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Evaluating different approaches for landing designs in RoadEng

Final year dissertation report for ENFO 410

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Abstract

The aim of the study is to compare and analyse three different approaches to landing design in RoadEng Terrain and Location modules in terms of accuracy of earthwork volume, cut/batter shapes, and pros and cons on different layouts.

Five common types of landing were designed. It was found that the method in Location using override parameter functions that enable the landing as a widened road were found to be most problematic. The method was found to underestimate earthworks volumes and have different cut/batter shapes compared to the other methods.

In Location, it was found the current version cannot provide any interaction between different alignments and misses an important template for the cut and benched construction method. It was also found in the study, neglecting the intersection between different alignments would cause error in shape of the cut and fill batter and earthwork.

It is recommended that users design the landing in Location first using individual alignment as it is easiest method to operate among all three methods and yields similar results to the Terrain method. The shape and elevation of the design should be recorded. Once finished the design, export to Terrain and merge with the original terrain model, then using Terrain module to design landing following the specifications obtained in Location.

It was also suggested to the developer to add graded pad function in Location and add interaction between different alignments. On the other hand, developer should also provide more detailed and accessible instructions for the user, teaching more advanced functions such as customising templates in Location module.

The project also studied one drone surveyed landing with its original design in Kopua Forest in Gisborne provided by Aratu Forests Limited. It was found the built landing was 23% smaller than the design in terms of area. The study found that routine survey using drones may have the potential to improving the quality of infrastructure. The landing was redesigned in the Terrain module according to the actual shape, and was found to have 33.5% difference in terms of earthworks volume. Potential future opportunity could be seen on comparing original LiDAR and resurveyed LiDAR post-construction and drone surveyed point-cloud as a research project.

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1. Introduction

Forest landings are an integral part of modern whole tree harvesting operations. They should be designed to ensure an efficient flow of products and processes. If a landing is not located, designed, or managed adequately, major consequences in terms of environmental, safety, production, etc. can result (FOA, 2020).

Landings are expensive to build. According to Visser (2011), the costs associated with landing construction can range from $4,000 to over $7,000. There is little recent research on landing costs in steep terrain however, consulting with Andy Costello, the harvesting planning manager at Aratu Forests Limited (AFL) in Gisborne area, landing costs in Gisborne region average $14,000 per landing with some cases up to $100,000.

During the construction, landing attributes, particularly in terms of size and shape of the landing can be compromised by many factors such as topographical constraints, road grades, etc., and calculating landing earthworks volume is challenging unless a road engineering design software is used. (FOA, 2020)

With the increasing accuracy and accessibility of LiDAR, Softree RoadEng has started to play an important role in geometric road design and landing design. Conventionally, forest infrastructure needs to be designed by manual surveying using a harvest block projection. Roads are broken down with control points to help to identify road location. Landings will be one of the control points that determine where the roads are located. The infrastructure can be planned more extensively by utilising LiDAR and RoadEng in the office, which gives more information and adds confidence on earthworks volume estimation and geometric infrastructure design.

There are several studies on utilising RoadEng for forest road design. Caliskan (2016) used GIS and RoadEng to determine environmentally sensitive road in a mountainous area. Kurulak (2019) also used RoadEng to minimise forest road cost in Ontario and has received positive feedback. However, publications about performance on landing designs in RoadEng were not found, this study aims to evaluate different potential approaches for landing designs in RoadEng and make recommendations for landing templates in different scenarios.

2. Literature review

2.1 Landings

The forest landing is not a well-defined term. It generally refers to an area designated in a forested area for further processing stems or trees harvested from the forest, storing them, and then loading them out for transportation. (Stokes et al., 1989). Landings should be designed to ensure an efficient flow of products and processes. (Sinclair and Wellburn, 1984). Landings can result in major consequences for safety, environment, production, quality, and value recovery, if not located, designed, or managed adequately. (New Zealand Forest Owners Association Incorporated, 2020)

For landings, the typical specification is 40 x 60 m or 40 x 80 m, but on sloped terrain the shape is determined by the least amount of excavation required to attain the desired area. Landings can be categorised into four types: (Visser et al., 2010)

1) Pad: A pad is a small landing used in a two-stage operation to transfer stems or trees from one extraction machine to another.
2) Skid: The most common landing type is a skid, typically serving one harvesting crew and accommodating all processing, storage, and loading functions.
3) Super-Skid: Super skids are processing areas that service several smaller pads to concentrate log making, cross-cutting, sorting, and loading activities. Stems can be provided by multiple crews over a larger forest area, and they will be forwarded by a two-stage machine to the super-skid off-road.
4) Central Processing Yard (CPY): CPY is the largest landing type. Stems are transported by off-road or on-road tracks. They are usually located near a mill, port, or railway head. They are also characterised by more automated processing capabilities and are relatively rare in New Zealand.

A typical layout of landing function and layout is shown in Figure 1 (Oregon OSHA, 1935).

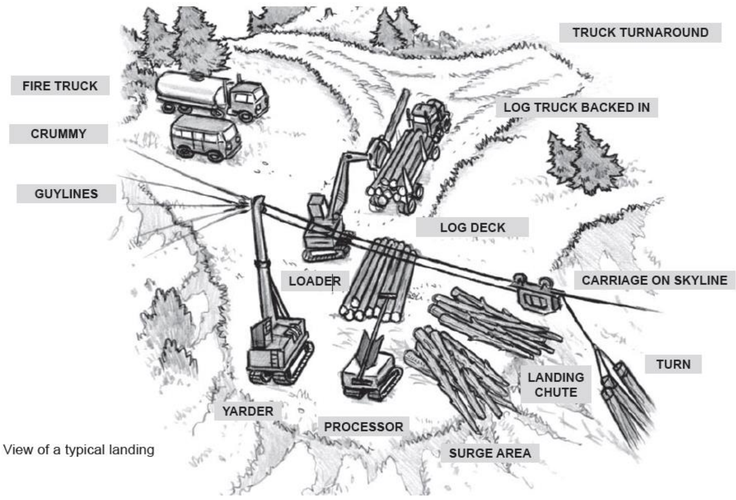


Figure 1 – Example of a typical landing defined in New Zealand (Oregon OSHA, 1935)

2.2 Landing Construction

According to FOA (2020) the same planning considerations that apply to road construction can be applied to landings. The following are some of the considerations that are unique to landings and should be considered when designing a landing layout:

- Topographical constraints, such as terrain steepness, geology, and soils may limit the scale, shape, and number of access points.
- Planning the landing and road site so that the road's adverse grade off the landing is less than 6% in the first 30 meters. If it does, then truck egress is considered in road construction and pavement. Create a favourable grade that is less than 12%.
- Environmental restrictions, such as water management, slash disposal, and diesel storage.
- The types of equipment that will be used on the landing.
- Specifications for the processing area.
- General log stacking and sorting criteria, such as the number and size of log stacks
- Tree length.
- Loading out location and truck access
- Machinery production and likely bottleneck location
- Crew requirements including parking, storage container, smoko hut.

The selection of the final landing location may be the result of a compromise between the factors listed above.

According to Sinclair & Wellburn (1984), the conventional landing design would be carried out in following steps:

- Site survey

- Additional survey
- Soil sampling
- Surface drainage
- Drainage structures
- Engineering plans
- Balancing elevations in final plans

Calculating landing earthworks is challenging unless road engineering design software is used. (FOA, 2020).

According to FOA (2020), there are four types of construction methods when constructing forest roads and landings.

- Cut and side-cast (Figure 2)

The simplest and lowest cost method, the fill cut from the hillside is pushed to the other side (side cast). It is only suitable for flat to rolling terrain and where there is no risk of sediment entering a water body.

