche application. The intended outcome of this study would be to create a shift within industry towards the uptake of CAD software packages for landing design by validating the approach.

The two key pieces of data used for this study were LiDAR derived Digital Elevation Models (DEM) of existing landings and corresponding aerial imagery, both sourced from Land Information New Zealand (LINZ). To calculate cut volume, a Digital Surface Model (DSM) of the original terrain was reconstructed using the DEM of the existing landing. This was achieved by extrapolating the contours that surrounded the landing across a hole created in the 3D model to interpolate the original terrain. With these two layers it was then possible to calculate the volume entrained between them using RoadEng's built in volume calculation tool. A new landing was then designed using the interpolated surface which was then compared to the original as built landing using the average cut depth.

The data was comprised of 15 landings across three different regions these being Hawkes Bay, Tasman, and Gisborne. It was found that the average cut depth for the original landings was 4.93 m with a standard deviation of 1.61 m. For the new RoadEng designs the average cut depth was 3.14 m with a standard deviation of 1.42 m. It was found that the average cut depth of the new RoadEng designs was 36% less than that of the original landings. This showed that it was in fact possible to design a landing with an equivalent surface area using less earth material. The main finding from the study was that adjusting the landing edge to better conform to the terrain played a key role in the reduction of earthworks. Adjusting the elevation of the lading was also a quick and easy way to balance earthworks.

Although these results were promising there were several underlying limitations to the methodology. These included its inability to reconstruct more complex topography, the influence that slash deposited onto the fill slope had on the earthwork's balances, and finally the lack of information around the construction method and design decisions such as location and 2D geometry of the landing that were not possible to infer from the DEM alone. This highlighted the need for a future study where DEMs of the terrain before and after construction are collected via UAV based remote sensing. This study would likely reinforce the findings in this report.

Acknowledgements

This research project would not have been possible without the help of university staff and industry professionals. Firstly, thank you to Professor Campbell Harvey for his guidance and mentorship throughout the course of this project.

Secondly, industry professional's Professor Rien Visser, Andrew Pedy, and David Robinson for their much needed and valuable insight.

Finally, thank you to all my friends, family, and fellow forestry undergraduates for their ongoing support throughout the course of my studies.

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1.0 Literature Review

1.1 Forest Landings

Although 'forest landing' is not a clearly defined term, it generally refers to a flat cleared area in a forest estate that is dedicated to the processing and storage of harvested trees before they are subsequently loaded onto a truck and transported to a nearby wharf or timber mill (Stokes et al., 1989). There are more than 100,000 landings in New Zealand's combined forest estate. Forest landings make up an integral part of modern commercial forestry operations and therefore should be designed to ensure efficient flow of products and processes. While building forest infrastructure is crucial to the economic success of an operation it also reduces the productive forest area by around 4% meaning careful planning and consideration needs to be carried out before constructing a new road or landing. Landings are typically rectangular in shape and twice as long as they are wide, whereas landings used in cable yarding operations are approximately 2.5 times longer. However, in stepper terrain where topography is a constraining factor, landings will come in many different shapes and sizes (FOA, 2020).

Landing construction costs can be significant. A study by Visser (2011) found that landing construction costs can range from $4,000 to over $7,000. Even higher estimates were given by an industry expert in Chen's 2021 study, saying that average landing construction costs in steeper terrain for the Gisborne region came in at around $14,000 with outlier cases as great as $100,000. Furthermore, if a landing is poorly located, designed, or managed, serious consequences can result with regards to safety, the environment, production, quality, and value recovery (FOA, 2020). Understandably companies are starting to invest more time and resources into the planning stages of landing construction to ensure they get it right the first time. This has seen the rise in popularity of Computer Aided Design (CAD) software combined with quality terrain information from Airborne Laser Scanning (ALS). These technologies have enabled forest companies to more accurately design forest infrastructure based on the constraints of the topography before construction commences.

1.2 Landing Types

A study by Visser et al. (2010) outlined the four broad categories that forest landings fall into.

- Pad: A 'pad' is a small landing that serves the purpose of transferring stems or whole trees from one extraction machine to another during a two-staging operation to a larger 'skid' for additional processing.
- Skid: A 'skid' is the most common type of forest landing which generally accommodates a single logging crew, their associated equipment, as well as facilitating the storage and loading out of log merchandise.
- Superskid: a 'superskid' is a designated processing area within a forest that services several smaller 'pads' to concentrate the log making process to a single area. This is generally done due to the constraints the topography places on 'skid' size construction.
- Central Processing Yard (CPY): CPY's are the largest landing type and generally exist outside of the forest estate. These are used to facilitate a greater level of quality control during the log making process.

The New Zealand Forest Road Engineering Manual likes to further define the types of landings by five main subcategories based on their respective layouts (FOA, 2020).

- Drive-through landings: Drive through landings consist of a loop road which enables log trucks to enter and exit along the same route without having to perform a tight turning circle. Logs can be stacked and loaded from either side of the road (Figure 1).

Figure 1. – An example of a drive through landing configuration taken from FOA (2020).

- Roadside landing: Roadside landings are very similar to drive through landings with the key difference being that the road is positioned to one side of the landing rather than running through the middle of it (Figure 2).

Figure 2. – An example of a roadside landing configuration taken from FOA (2020)

- Spur road end landing: spur road end landings are constructed at the very ends of roads and generally need to be designed to a larger size to provide enough room for trucks to turn around. Alternatively, if landing size is constrained trucks can use wider areas along a road to turn around then back onto the landing (Figure 3).

Figure 3. – An example of a spur road end landing configuration taken from FOA (2020).

- <u>Split-level landings:</u> Split-level landings are used in steeper terrain where space for machinery is constrained. A yarder is situated at the upper-level landing and hauls logs to a processing area on the lower-level landing (Figure 4).

Figure 4. – An example of a split-level landing configuration taken from FOA (2020).

- <u>Two-stage operation:</u> Two stage operations consist of two or more landings with the first being used to land and extract logs and the second being primarily dedicated to processing, storage, and eventual loading out onto a truck (Figure 5).

Figure 5. – An example of a two-stage landing configuration taken from FOA (2020).

1.3 Construction Principles

Several factors specific to landing design need to be taken into consideration before construction can commence (FOA, 2020). These factors include:

- Topographical constraints, like steepness, geology, and soils.
- Ensuring that the adverse grade of a road connected to a landing does not exceed 6% for the first 30m.
- Environmental constraints such as water control, slash management, and fuel storage.
- Types of machinery being used on the landing and space requirements for each.
- A designated area for processing which will differ depending on the landing type.
- General storage for log stacks and number of sorts.
- The length of the tree which needs to be two thirds of the way onto a landing during extraction to be considered safe.
- A designated loading area, truck access, and sufficient area for turning around.
- Productivity of machinery and whether any bottle necks will occur.
- Logging crew requirements such as vehicle parking, equipment storage, and a smoko hut.

According to FOA (2020) there are three different approaches to landing and road construction that are employed by contractors.

- Cut and side cast construction takes some, or all, of the excavated cut material and places it on the downhill slope to form the second half of the road prism. This technique is typically reserved for mellow rolling terrain where there is less of an erosion risk (Figure 6).

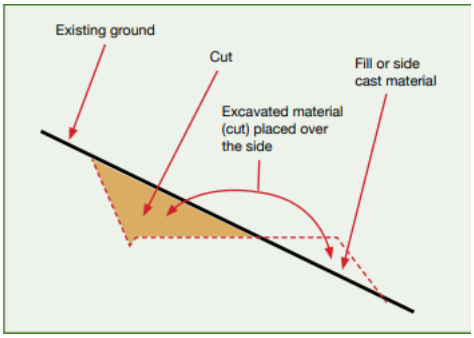


Figure 6. – Cut and side cast construction technique (FOA, 2020).

- Cut and benched fill is a construction method used on steeper hill country up to 35 degrees where the fill batter is not capable of supporting itself. At its simplest it involves the construction of secondary bench below the formation height of the road that provides extra stability to compacted fill material (Figure 7).

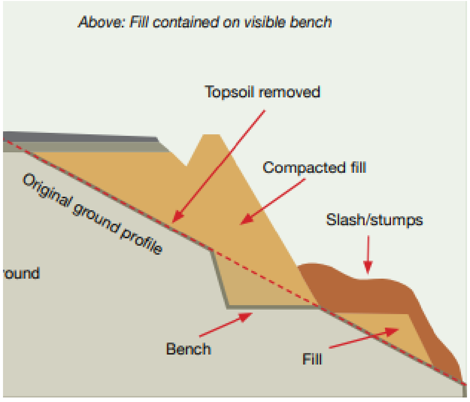


Figure 7. – Cut and benched fill construction technique (FOA, 2020).

- Full bench or end haul is a technique reserved for steeper terrain over 35 degrees. In end haul construction all the fill material is transported and stored at a more stable location meaning the road is constructed on solid in-situ material. Naturally this extra cartage of material carries high overheads (Figure 8).

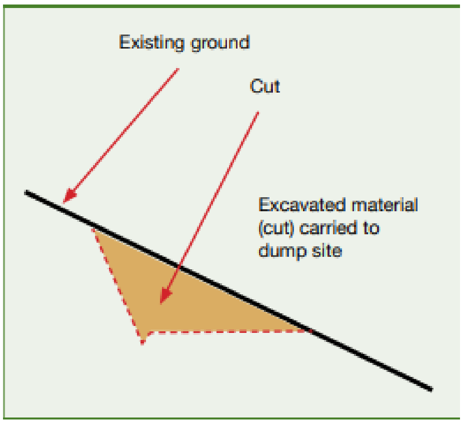


Figure 8. – Full bench or end haul construction technique (FOA, 2020).

1.4 Landing Specifications

When carrying out landing design specific values must be assigned to the angles of the cut and fill slopes (Figure 9). For the fill material the appropriate value will depend on the stable angle of repose for a given material (FOA, 2020). To create a stable surface, fill slopes should be built to an angle that is less than the angle of slope failure. Specific soil types are assigned a horizontal (H) and vertical (v) ratio when constructing fill slopes. For fined grained soils that have less cohesion a higher horizontal ratio of 2H:1V is assigned whereas most other soils can achieve a 1H:1V ratio. Cut slopes will generally hold a steeper angle than fill slopes. This is because the cut slope is comprised of solid in situ material which is in a denser state and thus has more cohesion which in turn increases its resistance to shearing. Fill slopes on the other hand are made up of loose excavated material that needs to be compacted to increase stability (MFLNRO, 2002). Common practice when constructing a landing is to use a cut slope of 200% and a fill slope of 70% (FOA, 2020). If more information about the soil at a particular site is known, then these values can be customized accordingly.

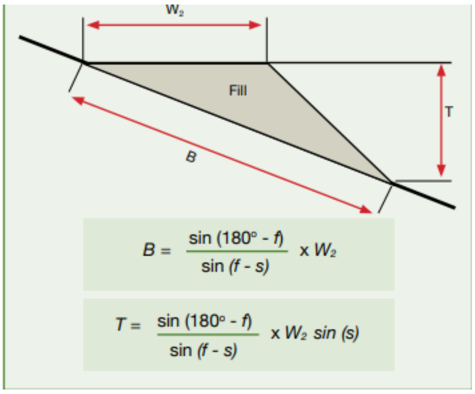
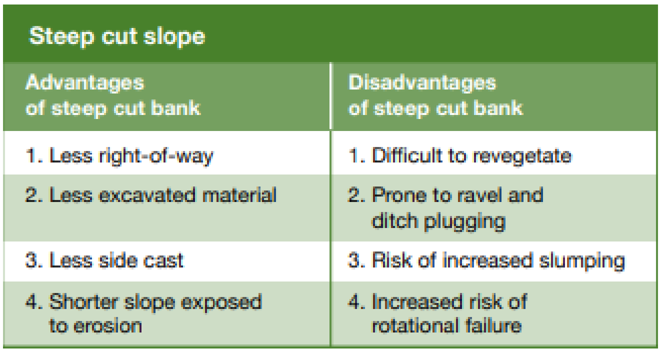


Figure 9. – Formulae used to determine road geometry based on formation width and the stable angle of repose for the fill slope.

1.5 Surface Area & Cut Volume

The most important element of landing construction is slope because as slope increases so does construction costs and environmental impact (Çalışkan, 2016; Kurulak, 2019). As the terrain gets steeper either more material needs to be side casted onto the downhill slope or carted away to make a sufficiently large enough landing surface area to carry out logging operations. The more material that must be excavated and or carted away the more work a contractor must carry out thus resulting in higher overheads. Typically, during side cast construction, a contractor will try to balance the cut and fill material to avoid the need to cart excess material off site. However, the greater the amount of unconsolidated soil that is side casted, the greater the risk that soil has to mobilize given the right rainfall event which could have potential adverse effects on the environment. If the in-situ soil of a site is sufficiently stable then a steeper cut slope can be made to limit the quantity of earthworks required in steep terrain (FOA, 2020). Although there are several advantages to using a steeper cut slope there are also a number of drawbacks that need to be considered (Table 1).

Table 1. – Advantages and disadvantages of using a steeper cut slope (FOA, 2020).



Steep cut slope	
Advantages of steep cut bank	**Disadvantages of steep cut bank**
1. Less right-of-way	1. Difficult to revegetate
2. Less excavated material	2. Prone to ravel and ditch plugging
3. Less side cast	3. Risk of increased slumping
4. Shorter slope exposed to erosion	4. Increased risk of rotational failure

Conversely, another approach to reducing the amount of material that is needed to construct a landing is through better balance of earthworks. This can be achieved by constructing a landing that better mimics the original contour of the hill rather than pushing unconsolidated soil into areas of higher elevation difference. The higher the elevation difference between the desired landing elevation and the downhill slope the greater amount of earth material that is needed to construct a landing. By pushing earth materials into areas of lower elevation difference the more surface area that can be achieved for less material. In theory this makes sense however, there has been a lack of research looking into how much of an influence this technique has on the amount of material needed to construct a landing.

1.6 Manual Design

Conventionally, detailed design of forest infrastructure is carried out using manual surveying methods and a harvest block projection (Chen, 2021). However, a full manual road design can be time consuming and challenging due to the surveying requirements and detailed design work that is required. A contractor who can follow these detailed plans is critical as well. Also, at any point on the proposed infrastructure, the location and earthwork details around quantities of cut or fill, and specificities like cut slope height and the location of the toe of the fill need to be known. To get this level of detail, the base information needs to be precise, otherwise the plans will not be accurate. Furthermore, calculating landing earthworks is challenging task that would ideally be carried out using road design software, rather than the slow and less flexible manual approach and calculations (FOA, 2020). Not only does this technology provide greater flexibility and fast calculations of earthworks volume but also allows engineers to better visualize road profiles (Çalışkan, 2016).