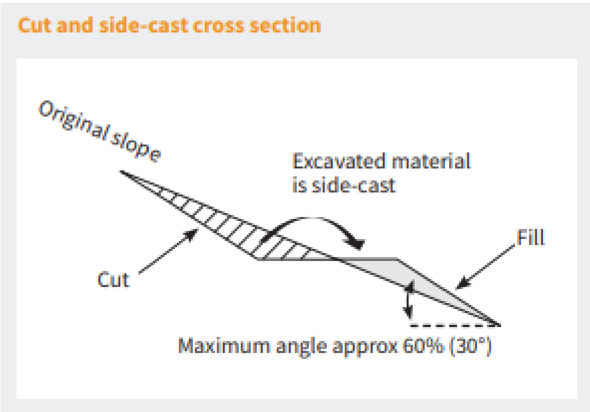


Figure 2 – Cut and side-cast method (FOA, 2020)

- Cut and benched fill (Figure 3)

A common method when constructing in steep terrain, where the fill cannot be retained on the original ground. Benches should be cut into the original ground profile to retain the fill

The efficiency of a harvesting operation is often very dependent on the configuration of the landing site. On average, landings are rectangular and twice as long as wide, but landings for cable yarding operations are approximately 2.5 times as long as wide.

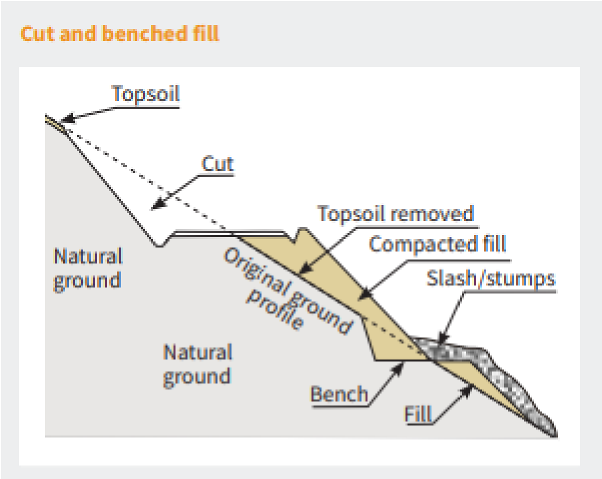


Figure 3 – Cut and benched fill method (FOA, 2020)

- Partial cut and benched fill and end haul

On steep slopes where some of the material needs to be cart away

- Full bench (Figure 4)

The road was built completely on a benched cut into the hill, all material needs to be end-hauled.

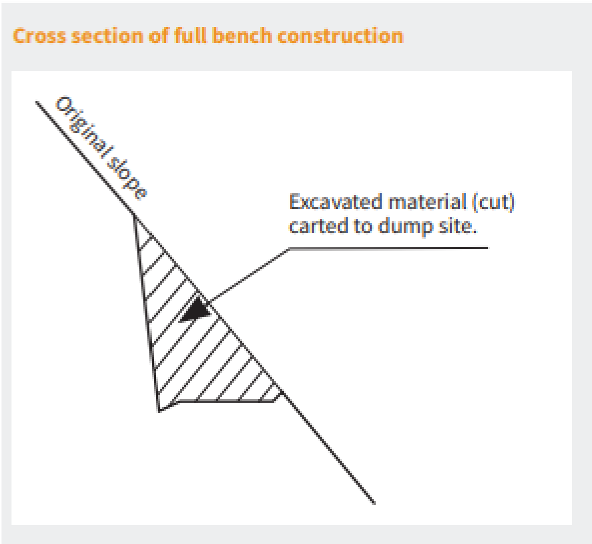


Figure 4 – Full bench method (FOA, 2020)

Design the landing shape to safely optimise the flow of logs through the work area, given the landform and other construction constraints. In many situations, the physical construction of the ideal landing is limited by site topography constraints. Therefore, the design of landings requires close liaison between the harvest planner, operations coordinators, and the logging and roading contractors.

Many serious work accidents and fatalities have been on landings. Some of these have been due to poor landing design and layout. The planner must understand their health and safety obligations when designing landings under the Approved Code of Practice for Safety and Health in Forest Operations (ACoP) and the Health and Safety at Work Act 2015 (HSWA). Also, some forest company's health and safety manuals may have specific requirements too. WorkSafe requires that all landings shall be planned and constructed to allow safe operations to allow for:

- Stems, stockpiles, and log stacks
- Safe areas
- Vehicle parking
- Fuel and chemical storage
- Load-out areas
- Truck turnaround.

Visser et al. (2011) measured 142 landings in 2009 yielding a mean landing size of 3868m^2 was obtained. A regression equation for landing size estimation was developed based on the data:

$$Landing\ size\ (m^2)\ =\ 390\ + 560\ *\ landing\ Age\ + 173 *\ log\ sort\ + 3.5 *\ Daily\ Prod$$

Where, landing Age = 0 when new; =1 when in use; and = 2 when complete

Log Sort = number of log sorts processed (n)

Daily Prod = estimated average daily production (tonnes/day).

Landings can also be categorised into different types based on different layouts. (FOA, 2020)

- Drive-through landing (Figure 5)
  A loop road is used in drive-through landings to allow vehicles to enter from one end, proceed through the centre of the landing, and exit from the opposite end. This decreases the amount of space needed for truck turning circles. The truck may be loaded from either side of the road since logs can be placed on both sides of the road. (FOA, 2020)

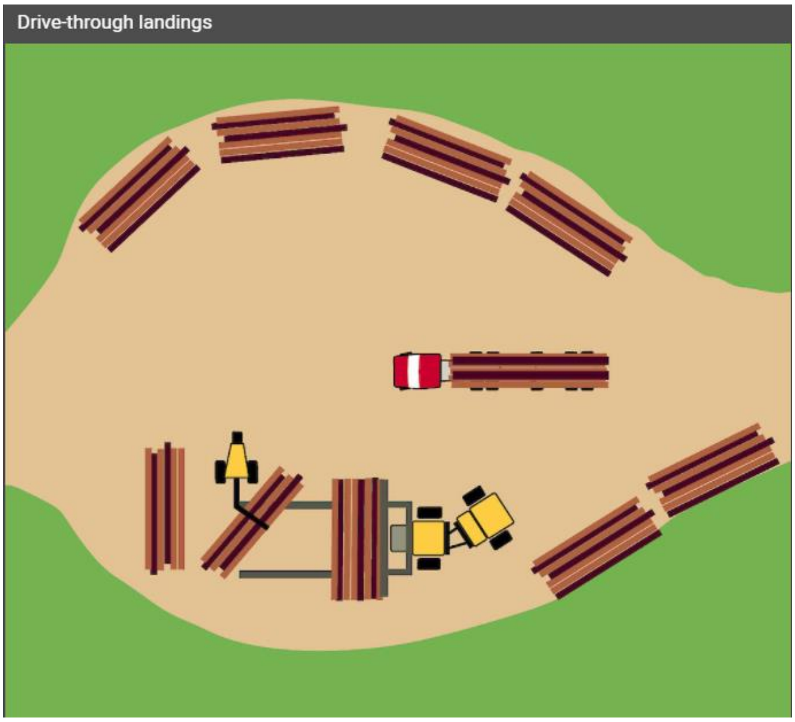


Figure 5 – Drive through landing (FOA, 2020)

- Roadside landing

  Roadside landings are similar to drive-through landings. But they are positioned to one side of the road only. (FOA, 2020)
- Road end landing (Figure 6)

  Road end landings are positioned at the end of the road. To offer turning room for trucks, landings are often constructed larger. This takes up space that might be utilised for log stacks or processing instead. Alternatively, log trucks can reverse into the landing by turning at a nearby wider road stretch or at a road junction when space is limited. (FOA, 2020)

Spur road landing

Figure 6 – Spur road landing (FOA, 2020)

- Split-level landing (Figure 7)

  In steep terrain, split-level landings are a viable option. The yarder is located on the upper level, while the landing and processing area is located on the lower level. Split-level landings have the benefit of requiring less earthworks and having shorter batter slopes. This has a reduced visual effect and building cost, and it may also provide better deflection for the yarder. (FOA, 2020)

Split-level landing with stems two-staged back to a processing site

Figure 7 – Split-level landing (FOA, 2020)

- Two-stage operations (Figure 8)

  Two-stage operations use two (or more) landings. One is for landing logs, while the other is for processing, stacking, and loading out. In mountainous areas where a typically sized skid is difficult to build, two-stage landings have become common. Dephasing an operation usually results in a safer work environment, less environmental impact, cheaper construction costs, and increased productivity. (FOA, 2020)

Figure 8 – Split-level landing (FOA, 2020)

2.2 RoadEng

RoadEng is a forest engineering software program developed by Softree that includes four modules (Softree, 2021). The Survey module allows you to input field road notes. Once the road notes are entered, a surface can be created and georeferenced. The geometric design of the road can be done with the surface in module three, Location. In the second module (Terrain) a Triangular Irregular Network (TIN) can be created from point cloud or raster datasets. For developing computer-generated models, LiDAR data files (LAS) is a good choice because the numbers of points from the LiDAR data can be reduced to improve the module's speed. Softree Terrain can create a full model of an area with contours, or a road corridor if the road is already defined in Survey. Using LiDAR data, RoadEng can identify earthwork, or cut and fill with material, along the roadway. By understanding the earthwork of the area, the number of cuts and fills needed to achieve the desired road specifications can be minimised. (FOA 2020).

Location is the third module that is capable of creating a road design by creating cross-sections. Location determines the horizontal and vertical alignment of roads.

Softree Optimal is the fourth module of RoadEng and is an extension in the Location module. Optimal allows you to create road parameters, such as the cost of the cut and fill sections and generates the most cost-effective alignment RoadEng can measure the variables include total m^3 of cut and fills, cost of the road cut, fill, and haul materials, mass haul from vertical alignment by free haul, overhaul, and end haul (m^3), material stripped (m^3), etc. (Softree, 2021).

There are studies on utilising RoadEng for road design, including designing forest roads in mountainous terrain. In 2002, Hearalt used the RoadEng system to design an optimum forest road variant aimed at the minimisation of negative impacts on the natural environment. Caliskan (2016) used GIS and RoadEng to design an environmentally sensitive road in mountainous area. Kurulak (2019) also used RoadEng to minimize forest road cost in Ontario and has all received positive feedback. The results have shown that RoadEng is helpful for earthwork volume prediction and geometric road design. However, publications about performance on landing designs in RoadEng were not found, the study is aimed to evaluate different potential approaches for landing designs in RoadEng and make recommendations on set up landing templates in different scenarios.

2.3 Photogrammetry and UAV

The unmanned aerial vehicle (UAV), also known as a 'drone', has become popular for commercial and civilian use. They are precision-equipped aircraft that can be controlled remotely. Inertial motion units and gyroscopes are used to identify the aircraft's alignment and location, allowing the pilot to monitor the navigation without having to do much manual work. In addition, a UAV system's location in a global reference system can be maintained in real-time using accurate and low-cost GPS. (Siebert & Teizer, 2014). Digital cameras can turn UAV systems into highly mobile sensor platforms, the application and efficiency of the UAV are improved even further. UAV systems usually consist of UAVs and ground equipment for planning and transferring flight routes to the UAV, as well as monitoring telemetry data from the UAV. In recent years, UAVs have been used for a range of purposes, including photogrammetry for 3D modelling (Colomina & Molina, 2014), remote sensing and mapping (Nex & Remondino, 2014), forest and agricultural applications (Saari et al., 2011; Rango et al., 2006.), and many other fields. Siebert and Teizer (2014) tested a UAV system that was designed to collect mobile 3D mapping data quickly and autonomously. They also created a performance model for estimating location errors in a variety of real-world construction scenarios. Hudzietz and Saripalli (2011) demonstrated that UAV-based structure-from-motion mapping is a viable choice for large-scale, high-resolution terrain modelling. Aerial maps of the landscape can then be reconstructed into three-dimensional terrain models. This feature means that a UAV-based platform for photo collection in large-scale terrain modelling is economic, efficient, and accurate. All of the successful applications are economic, efficient, safe, and easy to operate when images are being collected. Wang et al. (2018) have published a study on estimating earthwork volumes using the technology, based on the results of an accuracy test and the reliability of the survey, the project addresses the feasibility and effectiveness of using UAS systems and UAVs in estimating earthwork volumes, and the results had shown that the systems can achieve high accuracy with low cost and time consumption.

3. Objective

The aim of the study is to compare and analyse three different approaches for landing design in RoadEng in terms of accuracy of earthwork volume, cut/batter shapes, and pros and cons on different layouts. Finally, a recommendation on procedures of landing designs based on different scenarios will be given.

4. Methodology

This study will use three different approaches given by the two official tutorials produced by Softree (2020, 2019), UC RoadEng tutorial (Harvey, 2020) and AFL. The designs will be using the open source LiDAR data available from open source geoinformation websites (LINZ, Open Topography). The study location was located in one of AFL's plantation forests, Okiwa Forest in Gisborne, North Island, New Zealand.

The three approaches will be used to design different landing layouts:

- Drive-through landing
- Roadside landing (similar to drive-through landings)
- Spur road end landing
- Split-level landing
- Two stage operations (a large landing connects to a smaller one with skidder track)

The study aims to produce an evaluation on the pros and cons on the performance of different design approaches for different landing layouts. Finally, a recommendation on systematic procedure and methods on landing designs in RoadEng will be given based on the study.

The shape, location and elevation of the landing would be controlled by using the same shapefile in the background. In both Location module methods, advanced functions such as ditches and benching would be turned off to minimise the factor affecting results as in the Terrain module slope of cut and fill batter were both adjustable parameters. Slope for cut batter would be set as 300% and slope for fill batter would be set as 60% as the landing was only on 'paper', the consideration for soil could be excluded.

Approach 1: Override parameter method (Softree, 2021)

This method utilises the parameter overrides function that is built in RoadEng Location. In the example figure below, the landing was produced by overriding the left/right width parameters. In this approach, Templates contain parameters. These parameters control the geometry of the template such as sub-grade width, ditch depth, slope angles etc. It is possible to change these parameters individually at specific stations along the template thus reducing the number of different templates required.

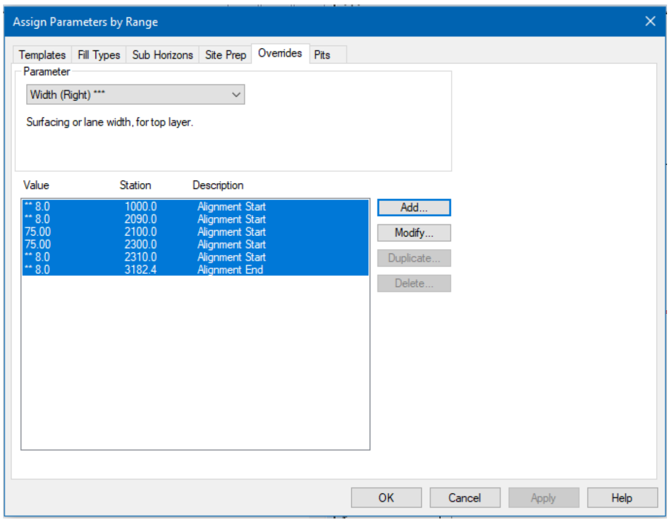


Figure 9 – Overriding parameter window (Softree, 2021)

This method is a utilisation of template parameter overrides. The road width will be set at several stations. In between the stations, the width will be interpolated.