1.7 CAD Software

Computer Aided Design (CAD) software provides a faster and more flexible approach to infrastructure design. With the help of LiDAR and CAD forest infrastructure can be more extensively designed from the office thereby adding confidence to earthworks volume estimates and the accuracy of the geometric design (Chen, 2021). Using this more office-based approach allows for several accurate options to be tested before going out into the field and ground truthing to verify that the ground profile accurately represents what was used to generate the model (Kurulak, 2019). This approach not only reduces the costs of planning but also speeds up the time until completion of a landing thereby increasing the productivity of an operation. Another advantage of the software is the flexibility it provides when safety, environmental or economic constraints that were not previously considered restrict the selection of a particular option. The outcome may be a change in landing position, or the selection of an alternative harvesting system (FOA, 2020). With the help of CAD software changes like these can be made in a matter of days rather than weeks without compromising the high level of detail required to design a quality piece of infrastructure. Some examples of CAD software include ROADENG, Civil3D, GEOCOMP, LUMBERJACK, and SDR Mapping and Design. These programs are easy to use for anyone with a basic understanding of the principles of terrain modelling. (FOA, 2020).

1.8 LiDAR Data

Light Detection and Raging (LiDAR) is an active remote sensing technology used to capture elevation data of above ground objects and surface topography (Evans et al., 2009). It achieves this by measuring the time it takes for emitted short wave light pulses to return to the sensors after reflecting of the object or surface being measured. This elevation data can then be used to generate highly accurate 3D models (Anderson, 1999; Hudzietz & Saripalli, 2011). One of the key advantages of this technology is its ability to penetrate vegetative cover and take elevation measurements of the terrain that lies beneath it. Penetrating through the tree canopy allows for accurate mapping of ground profiles which can be used to create a Triangulated Irregular Network (TIN), which can aid in the design of forest infrastructure (Hodgson & Bresnaham 2004; Schiess & Krogstad 2003). A TIN is a triangular mesh with nodes that consist of the actual digitized data points of a point cloud allowing it to represent a digital terrain surface using less data storage (Cope, 1993). Generally, when mapping terrain that lies beneath tree cover using LiDAR the data points need to be filtered so that the points that represent the overlying vegetation aren't included in the model. LiDAR is a very powerful tool however, laser scanners are incredibly expensive pieces of equipment, and the post processing of the resulting point cloud is labour intensive (Cardenal, 2008).

1.9 RoadEng Software

RoadEng is a forest engineering software program developed by Softree for the purpose of forest infrastructure design. The program is composed of four modules which include Survey, Terrain, Location, and Optimal (Softree, 2023). The 'Survey' module takes ground survey data and uses it to generate a 3D surface of the terrain. The 'Terrain' module also generates a 3D surface of the terrain, in this case a Triangular Irregular Network (TIN) using point cloud or raster data sets captured via remote sensing. A point cloud is just a collection of points in three-dimensional space with each point having its own unique set of X, Y, and Z coordinates. The generated TIN has a significantly greater vertical and horizontal resolution than aerial photos because LiDAR has finer point scaling (Wulder et al. 2008). 'Location' is the design component of RoadEng which is used to construct digital models of roads and or landings by specifying their geometry and alignments. The fourth and final module is 'Optimal', which is an extension of location which allows the user to add parameters such as cost of earthworks volumes which it will then use to generate a cost-effective solution.

While the 'Location' modelled in RoadEng can design forest landings, it is best suited to designing drive through and roadside landing layouts. This is because landing design approach relies on modifying the alignments of an existing road to create a larger area that will represent the landing surface. On the other hand, 'Terrain' model is better able to design spur road end and split-level landings because it doesn't rely on existing infrastructure within the model to create the landing surface. To create a landing within the 'Terrain' model the original terrain is loaded as a background model and a polygon that will represent the landing surface is drawn at the desired elevation. Next the 'Grading' tool can be used to create specified cut and fill slopes for this landing surface based on the terrain surface loaded in the background (Harvey & Riendinger, 2021). Another useful tool withing RoadEng's 'Terrain' module is the volume calculation tool. This function can calculate the volume above, below, and in between one or two surfaces. This makes for quick and easy estimates of earthworks volumes.

1.10 RoadEng Literature

To date studies on anything to do with computer aided landing design are rare. Existing literature focuses on minimising construction costs and environmental impact. Kurulak (2019) investigated the potential of using LiDAR data in RoadEng to produce a more cost-effective road design than one designed using a field-based method. All the road routes designed in the study where less cost effective than the ones already present in the field. However, a key flaw to the study was that these roads where already present in the field when the LiDAR data was captured which would could have contributed to there being less earth material accounted for in the road prism.

Conversely, Caliskan (2016) was more concerned with minimising impact than economics and carried out a case study using RoadEng to determine an environmentally sensitive route through mountainous terrain. Caliskan (2016) found RoadEng to be very user friendly and emphasized its ability to be consider multiple variables over a conventional manual based approach. He also highlighted the usefulness of the 3D modelling function for visualising earthworks and the flexibility to adjust the model to represent the actual constructed road if on the fly changes were made by the contractor.

Heralt (2002) was also concerned with the minimization of negative impacts on the natural environment using RoadEng to generate forest road variations which were analysed based on an environmental approach. This case study highlights RoadEng's capability as a decision-making tool but unlike Caliskan (2016), fails to emphasise the need to back road construction work carried out using computer programs with field studies. Kurulak (2019) likes to echo this by stating the need for ground truthing in the field to ensure the feasibility of a design. Furthermore, the experience of a machine operator and the equipment they are using plays a major role in whether this design translates to a successful outcome (Caliskan, 2016).

More recently a dissertation project completed by Chen (2021) compared several different approaches to landing design using RoadEng and analysed the accuracy of earthworks volumes and the geometry for each. It was found that two of the landing design techniques produced very similar earthworks estimates whereas one tended to underestimate. However, no work was done to determine how well these earthworks estimates translated to a landing that had be physically constructed using these designs. A basic methodology for determining the accuracy of a RoadEng based design with regards to the final constructed landing was laid out for future research.

2.0 Objectives

The aim of this study was to establish whether an equivalent landing surface area could have been constructed, moving fewer cubic meters of earth for a series of case study landings in steep terrain. To achieve this the project will be carried out as a desktop study using 1m DEMs and aerial imagery of existing landings taken from Land Information New Zealand's (LINZ) free to access spatial database. The two pieces of data will be used to redesign the existing landings in the CAD program RoadEng and compared to the originals using an average cut depth (m) metric. This information will be useful for the forest industry as companies will want to know whether investing more resources into detailed landing design prior to construction can achieve an equivalent landing area using less earth material. Presently forest companies utilizing RoadEng are primarily concerned with road design with landing design being considered a niche application.

3.0 Desktop Methodology

3.1 Method Overview

To work within the time and resource constraints of the project data was collected via a desktop study. This desktop methodology made use of publicly available LiDAR data and aerial imagery from Land Information New Zealand (LINZ) to recreate a Digital Surface Model (DSM) of the original terrain using the Digital Elevation Model (DEM) of the original as-built landing. This was achieved by extrapolating the contours that surrounded the landing in the 3D model to interpolate the original terrain profile. With these two layers it was then possible to calculate the volume entrained between them using RoadEng's built in volume calculation tool. Next the surface area of the original landing was measured and used as a target specification for the new landing design which was created using the interpolated surface. This new landing design was then compared to the original as built landing using the average cut depth to determine whether a more optimal outcome was achieved. This process has been summarised in Figure 10.

Average cut depth was calculated by dividing the total cut volume used to construct the landing by the surface area of that said landing. Using average cut depth to draw comparisons between two landings situated on the same site was crucial to this study because of the limitations of RoadEng's ability to measure and create features to a high enough level of accuracy. RoadEng could only design the new landings to within 100 square meters of the original landing area which was a difference of 10%. Comparing the earthworks directly would not have been correct given that the landing surface area is a function of the cut material used to construct it. This issue is explored later in the report.

Additionally, this approach was limited to simple scenarios with relatively uniform terrain. This was because the method was based off inferring the original topography using the terrain that surrounded the existing landing. It was not possible to recreate landings that were not significantly embedded into the hillside or that presided on relatively flat terrain or had been constructed directly on top of a ridge as there was no way of accurately inferring the original profile of the terrain. because of this most of the landings reconstructed in this study where either spur road end or roadside landings situated in relatively steep and uniform terrain.

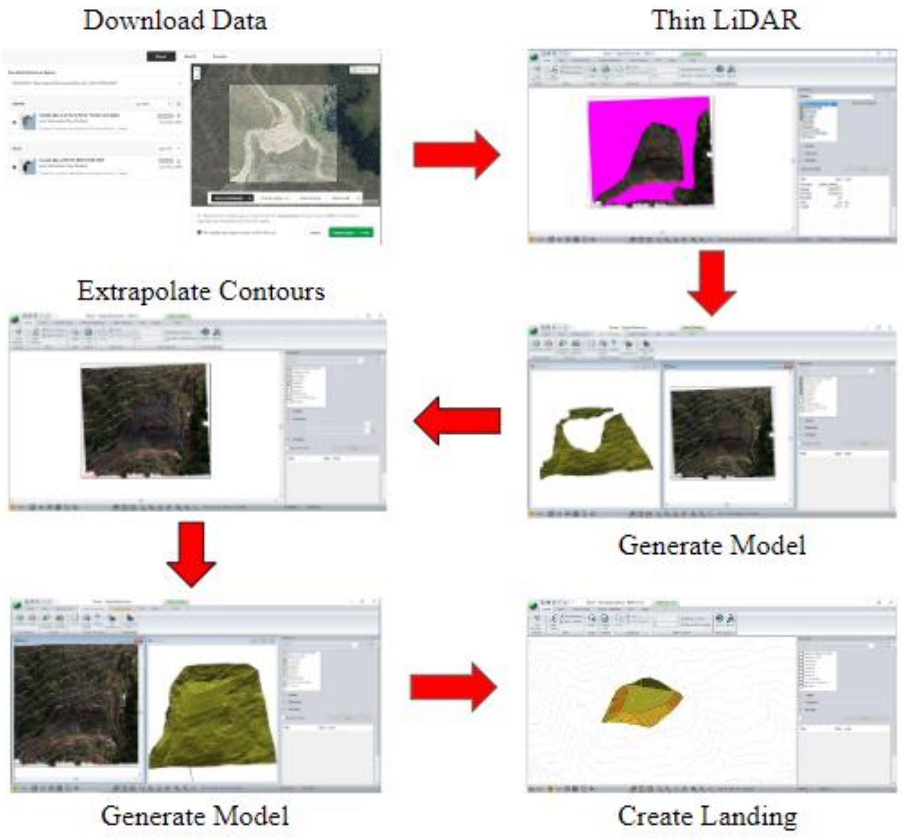


Figure 10. – Flow diagram illustrating the reconstruction process carried out in RoadEng.

3.2 Detailed Methodology

To work within the time and resource constraints of this project the data was collected from Land Information New Zealand (LINZ) which is an open access data resource that contains several informational geospatial layers that can be cropped and downloaded as a smaller file size depending on what the user requires. This study made use of 1m DEM layers and aerial imagery that predated the later to ensure that files contained elevation data that represented the as built landing. Coarser 8m data was also available however, this was not sufficiently accurate enough for landing design due to its inability to represent finer topographical details. Using the aerial imagery layer, it was possible to locate a suitable landing to reconstruct and then crop the data set along with the underlaid DEM for further processing in RoadEng. The LINZ website interface can be seen in Figure 11. Layer cropping is also demonstrated in Figure 12.

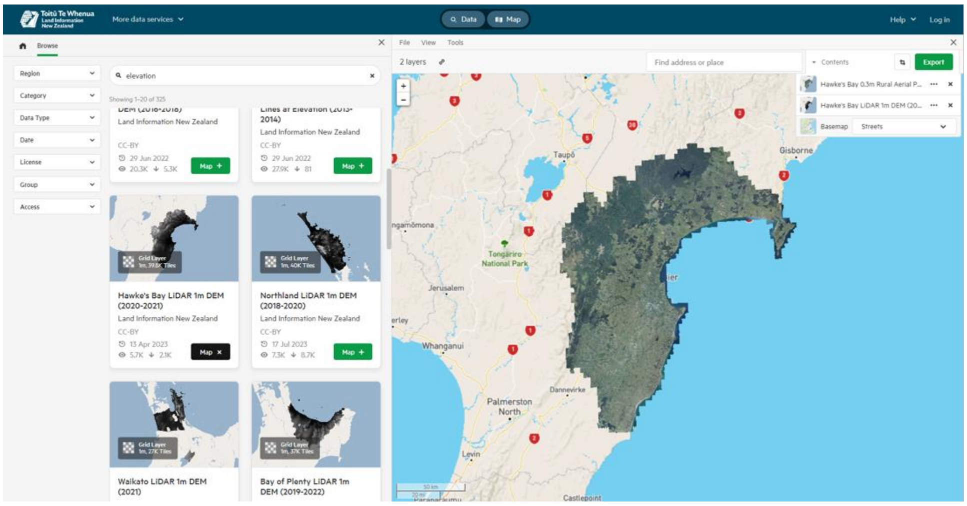
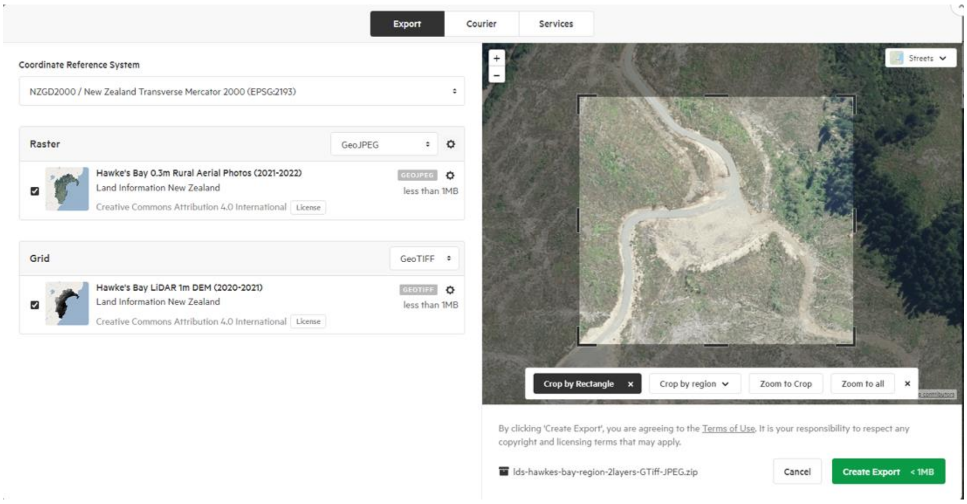


Figure 11. - Land Information New Zealand's data service user interface.



Coordinate Reference System: NZGD2000 / New Zealand Transverse Mercator 2000 (EPSG:2193)

Raster: GeoJPEG

☑ Hawke's Bay 0.3m Rural Aerial Photos (2021-2022) — Land Information New Zealand — Creative Commons Attribution 4.0 International — GEOJPEG — less than 1MB

Grid: GeoTIFF

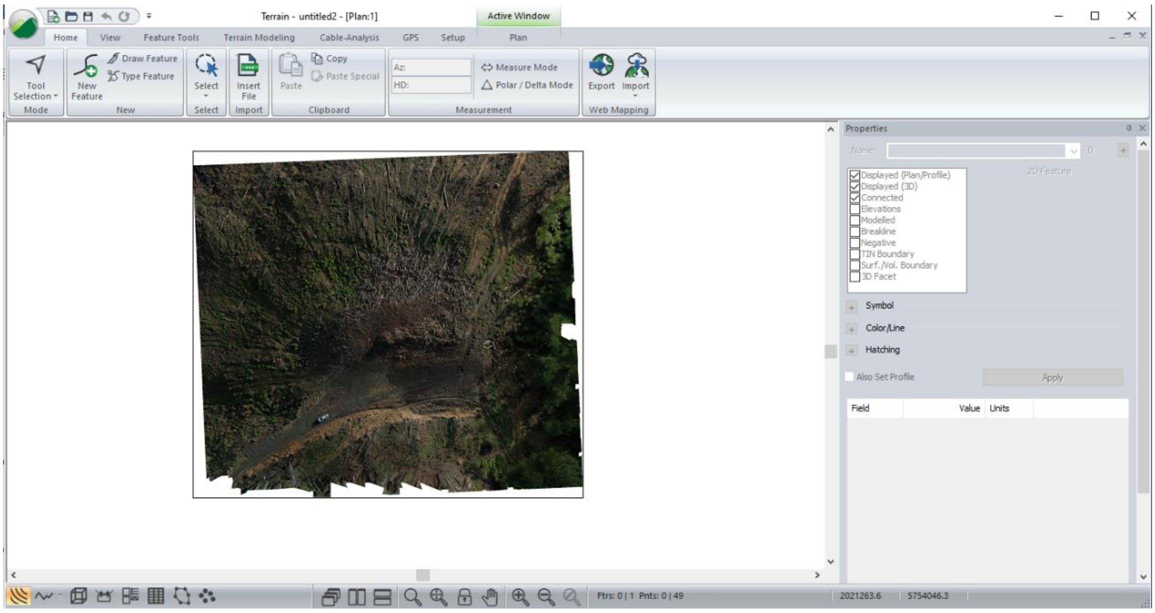
☑ Hawke's Bay LiDAR 1m DEM (2020-2021) — Land Information New Zealand — Creative Commons Attribution 4.0 International — GEOTIFF — less than 1MB

By clicking 'Create Export', you are agreeing to the Terms of Use. It is your responsibility to respect any copyright and licensing terms that may apply.

lds-hawkes-bay-region-2layers-GTiff-JPEG.zip

Figure 12. - Downloading the relevant DEM and aerial imagery using LINZ's cropping tool.

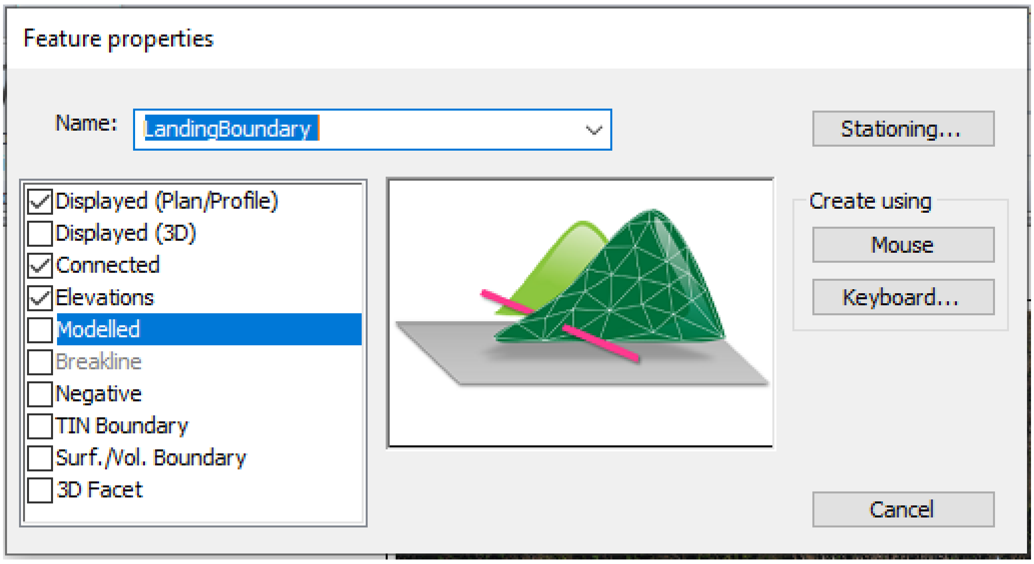
Once the two key layers had been obtained from LINZ and extract from the zip file the next step was to upload the aerial imagery to RoadEng (Figure 13). The aerial imagery was then used to create a polygon boundary that could be used to thin the LIDAR point cloud. This was necessary because the methodology took the elevation data that represented the as-built landing and used it to reconstruct the original terrain. To achieve this the component of the point cloud that represented the original landing had to be removed. In doing so it was then possible to interpolate the original terrain. This was done by extrapolating the surrounding contours across the hole that had been created in the 3D model and then generating a final 3D surface.



☑ Displayed (Plan/Profile)
☑ Displayed (3D)
☑ Connected
☐ Elevations
☐ Modelled
☐ Breakline
☐ Negative
☐ TIN Boundary
☐ Surf./Vol. Boundary
☐ 3D Facet
☐ Also Set Profile

Figure 13. – Aerial imagery of the original landing used to identify landing and terrain boundaries.

Once the aerial imagery had been uploaded it was then possible to create a polygon that would represent the boundary where the as-built landing finishes and the original terrain began (Figure 14, Figure 15). In some cases, the landing boundary was hard to identify using the aerial imagery alone. Generating the 3D surface before modifying the point cloud made it easier to accurately estimate the boundary line. This was often the case when the uploaded aerial imagery was particularly grainy or the images had been taken at a different time to when the elevation data was collected, and on the fly, modifications had been made to the landing during a harvest operation.



Name: LandingBoundary

☑ Displayed (Plan/Profile)
☐ Displayed (3D)
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☐ Modelled
☐ Breakline
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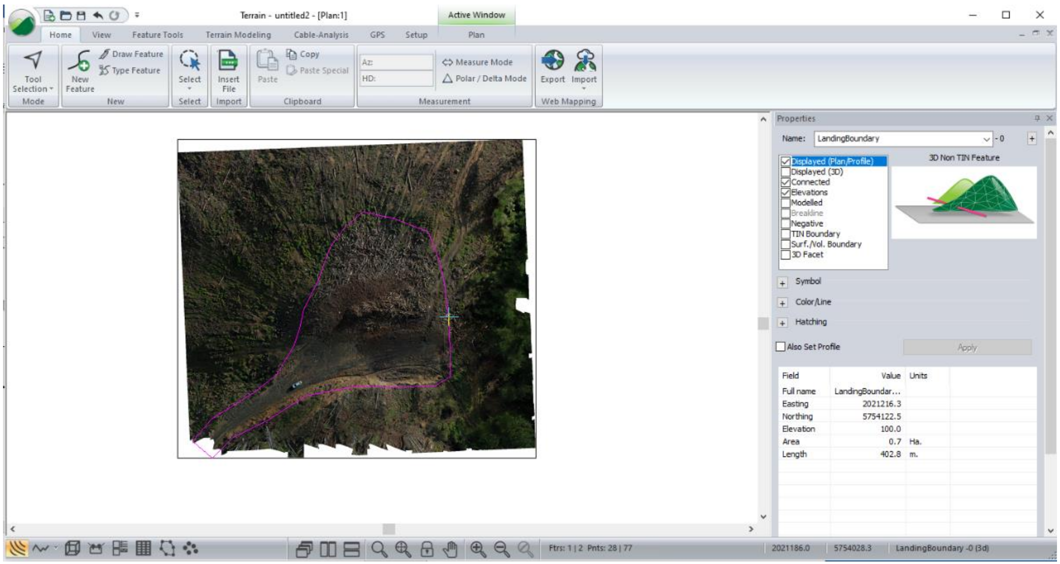
☐ TIN Boundary
☐ Surf./Vol. Boundary
☐ 3D Facet

Figure 14. - Feature properties pop up window which appears after selecting ‘create new feature’.



Name: LandingBoundary -0

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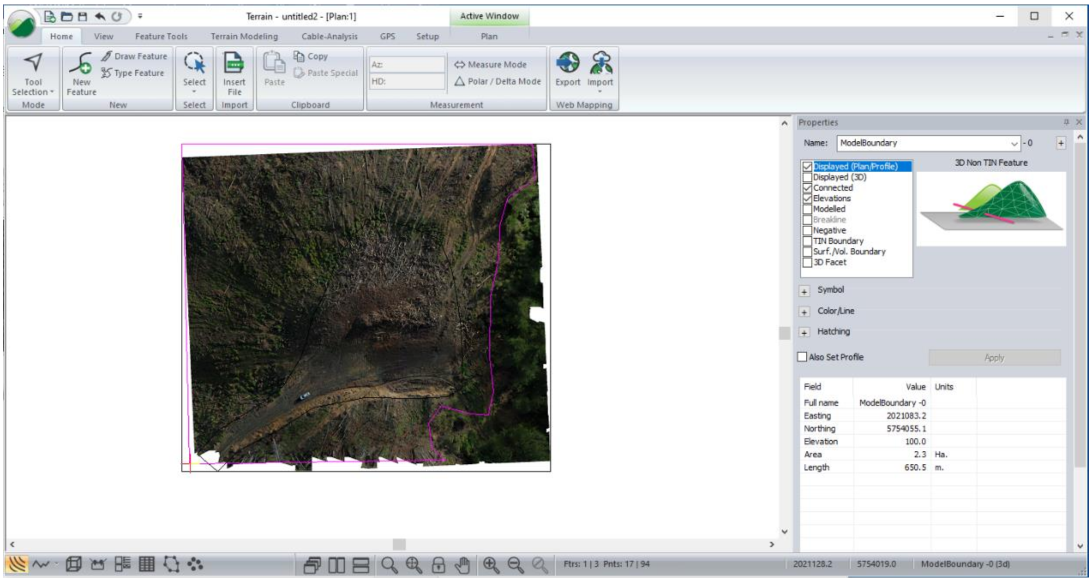
☐ Displayed (3D)
☑ Connected
☑ Elevations
☐ Modelled
☐ Breakline
☐ Negative
☐ TIN Boundary
☐ Surf./Vol. Boundary
☐ 3D Facet

☐ Also Set Profile

Field	Value	Units
Full name	LandingBoundar...	
Easting	2021216.3	
Northing	5754122.5	
Elevation	100.0	
Area	0.7	Ha.
Length	402.8	m.

Figure 15. - Landing-terrain boundary which will be used to thin the LIDAR point cloud.

Although the DEM layers being used in this study consisted of LIDAR data, it is possible to apply the same methodology with a point cloud collected via photogrammetry. However, photogrammetric DEMs are likely to contain a mix of unclassified points which don't all represent the ground surface. A lot of these points will represent vegetation scattered around the landing periphery which creates noise in the 3D model thus making it necessary to create a boundary around the model to crop them out (Figure 16). When left unfiltered, the vegetation points make it difficult for the software to calculate earthworks volumes later in the process. Alternatively, a point cloud collected using LIDAR can be uploaded into ArcGIS and reclassified so that it only contains ground points. Being able to reclassify the data rather than crop the model is more desirable because it preserves the surrounding terrain which will allow for a more accurate interpolation of the terrain that needs to be reconstructed. Photogrammetry uses digital imagery so it cannot recreate a ground surface entirely covered by forest but can filter out stand-alone trees from the point cloud. Data obtained from LINZ had already been classified so this step was not necessary.



Name: ModelBoundary -0

☑ Displayed (Plan/Profile)
☐ Displayed (3D)
☑ Connected
☑ Elevations
☐ Modelled
☐ Breakline
☐ Negative
☐ TIN Boundary
☐ Surf./Vol. Boundary
☐ 3D Facet

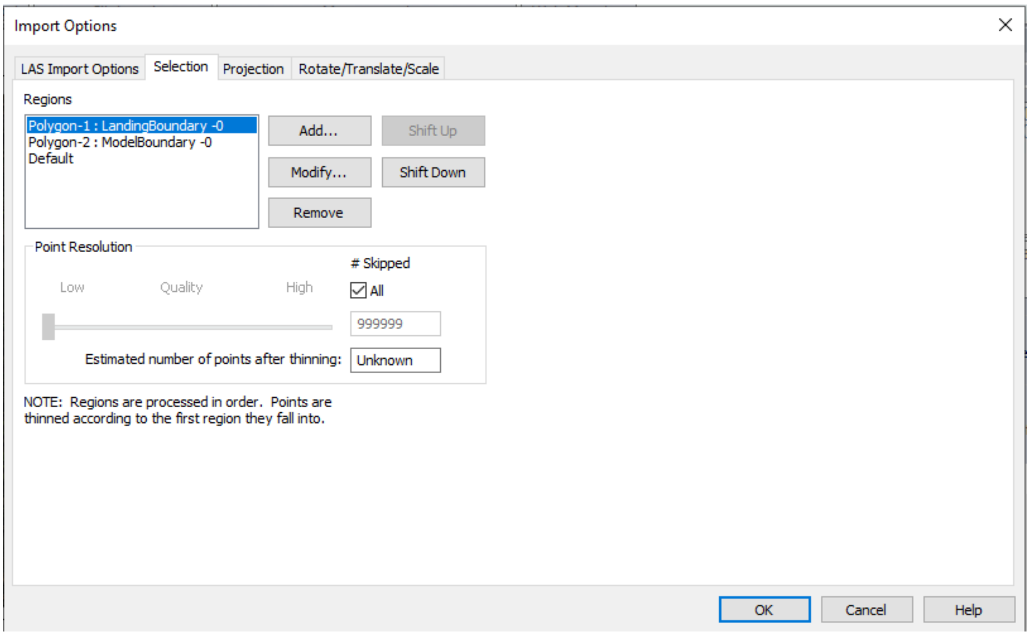
☐ Also Set Profile

Field	Value	Units
Full name	ModelBoundary -0	
Easting	2021083.2	
Northing	5754055.1	
Elevation	100.0	
Area	2.3	Ha.
Length	650.5	m.