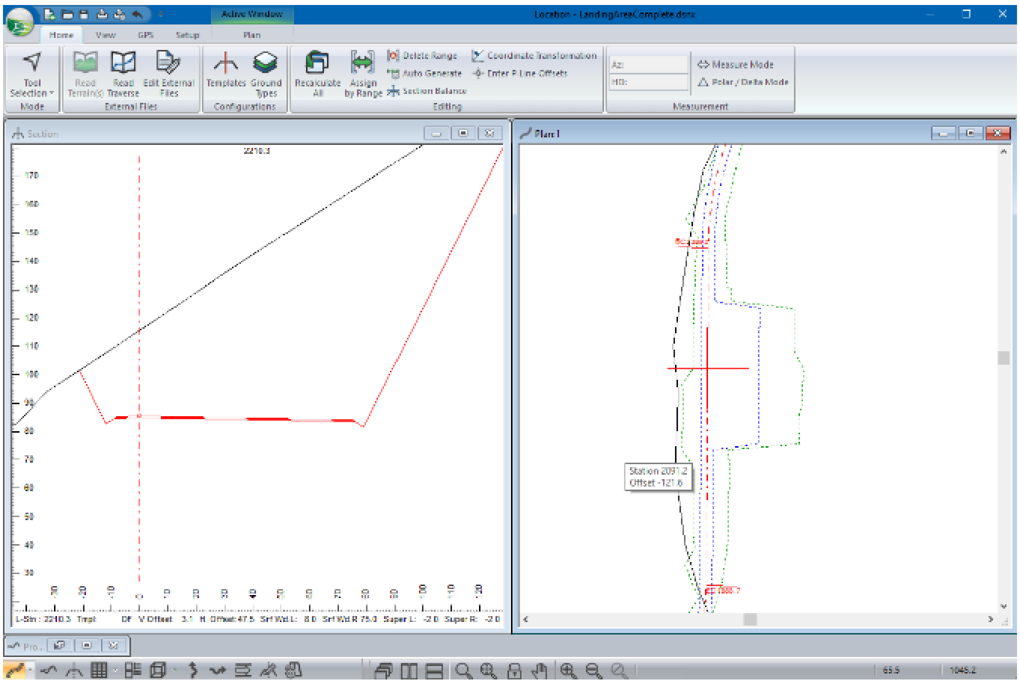


Figure 10 – landing plan view (Softree, 2021)

Approach 2: Terrain method

The method was illustrated and learnt from UC RoadEng tutorial (Campbell, 2021) and Terrain Tools tutorial (Softree, 2019)

The alternative technique for designing a landing requires a good knowledge of where the landing needs to be located, prior to road design. The landing feature was created and merged into the original terrain before the file is passed over to RoadEng9 Location.

This method is done by creating a polygon feature at the desired elevation level.

Figure 11 – landing polygon feature (Campbell & Reidinger, 2021)

After the shape is decided, in the terrain modelling function, the cut and fill batter slope could be set, and an example end product is shown below:

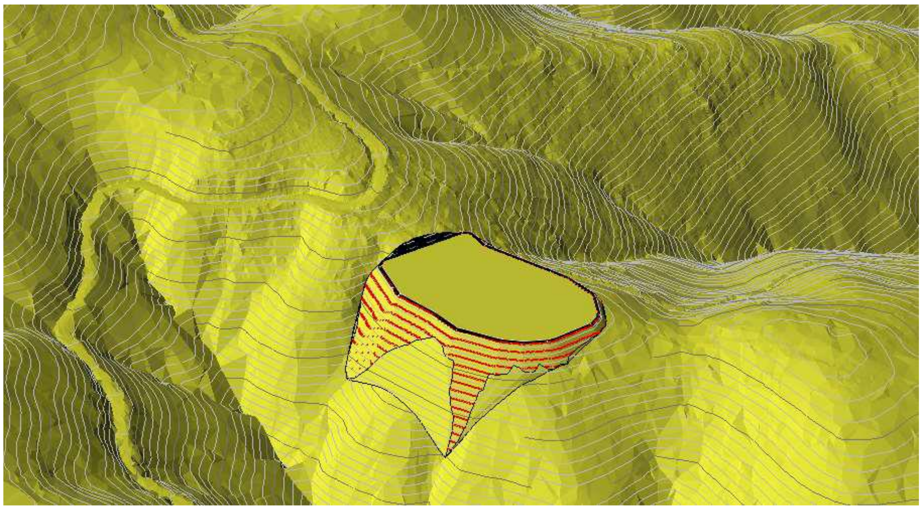


Figure 12 – landing example in terrain (Campbell & Reidinger, 2021)

In the Terrain module, small strips of road or skidder tracks would be also imported to the terrain module, and be merged with original terrain file to examine the influence of intersections between road and landing.

Approach 3: Independent alignment method

This approach was created by Andy Costello of AFL. The method is similar to the first approach which is using the override function to change the road parameters. The difference is that this method created two separate templates for landing edge profile and landing centre profile. The landing edge shows the amount of earthwork and shape of the landing edge. The landing centre profile shows the earthwork on levelling and achieve the desired area of the landing.

Elements needed for the templates is shown in Figure 9

Figure 13 – Centre template (left) Edge template (Right)

In edge template, the width was set to be zero to ensure

An example of landing edge profile is shown in the figures:

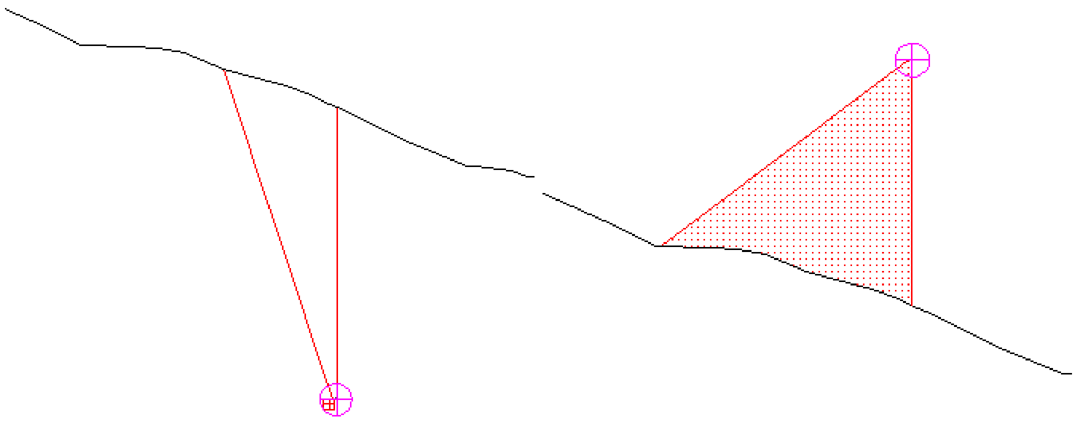


Figure 14 – cut and fill batter of landing edge template layout

A finished landing edge and centre alignments are shown in the figure:

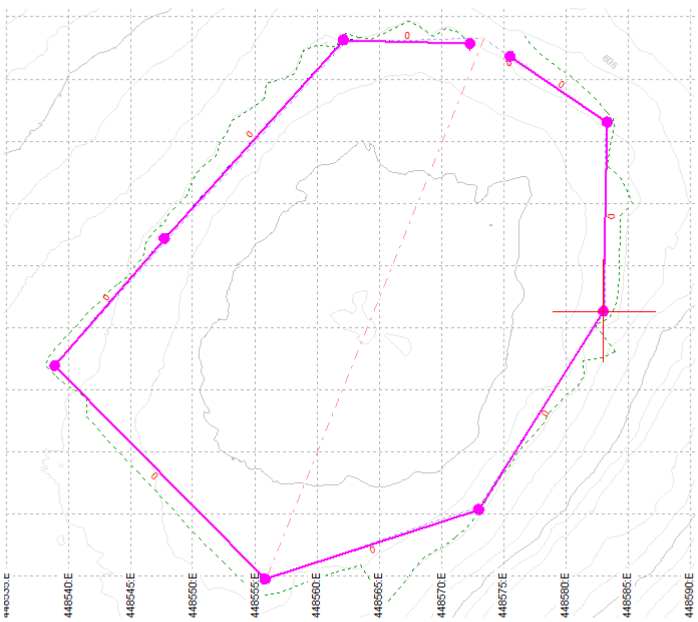


Figure 15 – Skid edge plan view example

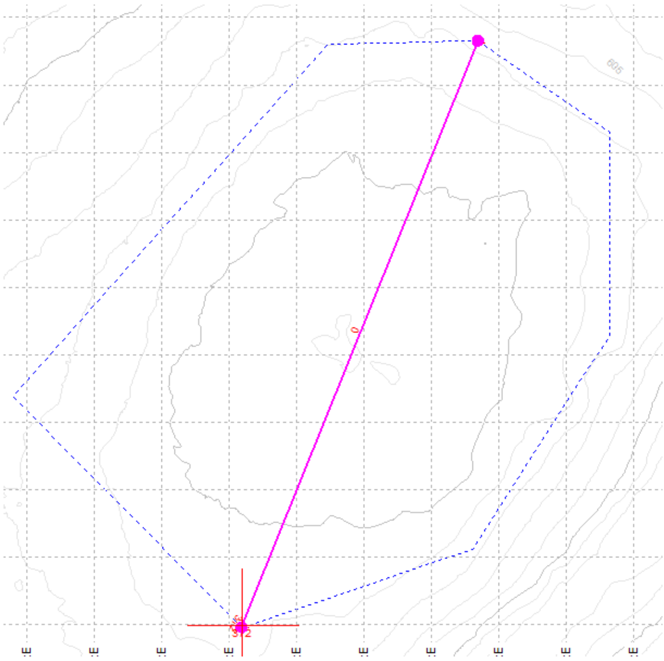


Figure 16 – Skid centre plan view example

Drone surveyed DSM

Although within the scope of the study, the comparison of the three methods disregards the accuracy and constructability of the design in real life due to lack of data of RoadEng-based landing construction. However, the accuracy of the estimation from RoadEng is the vital part to test if the software is trustworthy. So, in this report, the potential method for comparing the designed landing and constructed landing using the design in real life is given.

The comparison can be potentially done by two types of data. One is the re-surveyed aerial LiDAR data after the landing is built, which would be the most ideal and accurate method to undertake the comparison. However, the time span between two aerial surveys can be quite long and the cost of flight survey can be expensive. The second method is to utilise UAV photogrammetry, producing a digital surface model of the landing, which would be the main focus of this part as it has been proven to be an accurate and economically viable option. This part will be using a similar method that was carried out by Wang et, al (2017) and O'Driscoll (2018).

Step 1: Capturing a georeferenced image

A UAV can be used to perform the photogrammetric data acquisition with equipped digital camera. One of the landing construction in Kopua Forest (part of the AFL estate) was surveyed using a DJI Mavic Pro 2. 105 photos were taken and was input into DroneDeploy to produce a photogrammetry-based point cloud. With the help of image-processing photogrammetry software such as Pix4D or DroneDeploy, 3D results such as Digital Surface Model (DSM), Digital Terrain Model (DTM) and point cloud can be produced in an automated way. An example flight path is shown in the figure below.

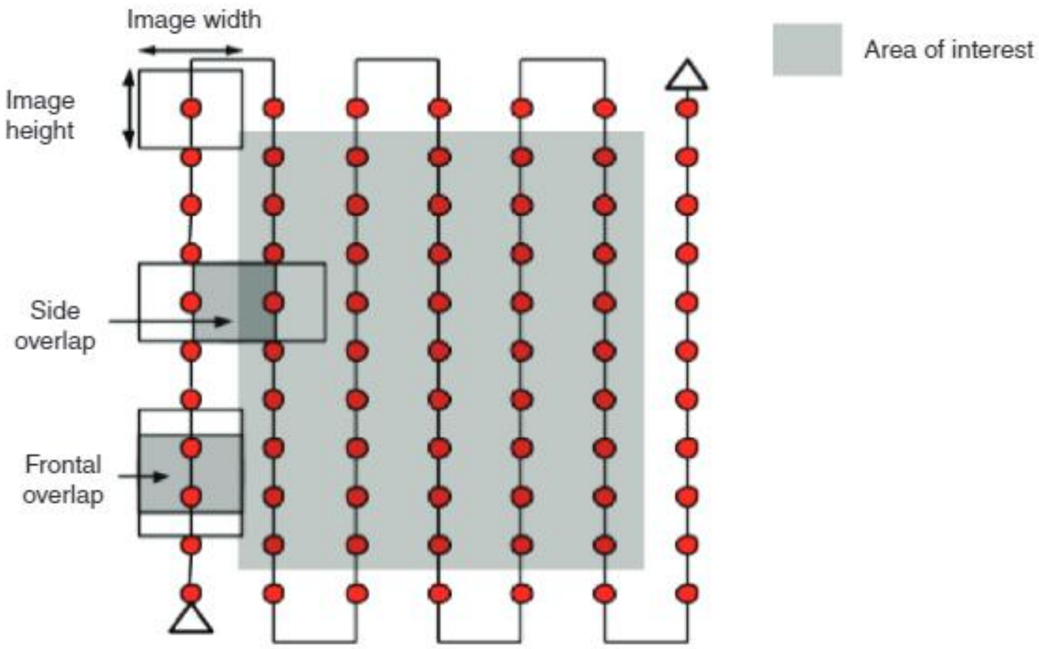


FIGURE 1 Grid mission image acquisition plan (14).

Figure 17 - Drone flying path example (Wang et al., 2017)

Step 2: Earthwork volume calculation in ArcGIS

A digital surface model can be produced using the spatial analysis tools in ArcGIS.

The earthwork volume will be estimated by comparing with district data.

Spatial resolution depends on ground sampling distance, which is the distance between two consecutive pixel centres measured on the ground. So, the volume could be estimated by using the formula:

$$V = L * W * (H1 - H2)$$

Where,

L=GSD=length of cell,

W=GSD=width of cell,

H1=terrain altitude of each cell at centre of cell, and

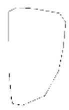
H2= base altitude of each cell at centre of cell.

5. Results and Discussion

Landings built

Five different types of landing were designed using the three different design methods in both RoadEng Location and Terrain modules. The location of the design landing was suggested by AFL according to the current harvest plan in one of AFL's mature forests in the Gisborne region. The shape and size of the landings were controlled by referencing a shared shapefile in the background. The specification of the landings can be found in Table 1. In this section, method 1, 2 and 3 will be referred to the 'Override parameter method', 'Terrain method' and 'Independent alignment method' respectively.

Table 1 – Specification of landings created

Landing type	Shape	Elevation (m)	Size (m^2)
Drive-through		458.0	3442
Road-End		532.5	3008
Road-side		477.5	3031
Split-level upper landing		466.0	332
Split-level lower landing		455.5	1735
Two-staging upper landing		542.0	3203
Two-staging lower landing		520.0	671

Drive-through landing

The drive-through landing was designed at an elevation of 458m and an area of 3442m^2. An example 3D view of the landing from method 2 (Terrain method) is shown in Figure 19.