2021128.2 | 5754019.0 | ModelBoundary -0 (3d)

Figure 16. - Model boundary which is used to remove noise created by vegetation at the edge of the point cloud.

Once a polygon that represents the boundary between the landing and the original terrain was created the LiDAR data set was uploaded and thinned according to the boundaries created. In this case all the points contained within the landing boundary and outside of the model boundary were skipped creating a hole in the 3D model so a new surface could be interpolated using manually drawn features (Figure 17). Depending on the number of points contained within the point cloud it would have been necessary to thin the dataset. However, this was not an issue with the data sampled from LINZ as it was comprised of a lower resolution point cloud. Upon first loading the data into RoadEng the software highlighted all the data pink as seen in Figure 18 which made it easy to identify the data that had been removed.

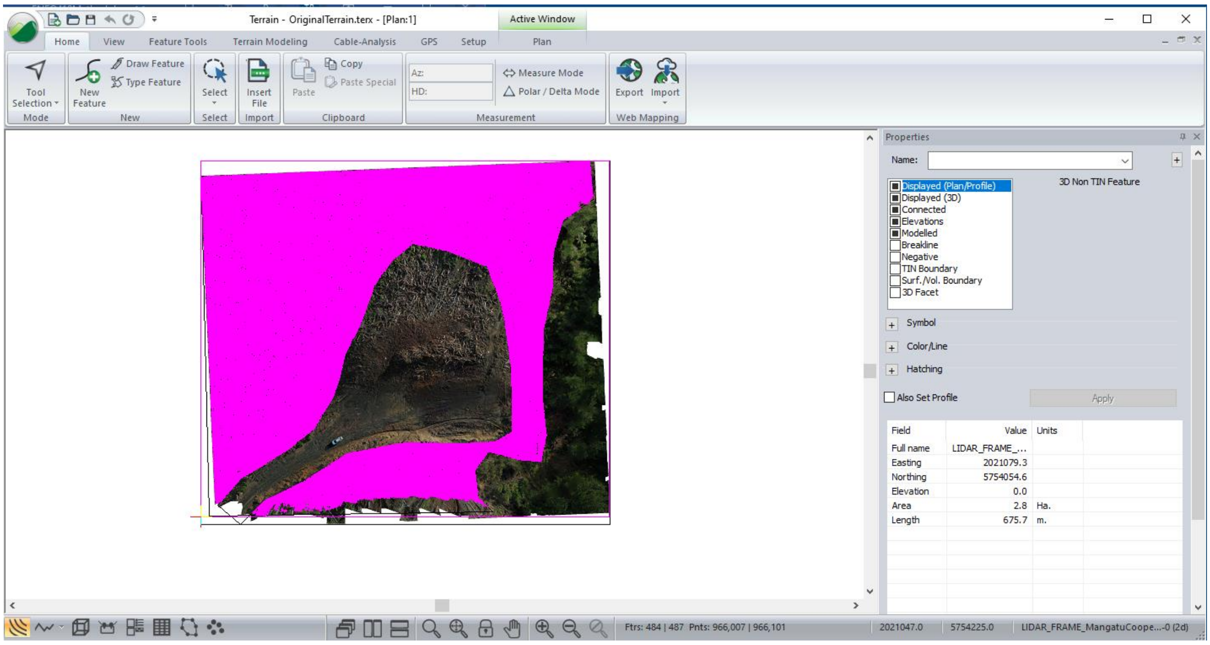


Regions
Polygon-1 : LandingBoundary -0
Polygon-2 : ModelBoundary -0
Default

Point Resolution
Skipped
☑ All
999999
Estimated number of points after thinning: Unknown

NOTE: Regions are processed in order. Points are thinned according to the first region they fall into.

Figure 17. - Import options pop up window which appears during the upload of the LIDAR data file.



Properties

Name:

3D Non TIN Feature

- ☒ Displayed (Plan/Profile)
- ☒ Displayed (3D)
- ☒ Connected
- ☒ Elevations
- ☒ Modelled
- ☐ Breakline
- ☐ Negative
- ☐ TIN Boundary
- ☐ Surf./Vol. Boundary
- ☐ 3D Facet

+ Symbol
+ Color/Line
+ Hatching

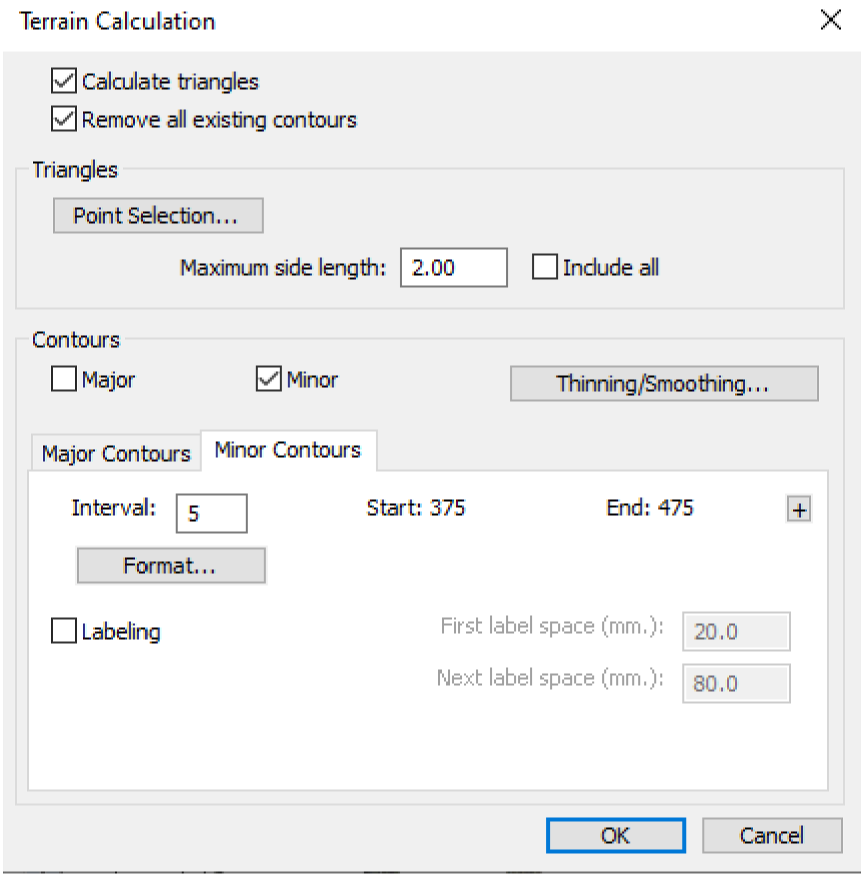
☐ Also Set Profile

Apply

Field	Value	Units
Full name	LIDAR_FRAME_...	
Easting	2021079.3	
Northing	5754054.6	
Elevation	0.0	
Area	2.8	Ha.
Length	675.7	m.

Figure 18. - Highlighted LIDAR point cloud which will appear in the RoadEng window after uploading.

After deselecting this data, it was then possible to generate a 3D model of the terrain (minus the as built landing) along with contours using the Generate Terrain tool in the Terrain Modelling tab. Selecting this tool prompts the settings window pictured in Figure 19. It is important to set the maximum side length to a small value such as 2m to ensure RoadEng does not create a terrain model that spans across the gap created in the point cloud. Major contours were also turned off and minor contours set to 5m intervals. The result was a 3D model of the terrain surface minus the as built landing as pictured in Figure 20.



Terrain Calculation

☑ Calculate triangles

☑ Remove all existing contours

Triangles

Point Selection...

Maximum side length: 2.00 ☐ Include all

Contours

☐ Major ☑ Minor

Thinning/Smoothing...

Major Contours | Minor Contours

Interval: 5 Start: 375 End: 475

Format...

☐ Labeling

First label space (mm.): 20.0

Next label space (mm.): 80.0

OK Cancel

Figure 19. - Terrain Calculation pop up window which appears after selecting the ‘Generate’ tool.

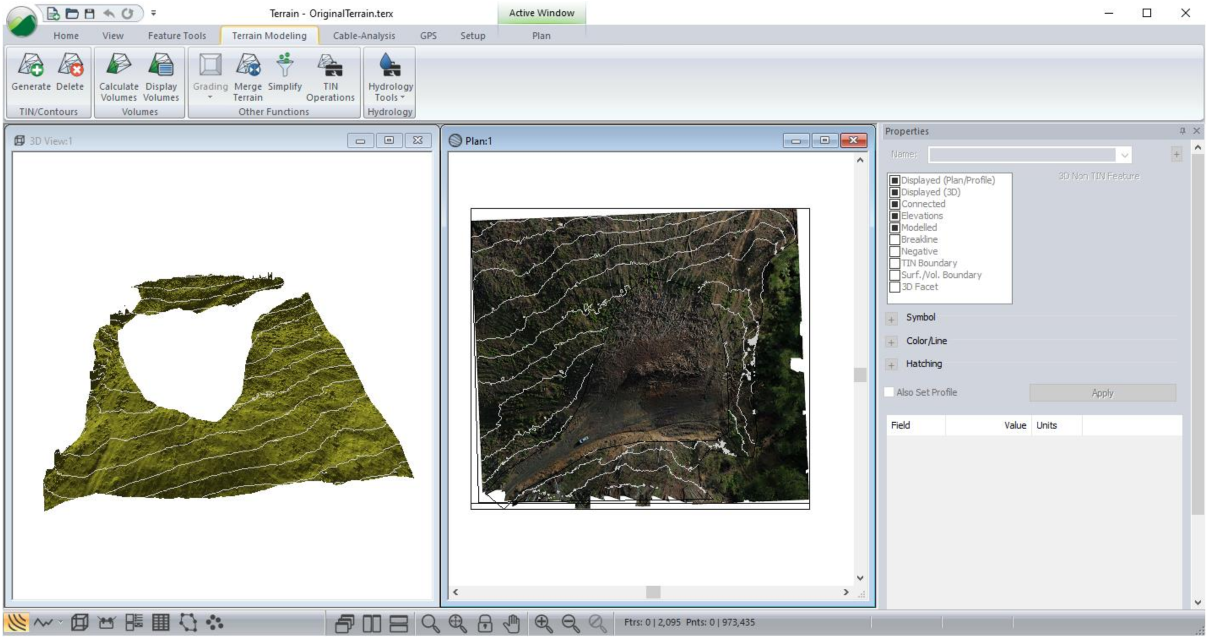
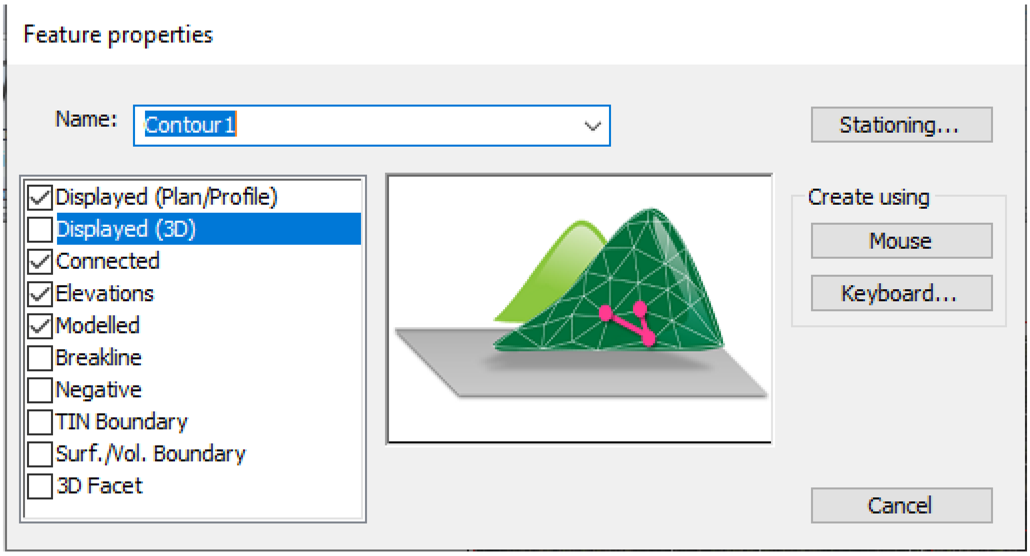


Figure 20. - The result of running ’Generate’ tool which is a 3D model of the terrain minus the original landing.

Using the 3D model that was generated, it was then possible to extrapolate the surrounding contours using the ‘create feature’ tool (Figure 21) to form an interpolation of the original terrain surface picture in Figure 22. In some cases, it was also necessary to project the slope down from the top of the cut batter to the cut fill boundary to recreate a more accurate surface. The wider the extent of the surrounding terrain, the easier and more accurate these methods were to carry out. It was also important that ‘Elevations’ and the ‘Modelled’ settings were selected when creating these features as seen in Figure 21. Once the new contours had been drawn a new 3D model could be generated. Because the distance between the new contour features was greater that the spacing between points in the data set the side length needed to be set to a higher value so that the generated TIN could fill the spaces between the manually drawn features Figure 23. The output will be a DSM that represents the original terrain (Figure 24).

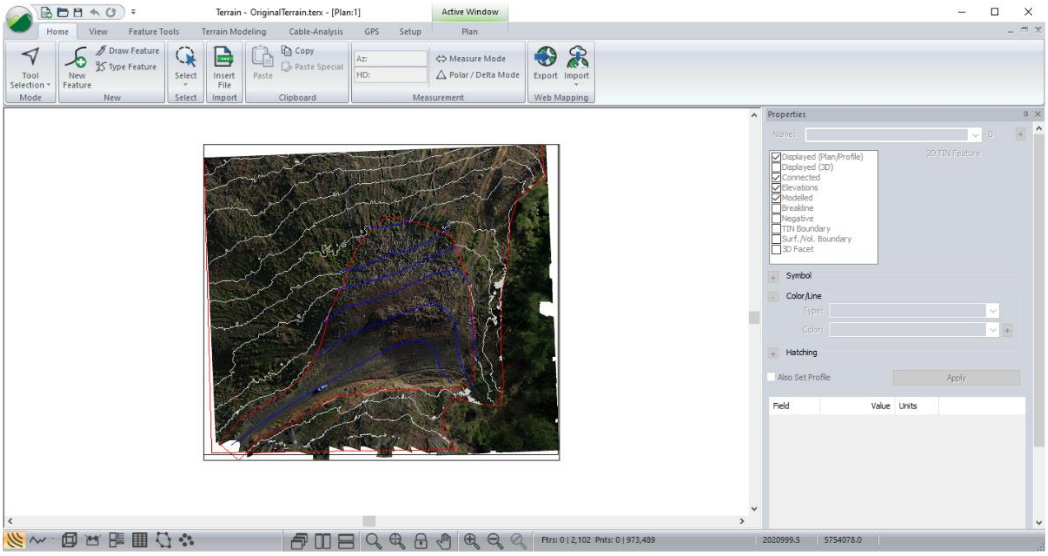


Feature properties

Name: Contour 1

☑ Displayed (Plan/Profile)
☐ Displayed (3D)
☑ Connected
☑ Elevations
☑ Modelled
☐ Breakline
☐ Negative
☐ TIN Boundary
☐ Surf./Vol. Boundary
☐ 3D Facet

Figure 21. - Feature properties pop up window which appears after selecting create new feature.



Terrain - OriginalTerrain.terx - [Plan:1]

Properties

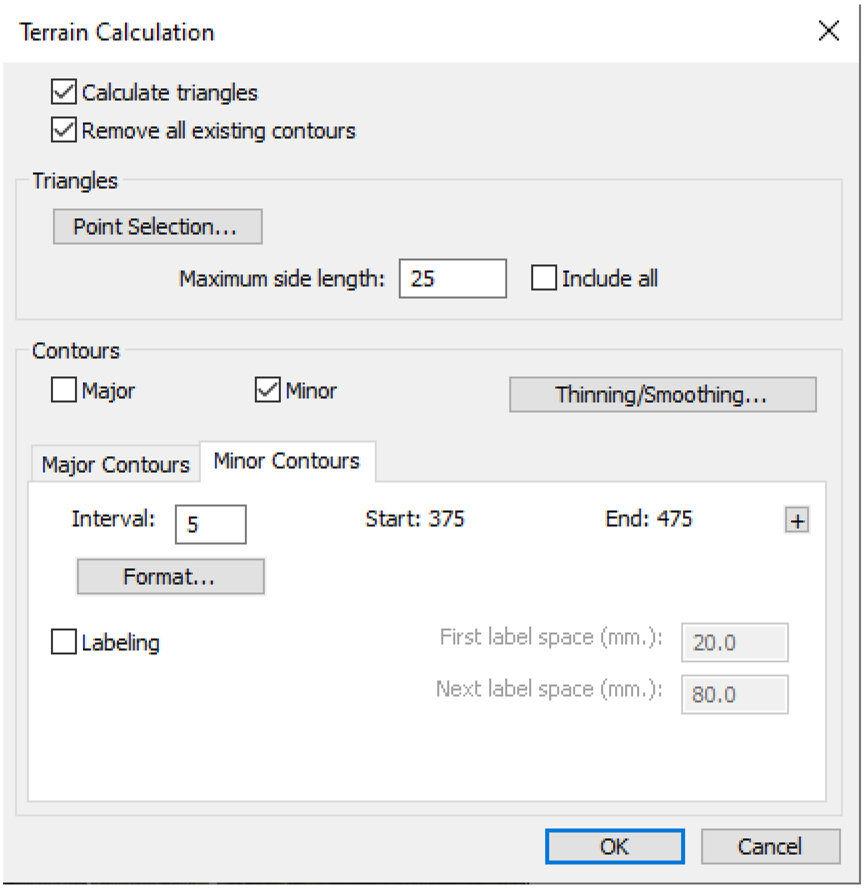
☑ Displayed (Plan/Profile)
☐ Displayed (3D)
☑ Connected
☑ Elevations
☑ Modelled
☐ Breakline
☐ Negative
☐ TIN Boundary
☐ Surf./Vol. Boundary
☐ 3D Facet

☐ Also Set Profile

Field	Value	Units

Ftrs: 0 | 2,102 Pnts: 0 | 973,489 2020999.5 5754078.0

Figure 22. - The result of interpolating the original terrain by extrapolating the surrounding contours across the hole in the 3D model.



Terrain Calculation

☑ Calculate triangles
☑ Remove all existing contours

Triangles

Point Selection...

Maximum side length: 25 ☐ Include all

Contours

☐ Major ☑ Minor Thinning/Smoothing...

Major Contours | Minor Contours

Interval: 5 Start: 375 End: 475

Format...

☐ Labeling First label space (mm.): 20.0
Next label space (mm.): 80.0

OK Cancel

Figure 23. - Terrain Calculation pop up window which appears after selecting the ‘Generate’ tool.

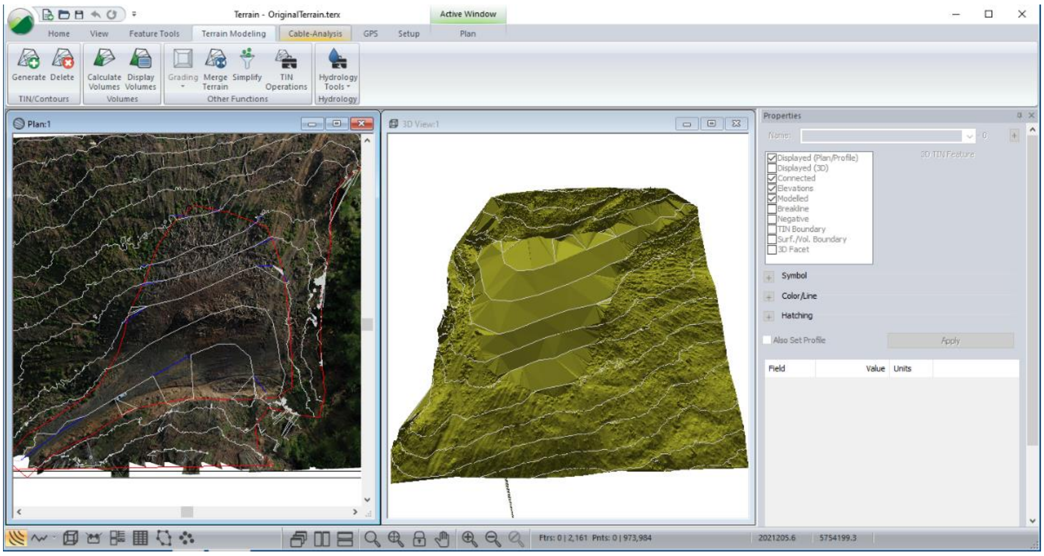


Figure 24. - The new interpolated model of the original terrain before the landing was constructed.

A lot of the landings downloaded from LINZ had slash piles sitting on them which meant this same process of thinning the point cloud and generating a new surface was needed to remove them. This step was important when it came to calculating the cut volume as the model would have calculated a smaller value than the actual. The polygon used to represent the slash boundary can be seen in Figure 25 and the final 3D surface produced after removing the points that represented the slash pile to generate a new model can be seen in Figure 26.

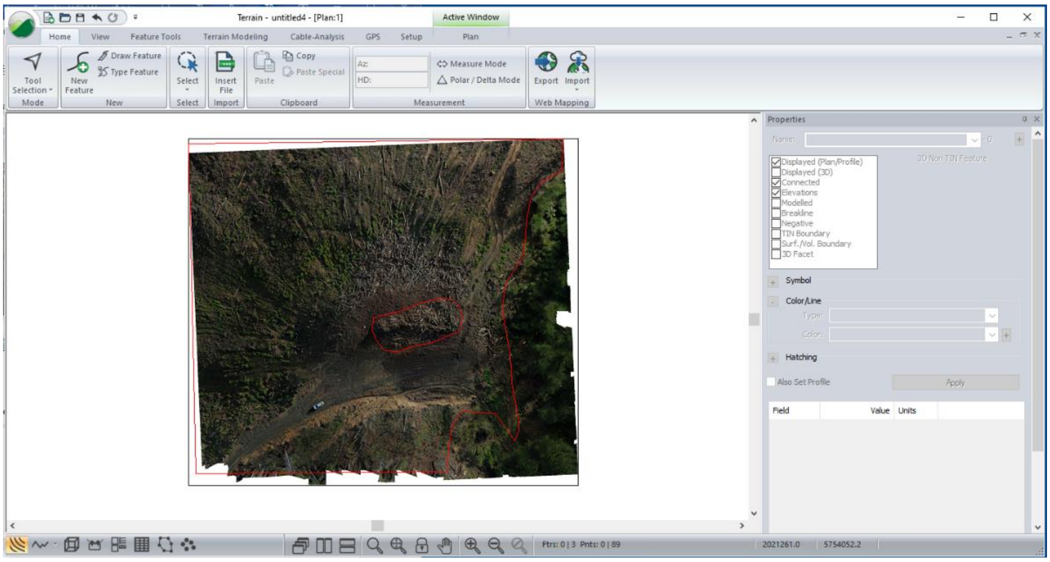


Figure 25. - Polygon representing the edge of the slash pile on the flat surface of the landing.

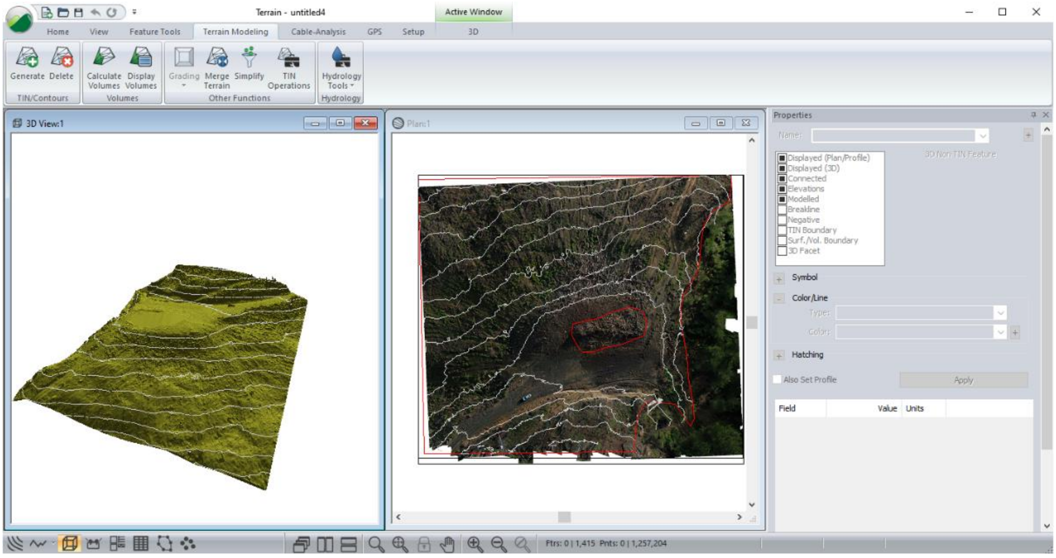
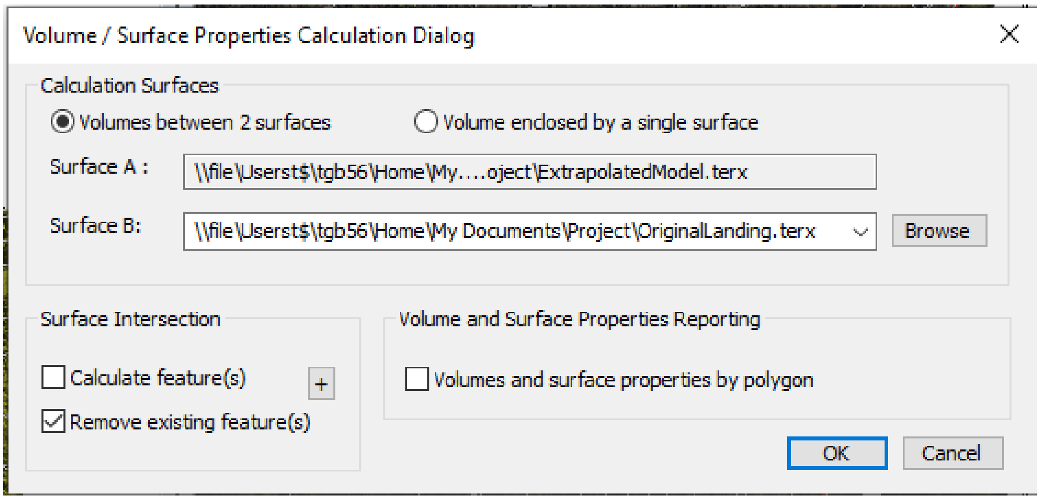


Figure 26. - The 3D model of the original landing after the slash pile was removed from the point cloud.

Once the new surface that represented the original terrain had been generated and the as built landing had been cleared of any slash piles it was then possible to calculate the cut volume entrained between the two layers. This was done using RoadEng's built in volume calculation tool. Clicking the tool prompted the settings window where the 'volume between 2 surfaces' option was selected and the two respective layers imputed into the drop-down menu for 'surface A' and 'surface B' as shown in Figure 27. The run time for this function will vary depending on the size of the layers and point cloud density. To decrease run times the polygon that represents the landing boundary was set to a 'surface/vol. Boundary' in its properties window prior to running the volume calculation which constrained the calculation to this area. An example of the two overlapping layers that the RoadEng is calculating the volume between can be seen in Figure 28.


Volume / Surface Properties Calculation Dialog

Calculation Surfaces

● Volumes between 2 surfaces ○ Volume enclosed by a single surface

Surface A : \\file\Userst$\tgb56\Home\My....oject\ExtrapolatedModel.terx

Surface B: \\file\Userst$\tgb56\Home\My Documents\Project\OriginalLanding.terx

Surface Intersection

☐ Calculate feature(s)

☑ Remove existing feature(s)

Volume and Surface Properties Reporting

☐ Volumes and surface properties by polygon

Figure 27. - Volume/Surface Properties Calculation Dialog pop up window which appears after selecting calculate volumes tool in the terrain modelling tab.