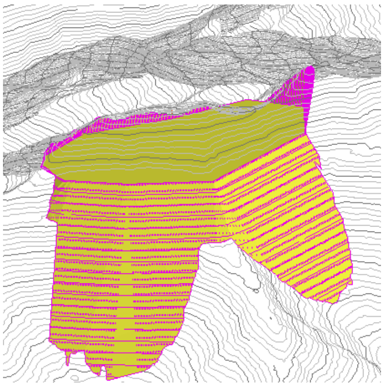


Figure 19 – Example 3D view of a drive-through landing

The plan views of the landing from the three methods are shown in Figure 20.

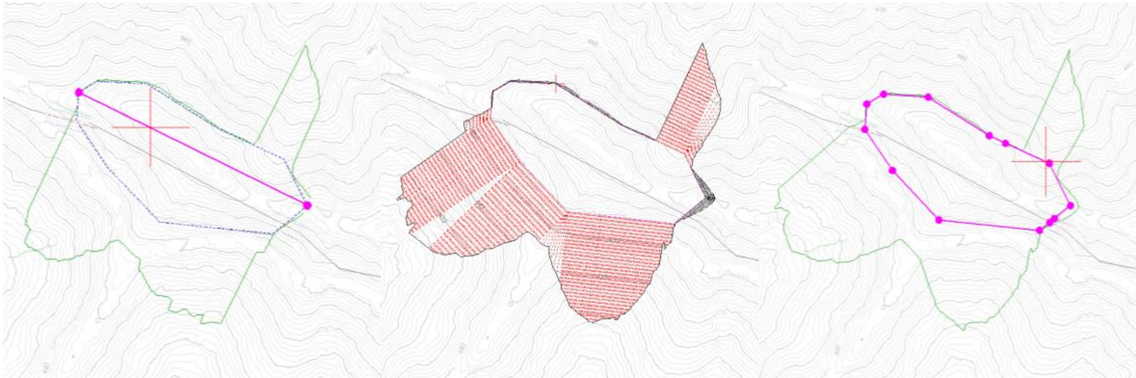


Figure 20 – Plan views of the drive-through landing (left: approach 1; middle: approach 2; right: approach 3)

The small portion of the fill batter on the top of the landing was caused by a sudden change of slope which makes that particular part of the landing level higher than the original ground-level, and the rest lower than the ground-level. As the RoadEng is calculating the parameters and templates perpendicularly to the alignment, the fill batter shape would form a straight line at the point that the landing changes from fill into cut.

Table 2 shows the earthwork estimation for different methods. Method 3 has three estimation because the landing edge and centre are two separate alignments. Override parameter method (Method 1) had the most different estimation compared to the other two methods.

Table 2 – Earthworks specification for drive-through landing

Method	Cut Vol. (m^3)	Fill Vol. (m^3)	Total earthwork volume (m^3)	Waste/Borrow (m^3)
Method 1	15100	13000	28100	2100
Method 2	15200	17600	32800	-2400
Method 3 (edge)	300	15400	15700	-15100
Method 3 (centre)	14600	1900	16500	12700
Method 3 (combined)	14900	17400	32300	-2400

Road end landing

The road-end landing was designed at an elevation of 532.5m and an area of 3008m^2. An example 3D view of the landing from Method 2 (Terrain method) is shown in Figure 21.

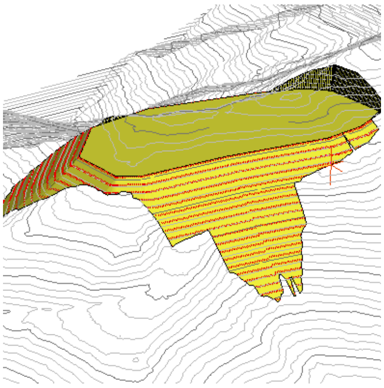


Figure 21 - Example 3D view of a road end landing

The plan views of the landing from three methods are shown in Figure 22. In the figure, it can be found that the override parameter method (Method 1) does not show the cut and fill batter at the start and the end of the alignment.

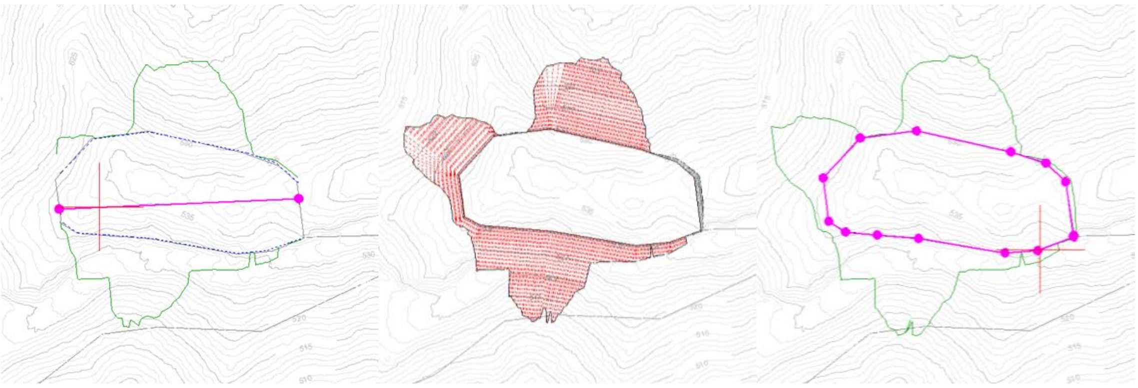


Figure 22 - Plan views of the road end landing (left: Method 1; middle: Method 2; right: Method 3)

Table 3 shows the earthwork estimation for different methods. Override parameter method (Method 1) had the most different estimation compared to the other two methods.

Table 3 - Earthwork specification for road end landing

Method	Cut Vol. (m^3)	Fill Vol. (m^3)	Total earthwork volume (m^3)	Waste/Borrow (m^3)
Method 1	5900	6200	12100	-300
Method 2	6100	7500	13600	-1400
Method 3 (edge)	100	5900	6000	-5800
Method 3 (Centre)	5900	1300	7200	4600
Method 3 (Combined)	6000	7200	13200	-1200

Road side landing

The road side landing was designed at an elevation of 477.5m and an area of $3031\mathrm{m}^2$. An example 3D view of the landing from method 2 (terrain method) is shown in Figure 23.

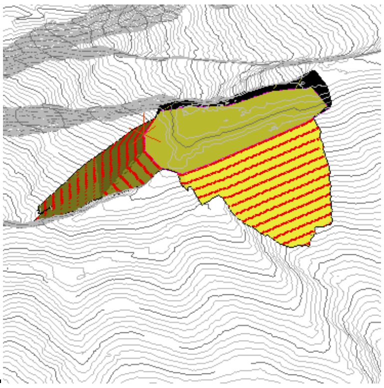


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Figure 23 - Example 3D view of a road side landing

The plan views of the landing from three methods are shown in Figure 22. In the figure, it can be found that the override parameter method (Method 1) does not show the cut and fill batter at the start and the end of the alignment which is similar to the road end landing results.

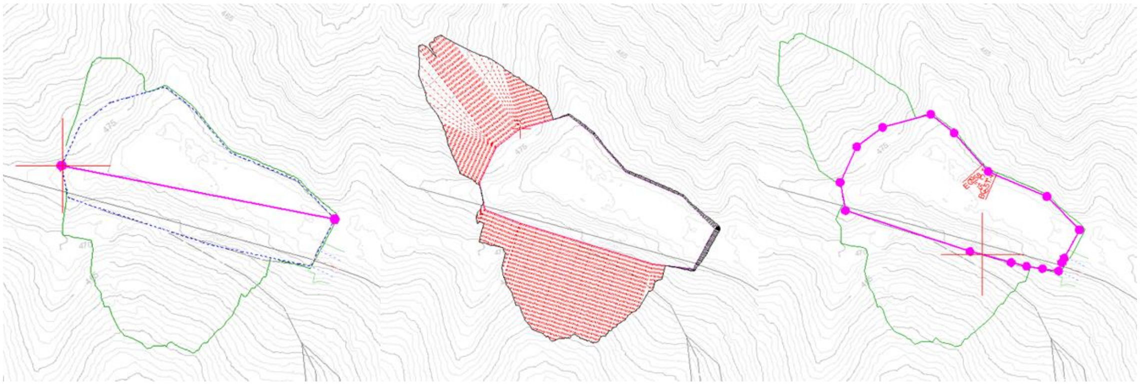


Figure 24 - Plan views of the road side landing (left: Method 1; middle: Method 2; right: Method 3)

Table 4 shows the earthworks estimation for different methods. Override parameter method (Method 1) had the most different estimation compared to the other two methods, which is similar to other landing results.

Table 4 - Earthwork specification for road side landing

Method	Cut Vol. (m^3)	Fill Vol. (m^3)	Total earthwork volume (m^3)	Waste/Borrow (m^3)
Method 1	8100	7000	15100	1100
Method 2	8200	9600	17800	-1400
Method 3 (edge)	200	7600	7800	-7400
Method 3 (centre)	8000	1600	9600	6400
Method 3 (Combined)	8200	9200	17400	-1200

Split-level landing

The split-level landing was designed into two separate part. The upper part was designed as a yarder pad with an elevation of 466m and an area of $332\mathrm{m}^2$. The lower part was designed as a processing and loading area with an elevation of 455.5m and an area of $1735m^2$. An example 3D view of the landing from Method 2 (Terrain method) is shown in Figure 25.

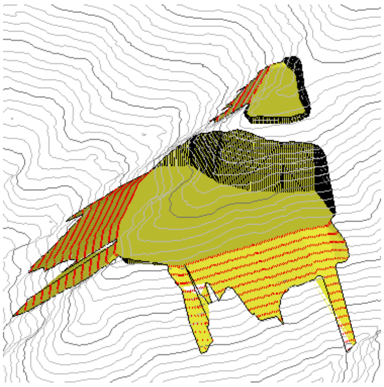


Figure 25 - Example 3D view of a split-level landing

The plan views of the landing from three methods are shown in Figure 26, 27 and 28. In the figure, it can be found that the override parameter method (Method 1) does not show the cut and fill batter at the start and the end of the alignment which is similar to the road end landing results. It can be also found in both Figure 27 and Figure 28 that the fill batter shape from override parameter method (Method 1) was also different from the other two methods.

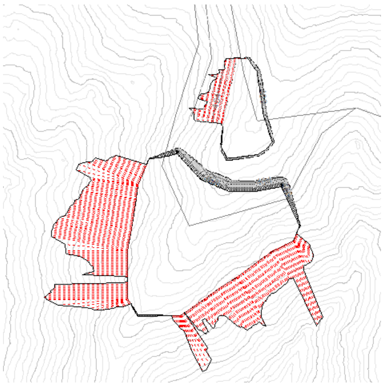


Figure 26 – Plan view of the Split-level landing (Method 2)

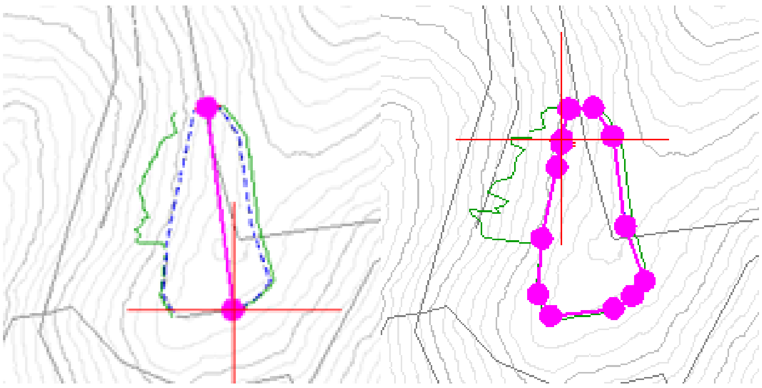


Figure 27 – Plan view of the upper pad of the split-level landing (left: Method 1; right: Method 3)

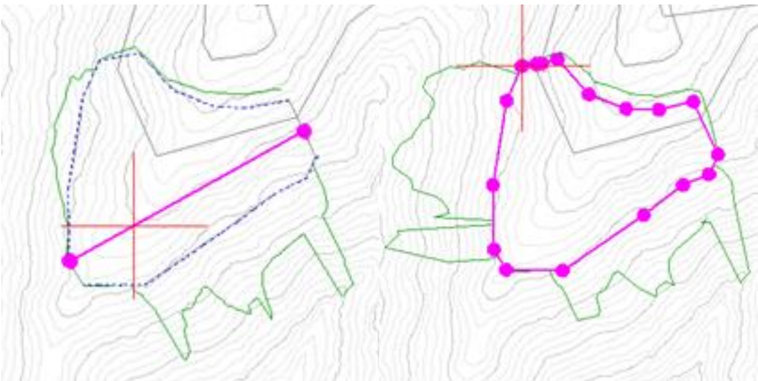


Figure 28 - Plan view of the lower pad of the split-level landing (left: Method 1; right: Method 3)

Table 5 shows the earthwork estimation for different methods. Override parameter method (Method 1) had the most different estimation compared to the other two methods, which is similar to other landing results.

Table 5 - Earthwork specification for split-level landing

Method	Cut Vol. (m^3)	Fill Vol. (m^3)	Total earthwork volume (m^3)	Waste/Borrow (m^3)
Method 1 (upper pad)	700	<100	700	700
Method 1 (lower pad)	6500	700	7200	5800
Method 1 (combined)	7200	700	7900	6500
Method 2 (upper pad)	700	<100	700	700
Method 2 (lower pad)	6800	1100	7900	5700
Method 2 (Combined)	7500	1200	8700	6500
Method 3 (upper edge)	<100	<100	<100	<100
Method 3 (upper centre)	600	<100	600	600
Method 3 (upper pad combined)	600	<100	600	600
Method 3 (lower edge)	600	1000	1600	-400
Method 3 (lower centre)	6100	200	6300	5900
Method 3 (lower combined)	6700	1200	7900	5500
Method 3 (upper lower combined)	7400	1200	8600	6200

Two-staging landing

The split-level landing was also designed into two separate part. The upper part was designed as a processing and loading area with an elevation of 542m and an area of 3203m^2. The lower part was designed as an extraction area with an elevation of 520m and an area of 671m^2. An example 3D view of the landing from Method 2 (Terrain method) is shown in Figure 29.

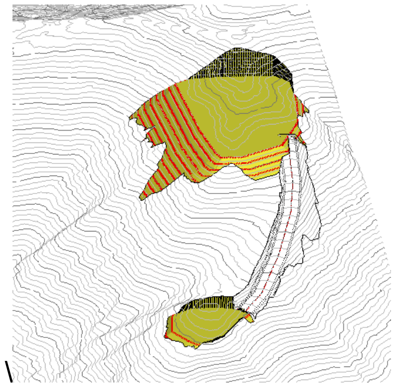


Figure 29 - Example 3D view of a two-staging landing

The plan views of the landing from three methods are shown in Figure 30 and 31. In the figure, it can be found that the override parameter method (Method 1) does not show the cut and fill batter at the start and the end of the alignment which is similar to the road end landing results.