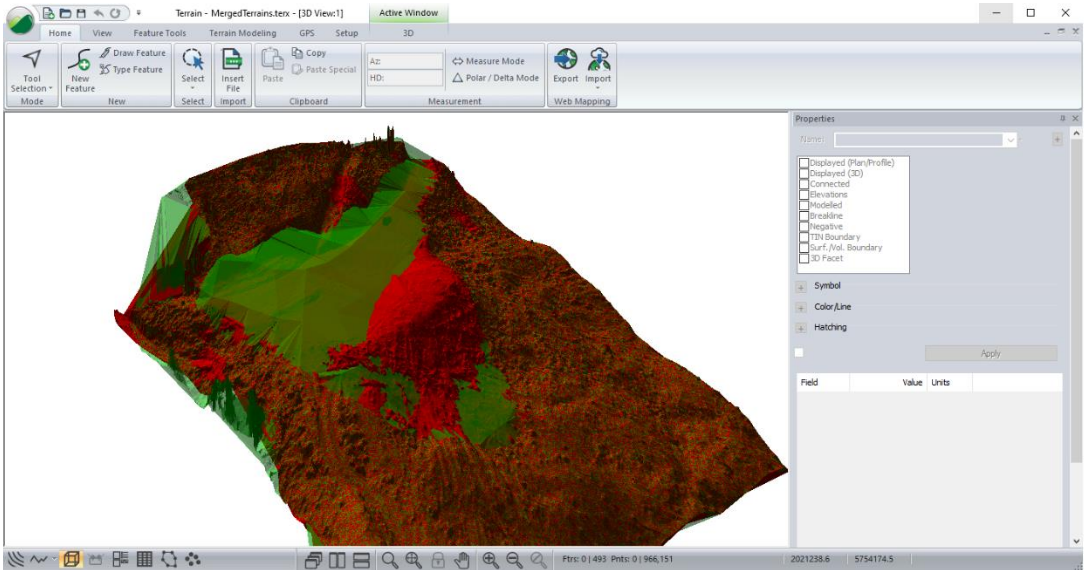
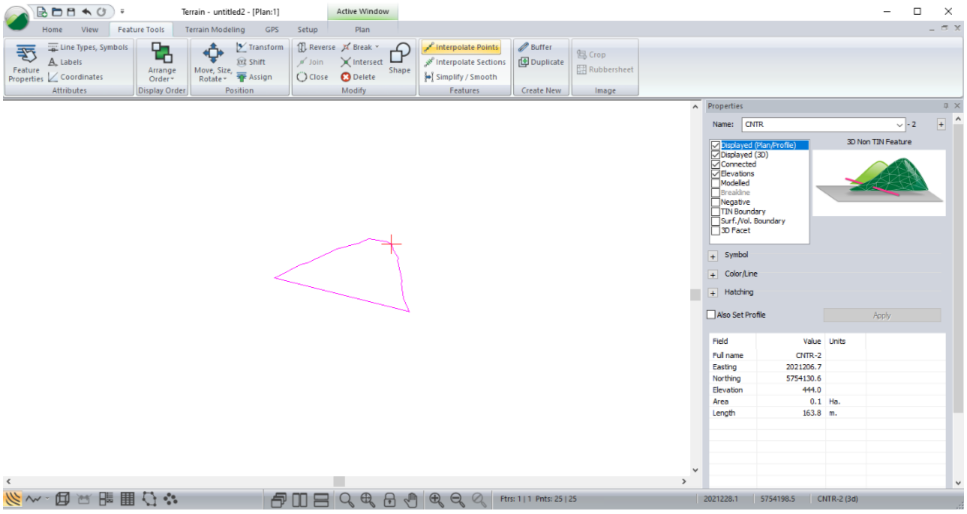


Figure 28. - The interpolated surface of the original terrain overlain onto the as built landing in RoadEng's 3D window.

Once the cut volume of the original as built landing had been calculated the next step was to redesign the landing using the interpolated 3D surface in terrain to determine whether a smaller average cut depth could be achieved. The landing design followed the methodology laid out in the School of Forestry RoadEng landing design tutorial created by Harvey & Riendinger (2021). Firstly, the surface area of the original as built landing had to be measured using RoadEng's built in measuring tool. Once this target surface area had been obtained the next step was to select a smooth contour to represent the landing edge which was then copy and pasted into a new terrain file. Again, using RoadEng's measuring tool the desired surface of the new landing area was mapped out along the contour line. Once the desired surface area was obtained the contour was broken at two ends and then closed using the 'close feature' option in the 'modify selected features' drop-down menu to create a closed polygon that would represent the edge of the landings surface area Figure 29.



Name: CNTR - 2

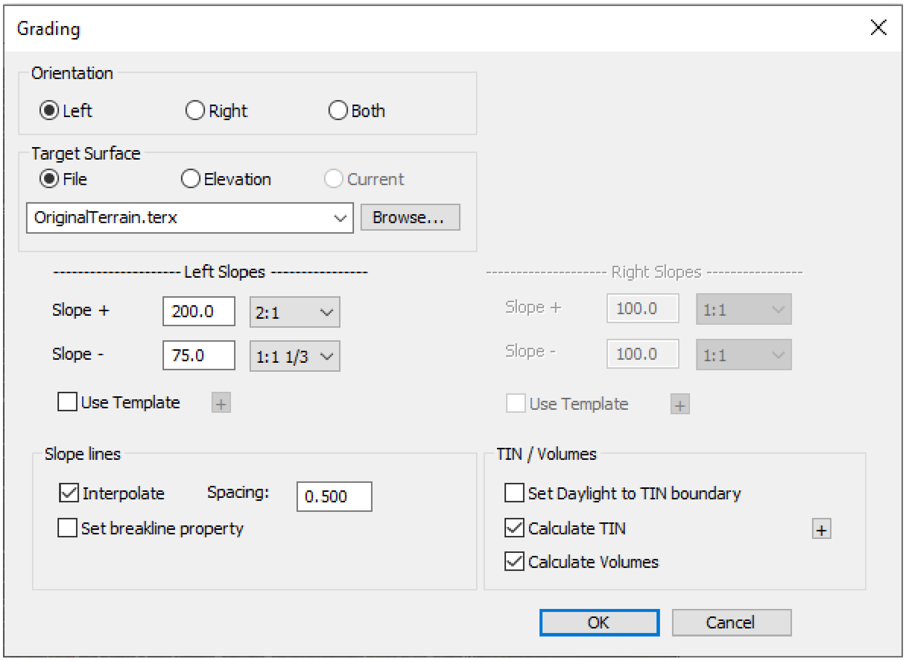
☑ Displayed (Plan/Profile)
☑ Displayed (3D)
☑ Connected
☑ Elevations
☐ Modelled
☐ Breakline
☐ Negative
☐ TIN Boundary
☐ Surf./Vol. Boundary
☐ 3D Facet

☐ Also Set Profile

Field	Value	Units
Full name	CNTR-2	
Easting	2021206.7	
Northing	5754130.6	
Elevation	444.0	
Area	0.1	Ha.
Length	163.8	m.

Figure 29. - Polygon drawn using a contour from the original terrain model to represent the edge of the new landing design.

With this landing edge it was then possible to create the final landing design by selecting the feature and then using the ‘Grading’ tool in RoadEng’s ‘Terrain Modelling’ tab. Importantly the Original Terrain layer that was previously created was selected as the Target surface in the settings window. It was important to ensure that this layer corresponded to the contour that was used to create the landing edge otherwise the ‘Grading’ function wouldn’t work. The other settings used to construct the landing can be seen in Figure 30 below. The specifications used to design the landing in this study were a 200% cut batter and 75% fill slope as illustrated in Figure 30.



Orientation
● Left ○ Right ○ Both

Target Surface
● File ○ Elevation ○ Current
OriginalTerrain.terx

-------------------- Left Slopes ---------------
Slope + 200.0 2:1
Slope - 75.0 1:1 1/3
☐ Use Template

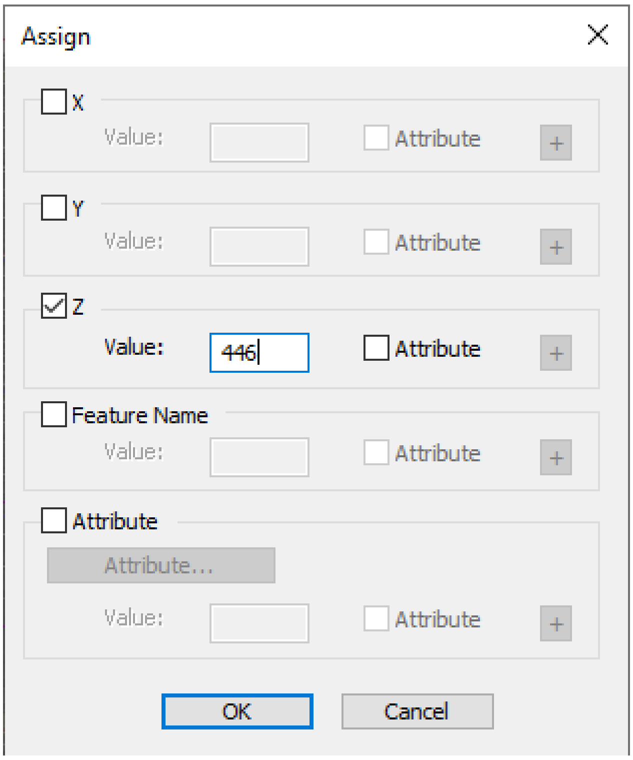
-------------------- Right Slopes ---------------
Slope + 100.0 1:1
Slope - 100.0 1:1
☐ Use Template

Slope lines
☑ Interpolate Spacing: 0.500
☐ Set breakline property

TIN / Volumes
☐ Set Daylight to TIN boundary
☑ Calculate TIN
☑ Calculate Volumes

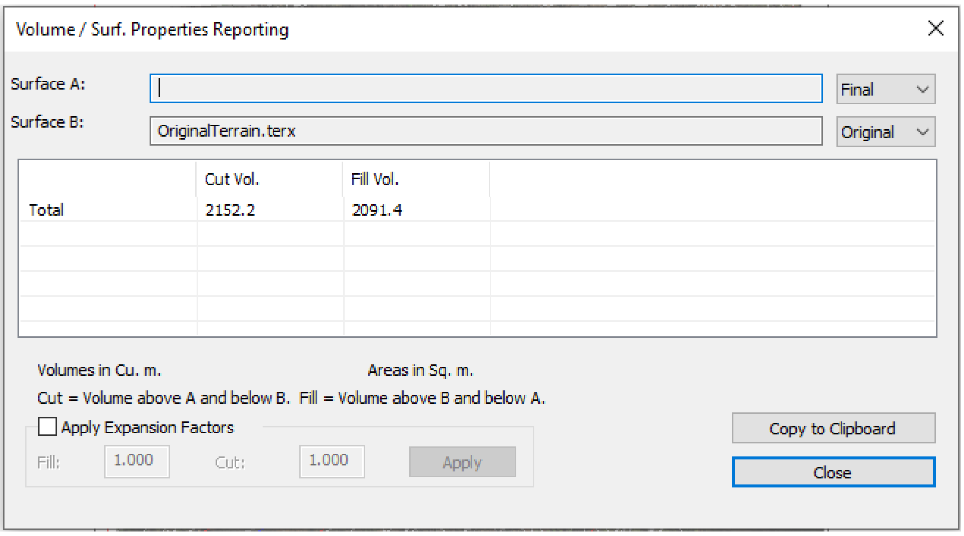
Figure 30. - Grading pop-up window which appears after selecting ‘Grading’ tool in terrain modelling tab.

After RoadEng has generated the new landing a pop up will appear with values for cut and fill used in the resultant design. If these values were unbalanced, it was necessary to delete all the new generated features apart from the original landing edge created. Adjusting the elevation of the remaining polygon altered the cut volume required which achieved a better cut fill balance (Figure 31). If there was significantly more cut than fill raising the landing elevation by 1-2m reduced the cut and increased the fill which resulted in a better balance of earthworks (Figure 32). The opposite applied for any landings with an excessive amount of fill. Although reducing the amount of cut to increase the fill volume may seem counter intuitive, in a real-world context this worked within the software. This was because the polygon that represented the landing edge followed the contour of the original terrain so that the initial landing design was embedded in the hill slope and only consisted of cut volume until its elevation was increased allowing the 'Grading' function to project a fill slope from the landing edge down to the target surface.



☑ Z
Value: 446

Figure 31. - Assign pop up window which appears after selecting Assign in the modify selected feature drop down menu.



Volume / Surf. Properties Reporting

Surface A: Final

Surface B: OriginalTerrain.terx Original

	Cut Vol.	Fill Vol.
Total	2152.2	2091.4

Volumes in Cu. m. Areas in Sq. m.

Cut = Volume above A and below B. Fill = Volume above B and below A.

☐ Apply Expansion Factors

Fill: 1.000 Cut: 1.000

Figure 32. - Volume/Surface Properties Reporting pop up window that appears after generating the new landing using the ‘Grading’ tool.

Finally, the result will be a 3D model of the new landing design as pictured Figure 33 below. It should be noted that if the boundary of the terrain file used to construct the model is too close to the generated landing this will result in an unrealistically long fill batter. To prevent this from happening and to ensure the earthworks volumes RoadEng calculates are accurate the Digital Elevation tile downloaded from LINZ needs to have sufficient spacing between the edge of the original landing and the respective layers boundary so that RoadEng doesn’t generate a landing that extends beyond the boundary of the model.

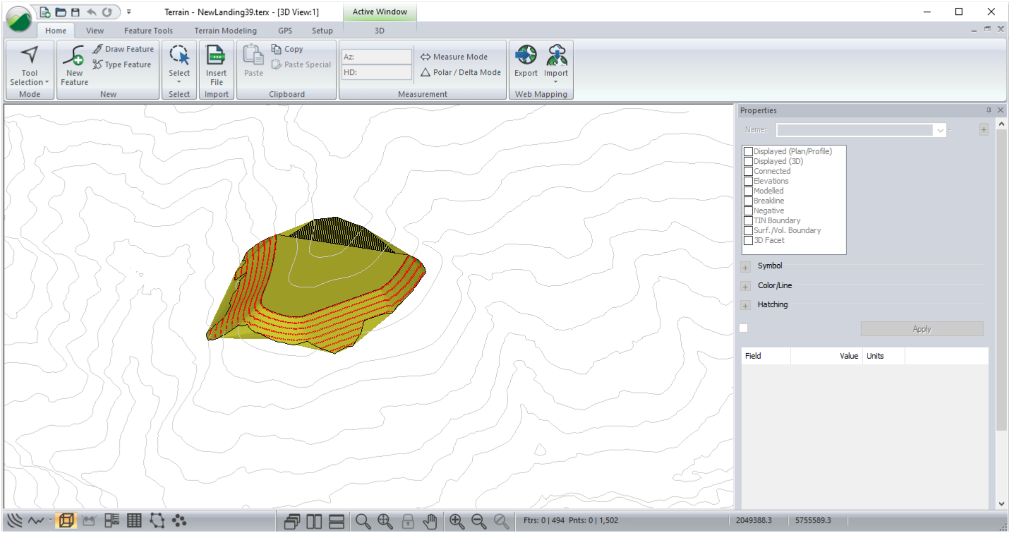


Figure 33. - The final designed landing in the 3D window which was a result of grading the polygon feature that represented the landing edge.

5.0 Results

15 landings across three regions were assessed. The three regions were Hawkes Bay, Tasman, and Gisborne. These landings were chosen based off their suitability for reconstruction which is further explained in the discussion section. The key variables measured included the landing type, surface area, cut and fill volumes for both the as built and newly designed landing as well as the average slope of the terrain the landings were situated on. With these values the average cut depth of each landing was obtained by dividing cut volume through by surface area for both the original landings and the new RoadEng designs. The percentage difference between the average cut depth was also calculated to determine whether the modifications had any effect on reducing the amount of cut volume needed to design a landing of a similar surface area. A smaller average cut depth indicates that less cut material was used to construct any given landing. All the landings assessed in this study presided in terrain greater than 45 degrees which is considered extremely steep in commercial forestry.

The first variable that was measured was the surface area of the as built landing. This was done using RoadEng's built in measurement tool with its area unit being square meters. One of the limitations of RoadEng was that the given units for the area of a polygon used to represent the landing area are only given to one decimal place and are in hectares rather than meters squared. This meant that it was necessary to use the measurement tool when designing the new landing to achieve a high enough level of accuracy. Although this was significantly more accurate even with only slight adjustments to the shape of the polygon to achieve the desired area it was only possible to design it to within a factor of one hundred. Because of this limitation the original surface area of the landing was used as an approximate target rather than an absolute and is the main reason the average cut depth was used rather than comparing earthworks volumes directly. This was important to do because a reduction in the amount of cut material used to construct a landing was not necessarily a better outcome if the resultant landing is significantly smaller as well. In most cases the new landings were designed with slightly larger surface areas than the originals to prevent bias that would favour the new RoadEng designs.

The average surface area of the as built landings was 2,270 m^2 and the average surface area of the newly designed landings was 2,284 m^2. Only 14 m^2 separated these two averages which is less than a 1% difference in area. Figure 34 shows the minor differences between the as built and redesigned landings as well as the relative similarity in area of the landings that made up the sample set.

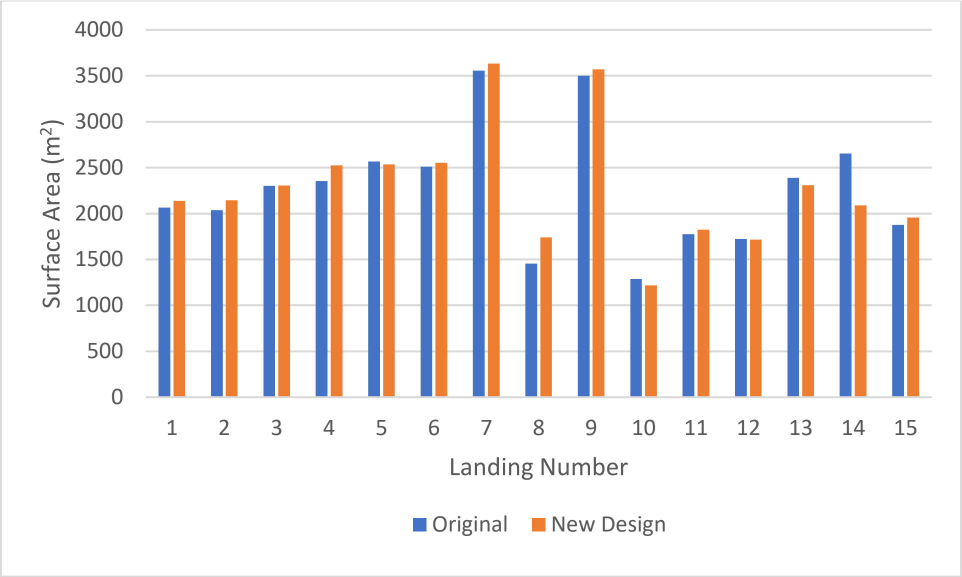


Figure 34. - Surface areas of the original as built landing and their respective re designed counterparts.

By comparison the second key variable that was measured, cut volume, had significant differences not only between as built and redesigned landings but also between the landings themselves which was interesting given the relative similarity of surface area and average slope. The average cut volume of the as built landings was 13,874 m^3 with a standard deviation of 7,221 m^3 and the average cut volume of the new designed landings was 8,853 m^3 with a standard deviation of 5,302 m^3. The difference between the two mean cut volumes was 5,021 m^3. The variability of cut volume within and between landing designs can be seen in Figure 35.

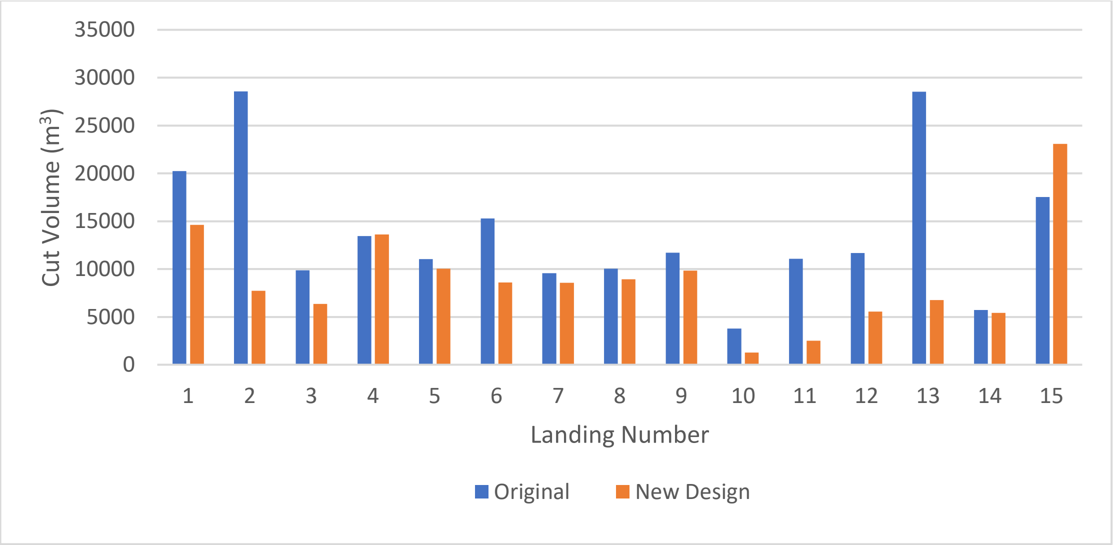


Figure 35. - Cut volume of the original as built landings and their respective redesigned counterparts.

Although these numbers are interesting to look at, they don't necessarily make for a fair comparison because as discussed earlier due to the limitations of RoadEng it was not possible to create a new design with the exact surface area of the original landing therefore it was necessary to divide the cut volume through by the surface area to obtain average cut depth to give an indication whether or not the same landing area using less earth material was achieved. Although this average cut depth makes it possible to compare two landings situated on the same terrain it is not possible to compare between average cut depths that represent landings on different topography's because the value is not isolated from the change in the slope or unique features in the terrain. By isolating earthworks volume from a changing surface area this would allow for a fairer comparison.

Looking at the data in Figure 36 there is clearly a large amount of variation within and between the average cut depths for each landing with some of these values clearly being infeasible. Any landing with and average cut depth greater than 8m was considered infeasible and treated as an outlier along with any redesigned landings that increased the average cut depth. After excluding these outliers, it was found that the average cut depth of the original landings was 4.93 m with a standard deviation of 1.61 m. As for the new RoadEng designs it was found that the average cut depth was 3.14 m with a standard deviation of 1.42 m. The new RoadEng designs had an average cut depth that was 36% less than that of the original landings. The average cut depth for both the original landings and the new RoadEng designs have been plotted in Figure 36 below to visually illustrate the difference expressed by these numbers.

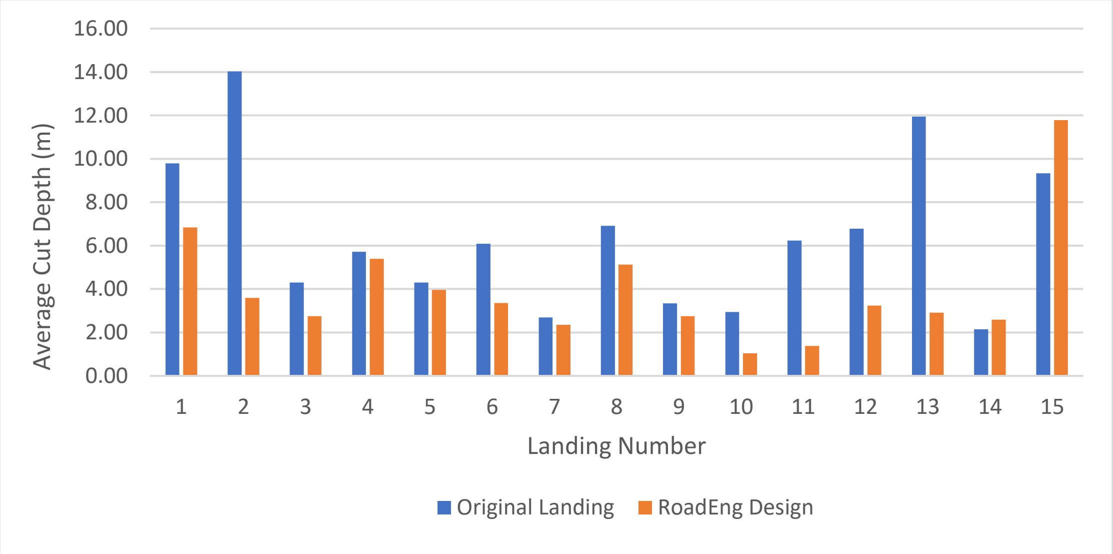


Figure 36. – Average cut depth of the original landings and the new RoadEng designs.

The differences in average cut depth between the original landings and the new RoadEng designs were also expressed as a percentage to highlight where improvements had been gained or lost when redesigning the landings. The average percentage difference between the two sample sets was 35% with a standard deviation of 25%. Out of the feasible cut depths the greatest improvement was a 78% whilst the lowest was 6% which was a range in values of 72%. The two negative outliers where -21% and -26% respectively. These percentage differences in average cut depth have been illustrated in Figure 37 below and the values themselves can be found in the appendices in Tables 2-7.

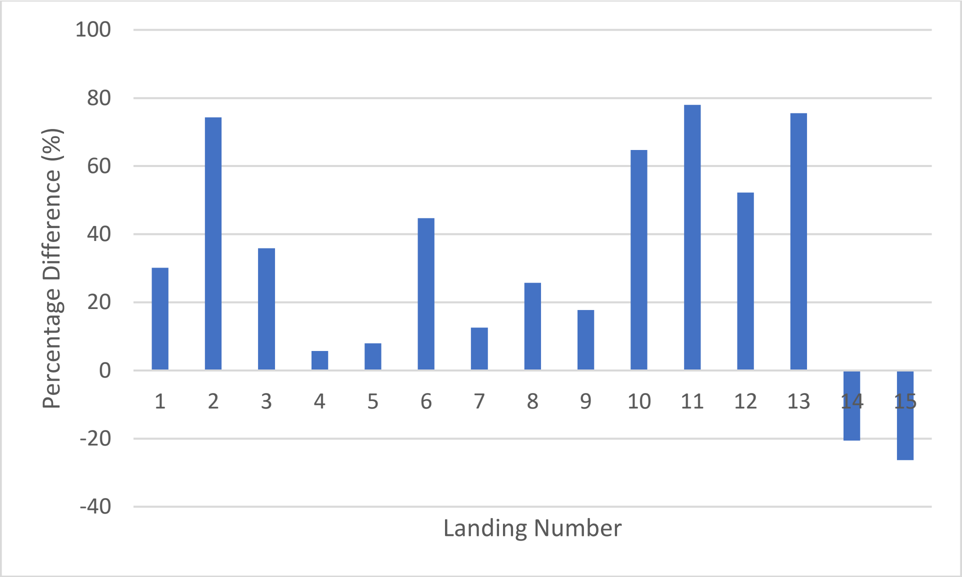


Figure 37. - Percentage differences between the average cut depth of the original landings and the new RoadEng designs.

To test the validity of the data a standard t test was carried out. The critical value was identified to be 2.05 and the t value was calculated as 2.27 showing that a statistical difference existed between the two samples. To illustrate this difference the average cut depths were plotted as a box and whisker graph which can be seen in Figure 38. Both the lower quartile and mean values for the sample of new RoadEng designs where less than the lower quartile of original landings whose mean was significantly less than the lower quartile of the new RoadEng designs. This indicates a significant difference between the two samples.

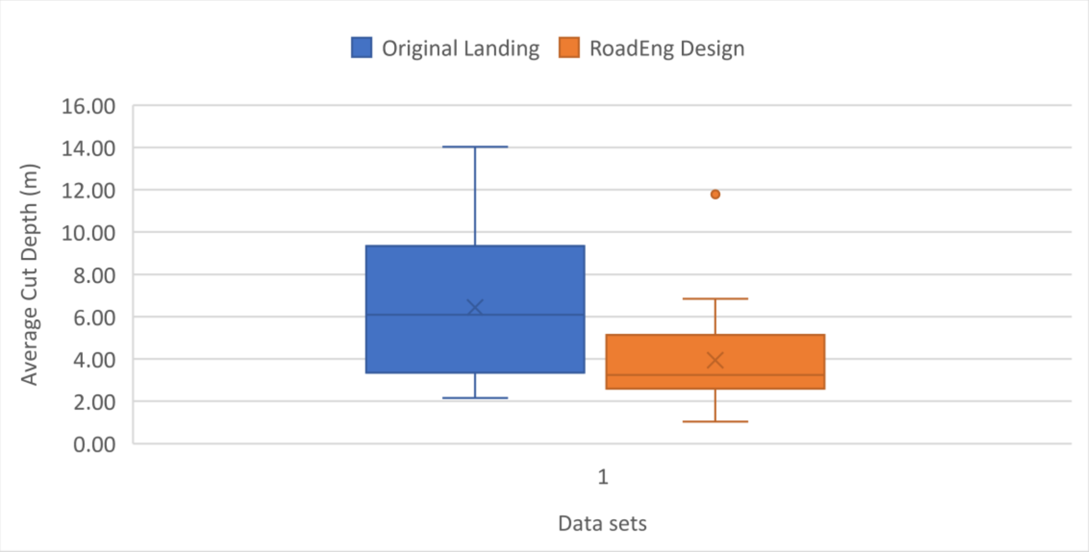


Figure 38. - Box and whisker plot of the average cut depths of the original landings and the new RoadEng designs.

6.0 Discussion

As discussed earlier in this report it was important to use the average cut depth when comparing the new landing designs to the original as built construction due to the limitations of RoadEng's ability to design a new landing to the exact same surface area as the original. This allowed for a fairer comparison of the two designs rather than directly comparing earthworks volumes which are a function of landing surface area. Also, generally where possible the new landing designs were designed with a slightly larger surface area given the choice so as not to create a bias that would be favourable to the new design. This produced some interesting results were in a lot of cases landings designed with a slightly larger surface area were still able to significantly reduce their earthworks volume despite the cut volume being a function of area demonstrating the importance of well-balanced fill material which is a result of a landing that better mirrors the existing terrain.

When analysing the data to determine the driving forces behind the difference in improvement of the average cut depth it was found that modifying the landing edges so as to better conform to the topography was the key factor. Intuitively this makes sense because the greater the difference in elevation between a landing surface and the underlying terrain the more earth material that is needed to build the landing up to a desired elevation. When the edge of a landing follows the contour of the terrain more closely this difference in elevation is significantly smaller and hence less earth material is needed to construct an equivalent landing area. No correlation between the type of ladings and how much the new RoadEng design improved the average cut depth was found.

Although the results from this study where promising, there were several limitations to the methodology that need to be discussed. The first of which was the inability of the method to differentiate between the construction method employed by the contractor using the Digital Surface model alone i.e., end haul vs cut and fill techniques or even secondary benching. This posed an issue when calculating the earthworks balance for the as built landing because as a rule during cut and fill construction these values want to be as close as possible to avoid the extra expense of having to cart surplus material off site. However, given that all the landings in this study had been built on sites with slopes greater than 45 degrees there is a high likelihood that some of these landings will have been constructed using end haul or at least partial end haul methods to minimise the amount of cut material being side cast. The importance this plays in minimising environmental consequences and creating a more robust piece of infrastructure was outlined earlier in the report. It should be noted that this average slope value was a representation of the entire LiDAR tile and not the specific piece of terrain that the landing had been constructed on which may have been a more useful indicator.

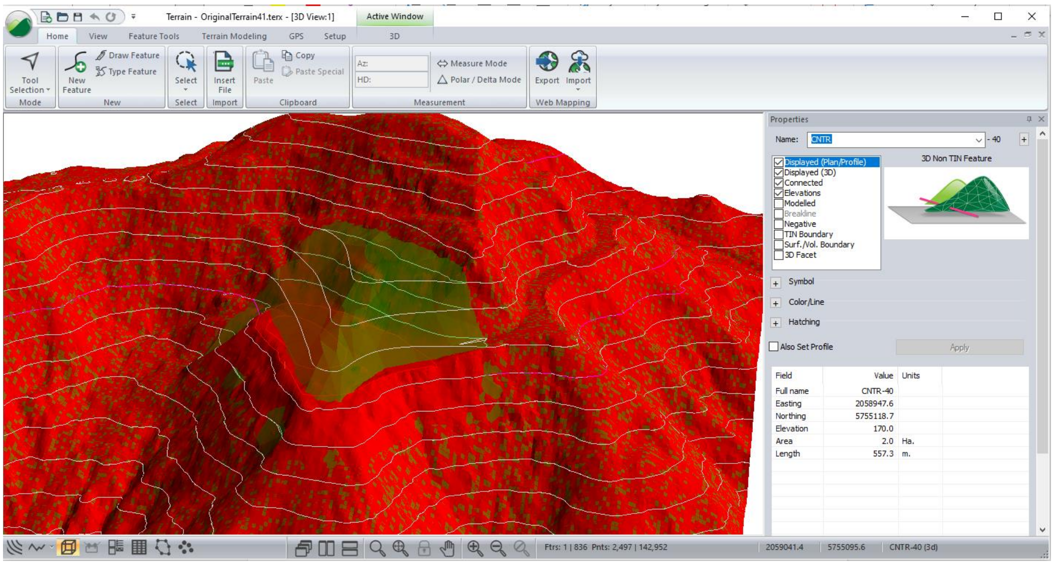
Another possible reason for these disparities is likely to be the harvest residue deposited onto the side of the fill slope in 2nd and 3rd rotation forests which would have skewed the earthworks balance towards having more fill than cut whereas a landing constructed using an end haul approach would have significantly more cut than fill. It was relatively simple to remove any slash piles resting on top of a landing by extrapolating the flat surface underneath the pile. This ensured that there would not be less cut than actuality however, it would be near impossible to remove any slash from the fill slope using LiDAR alone as there is no way of knowing where the slash finishes and the fill material starts. This was an issue because initially when developing the methodology for this study cut to fill balance was identified as a potential way of sense checking the model due to the limited nature of using the contours of the original terrain that surrounded the as built landing before it was removed to interpolate the original surface where there was the potential to miss unique features in the terrain. However, because there was no way of knowing with any certainty that the landing was constructed using cut and fill techniques, this approach was made redundant.

The second key issue that was identified was not only the lack of information around the way in which the landing was constructed, but also the design decisions such as location and two-dimensional geometry that were made and why the contractor/forest manager designed the landing in such a way. Again, inside information such as this was not possible to infer from the Digital Surface (DSM) alone and would need to be a key factor to take into consideration for future studies. This is important because the goal of this study was to achieve the most optimal outcome from a landing which was a fixed surface area for the least amount of cut material possible which meant redesigning landings so that they would follow the natural topography of the slope by using contours to dictate where the edge of a landing would lie. However, this optimal design might not always be able to meet the objectives of an operation as a landing might have been designed to accommodate specific machinery or a certain layout that would allow for better productivity during the log processing stage of an operation. Nevertheless, this still highlights the opportunity to significantly reduce the amount of material needed to construct a landing given the design meets the objects of the overall harvest operation.

The third issue that was identified was that it was only possible to reconstruct certain types of landings that were on very steep and relatively uniform terrain where it was much easier to interpolate the contours to get a more accurate final surface. It was not possible to accurately recreate landings located along the tops of ridgelines or ones that had been constructed on highly ununiform terrain with inconsistent and unique terrain features that could not be reconstructed by simply extrapolating the surrounding contours to interpolate the original 3D surface. Whereas this would not be an issue with two separate LiDAR files containing surface elevation data before and after the construction of the as built landing which could simply be overlaid providing a significantly more accurate cut volume measurement. Also, the shapes of the landings could be a lot more complex and be located on mellower topography and would pose little issue apart from making sure they were lined up correctly.

Acknowledging the limitations of the approach that was used to obtain the metrics for this report there was also several outliers within the data that needed to be examined. The first of these outliers was landing 14 which interestingly produced an average cut depth that was worse than that of the original design at 2.59 m which was a 21% decrease. This scenario highlighted the importance of using the average cut depth rather than directly comparing cut volumes for a given site because at 5314 m^3 the cut volume was 5% less than that of the original as built landing along with the surface area being 21% smaller at 2088 m^2, illustrating that it's not just the amount of cut material that is used to construct a landing that's important, but how it is used. In this scenario the contractor had already constructed a landing that followed the contour of the natural topography well so the shape of the landing in the new design was relatively similar. The predominate modification being made was the elevation of the landing itself which would influence the location of the top of the cut batter. This did not produce a more optimal outcome. This could have come down to the fact that the contractor had in fact build a superior landing or it also could have had something to do with errors in the reconstructed surface.

The issue of accurate reconstruction was especially highlighted when attempting to reconstruct the original surface using the original landing 15. Because the original terrain surface was interpolated by extrapolating the generated contours across the hole created in the 3D model there was the possibility for a unique terrain feature to be missed or misinterpreted which would result in the cut volume being much greater or less than what the value should be. In the case of landing 15, the cut volume was 17513 m^3 and the fill volume was 2434 which was an 86% imbalance in earthworks volume. It could be argued that this was due to the landing being constructed using end haul, however underlaying the as build landing as a background in the 3D window showed that it was more likely a misinterpretation of the actual terrain profile (Figure 39). There was also the possibility that this landing could have been used as a dump site for another landing that was constructed using end haul.



Terrain - OriginalTerrain41.terx - [3D View:1]

Name: CNTR - 40

☑ Displayed (Plan/Profile)
☑ Displayed (3D)
☑ Connected
☑ Elevations
☐ Modelled
☐ Breakline
☐ Negative
☐ TIN Boundary
☐ Surf./Vol. Boundary
☐ 3D Facet

☐ Also Set Profile

Field	Value	Units
Full name	CNTR-40	
Easting	2058947.6	
Northing	5755118.7	
Elevation	170.0	
Area	2.0	Ha.
Length	557.3	m.

Ftrs: 1 | 836 Pnts: 2,497 | 142,952 2059041.4 5755095.6 CNTR-40 (3d)

Figure 39. – The reconstructed terrain surface overlain onto the original landing 15.

Three other outliers existed in the dataset. These where landings 1, 2 and 13. All three of these landings were excluded from the dataset before calculating the average because all three of the existing landings had average cut depths that where greater than 8m. An average cut depth as large as this is clearly infeasible as even constructing landings on soils with a high level of cohesion a cut batter greater than this would have a high risk of failure. Typically, when constructing exceptionally tall cut slopes a contractor will employ a terracing technique to help to stabilize the slope. Examining the DEMs of the original landings it was clear to see that none of the landings had been constructed using this technique, so these exceptionally large average cut depths were infeasible. Again, these errors where likely due to a result of errors in the reconstructed DSM of the original terrain which must have been an over approximation of the actual terrain profile in this situation.

These issues highlighted the need for a future study that would likely strengthen the findings from this report. The best way to carrying out this study would be to obtain DSMs of the actual terrain before and after construction rather than trying to reconstruct the original surface using the DEM of the existing landing. At least one of these layers, the terrain before construction, would need to be collected via airborne LiDAR mounted to an Unmanned Aerial Vehicle (UAV) or drone. The second layer, the terrain after landing construction, could be collected using a cheaper aerial-based photogrammetry approach provided the layer was free of any nearby vegetation which would create noise in the 3D model. Also, it would be important to work closely with the contractor and forest manager involved in the landing construction to gain a better understanding around some of the design decisions being made such as size, shape, and location. Ideally this future study would be carried out in a first rotation forest to ensure that slash deposited onto the side of a fill slope didn't influence earthwork calculations. Also, collecting a larger sample set with a normal distribution to produce a better t test result would be beneficial. The results obtained for this future study could be used to investigate the accuracy of the reconstruction method and compare the two methodologies to determine the validity of the results obtained in this report. Greater similarity in landing surface area would also create a fairer test and would remove the need to compare the different landings using the average cut depth.

7.0 Conclusion

The aim of this study was to establish whether an equivalent landing surface area could have been constructed, moving fewer cubic meters of earth material for a series of case study landings in steep terrain. This was achieved by using RoadEng's Terrain Module to reconstruct the original terrain surface by taking the DEM of the existing landings, cropping out the elevation points that represent the landing in the 3D point cloud and then generating contours which could then be extrapolated across the hole in the 3D model to interpolate a new 3D surface. With the original terrain surface, it was then possible to redesign the landing in RoadEng and finally compare them to the originals using the average cut depth to determine whether a better outcome was achieved in terms of a reduction in earthworks for an equivalent landing area.

It was found that the average cut depth for the original landings was 4.93 m with a standard deviation of 1.61 m. For the new RoadEng designs the average cut depth was 3.14 m with a standard deviation of 1.42. The average cut depth of the new RoadEng designs was 36% less than that of the original landings. This showed that it was in fact possible to design a landing with an equivalent surface area using less earth material. The key factor that influenced this was how well the landing edge followed the contour of the terrain.

Although these results where promising there were several limitations to the methodology that impacted the accuracy of the results. However, despite this a future study would likely only strengthen the findings in this report. This study would want to capture DEMs of the terrain before and after landing construction which would negate the need to reconstruct one layer using another. This could be achieved using UAV based remote sensing and would want to work closely with the harvest planner and or contractor involved to better understand some of the key design decisions being made such as the location and shape of the landing as well as the construction techniques being employed.

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Appendix

Table 2. - Landing data for the as built landings from the Hawkes Bay sample.

	Original Landing				
Landing No.	1	2	3	4	5
Surface Area (m^2)	2065	2037	2300	2353	2567
Cut Volume (m^3)	20225	28581	9879	13453	11035
Av. Cut Depth (m)	9.79	14.03	4.30	5.72	4.30

Table 3. - Landing data for the new designs from the Hawkes Bay sample.

	New Design				
Landing No.	1	2	3	4	5
Surface Area (m^2)	2137	2143	2306	2525	2534
Cut Volume (m^3)	14628	7714	6351	13615	10027
Av. Cut Depth (m)	6.85	3.60	2.75	5.39	3.96
Difference (%)	30	74	36	6	8

Table 4. - Landing data for the as built landings from the Tasman sample.

	Original Landing				
Landing No.	6	7	8	9	10
Surface Area (m^2)	2510	3555	1453	3501	1287
Cut Volume (m^3)	15275	9578	10048	11713	3796
Av. Cut Depth (m)	6.09	2.69	6.92	3.35	2.95

Table 5. - Landing data for the new designs from the Tasman sample.

	New Design				
Landing No.	6	7	8	9	10
Surface Area (m^2)	2554	3632	1739	3571	1217
Cut Volume (m^3)	8589	8554	8927	9825	1265
Av. Cut Depth (m)	3.36	2.36	5.13	2.75	1.04
Difference (%)	45	13	26	18	65

Table 6. - Landing data for the as built landings from the Gisborne sample.

	Original Landing				
Landing No.	11	12	13	14	15
Surface Area (m^2)	1776	1722	2389	2655	1876
Cut Volume (m^3)	11075	11680	28545	5710	17513
Av. Cut Depth (m)	6.24	6.78	11.95	2.15	9.34

Table 7. - Landing data for the new designs from the Gisborne sample.

	New Design				
Landing No.	11	12	13	14	15
Surface Area (m^2)	1824	1716	2310	2088	1958
Cut Volume (m^3)	2505	5561	6741	5413	23085
Av. Cut Depth (m)	1.37	3.24	2.92	2.59	11.79
Difference (%)	78	52	76	-21	-26