Figure 30 - Plan view of the upper pad of the two-staging landing (left: Method 1; Middle: Method 2; right: Method 3)

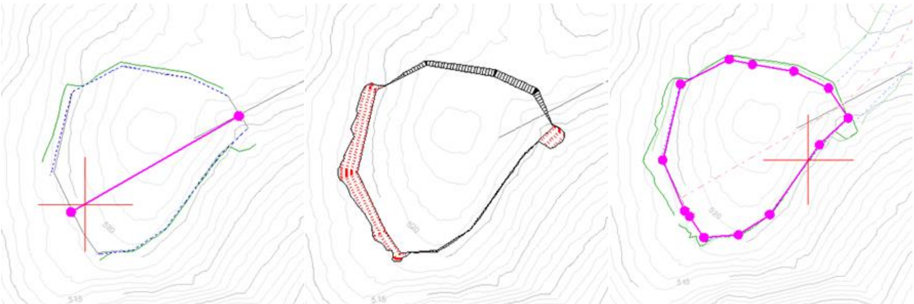


Figure 31 - Plan view of the lower pad of the two-staging landing (left: Method 1; Middle: Method 2; right: Method 3)

Table 6 shows the earthworks estimation for different methods. In the two-staging landing results, it was found all three methods yield similar results.

Table 6 - Earthworks specifications for the two-stage landing design.

Method	Cut Vol. (m^3)	Fill Vol. (m^3)	Total earthwork volume (m^3)	Waste/Borrow (m^3)
Method 1 (upper)	8100	3600	11700	4500
Method 1 (lower)	1500	<100	1500	1500
Method 1 (combined)	9600	3600	13200	6000
Method 2 (upper)	8400	4000	12400	4400
Method 2 (lower)	1500	<100	1500	1500
Method 2 (combined)	9900	4000	13900	5900
Method 3 (upper edge)	300	2300	2600	-2000
Method 3 (upper centre)	8000	1500	9500	6500
Method 3 (upper combined)	8300	3800	12100	4500
Method 3 (lower edge)	<100	<100	<100	<100
Method 3(lower centre	1500	<100	1500	1500
Method 3 (lower combined	1500	<100	1500	1500
Method 3 (combined)	9800	3900	13700	5900

Cut/fill batter comparison

According to the model produced, it can be found that cut and batter profile obtained by grading pad method in terrain were similar to the one produced by individual alignment method. This result could be explained by the TIN calculation algorithm built in RoadEng. These two methods both had landing edge profile as their centre alignments, thus the edge profile was calculated every 0.5m along the alignments. The override parameter method on the other hand, was found to be producing different shape of edge profile from the other two methods. There were two possible reasons for such difference. The first reason is that in Location, the horizontal alignment only accounts for sections that are perpendicular to the alignment. For example, if the report points were set as 0.5m, it meant the alignment would apply the template that was set for it every 0.5m along the alignment perpendicularly to the centreline. Such a mechanism makes the method to be incapable of taking the start and end of the alignment into account. The difference was found to be significant when the alignment finished on fill.

An example is shown in Figure 32.

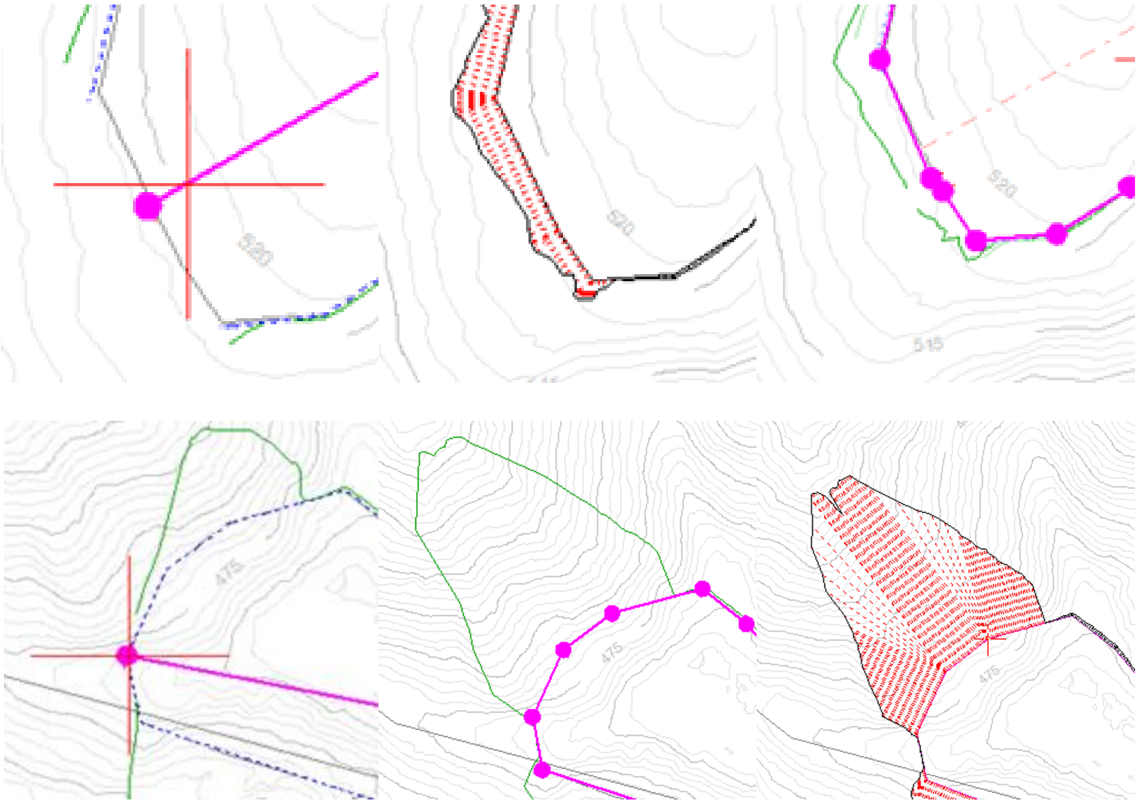


Figure 32 – Cut difference (top row) and fill difference (bottom row) example in plan view (Methods 1, 2 & 3 from left to right, respectively)

The second reason for the difference was also found to be associated with the alignments. The cut/fill shape was also estimated perpendicular to the alignments instead of perpendicular to the edge, which means when the contour lines/slope were close to horizontal to the edge profile, the cut/fill batter would be underestimated. An example of such situation is shown in Figure 33

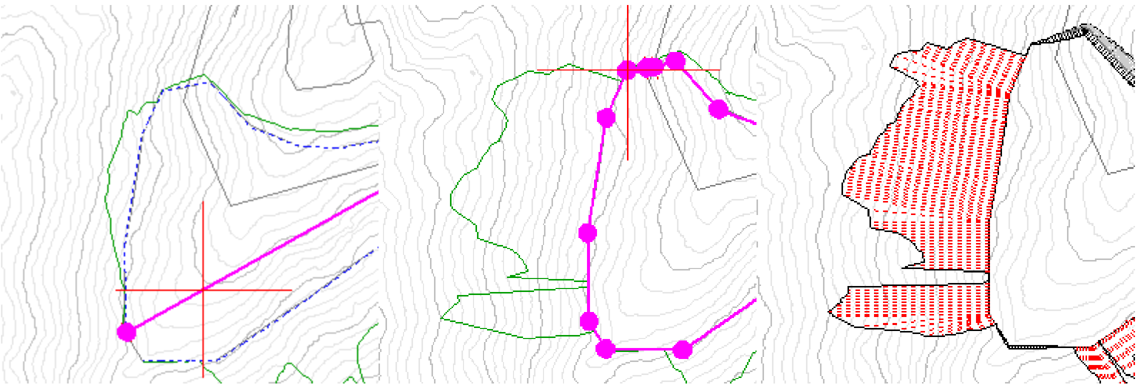


Figure 33 – Cut and fill difference caused by distortion (Methods: parameter override, individual alignment, graded pad in terrain from left to right)

Earthwork volume

After the designs were completed, the earthwork volume for different landings from each method were able to be produced. Figure 34 suggested that without the consideration of the road alignments, the design method in Terrain module and Individual alignments method in Location module tends to produce similar results. The Override parameter method had shown to have less volume than the others.

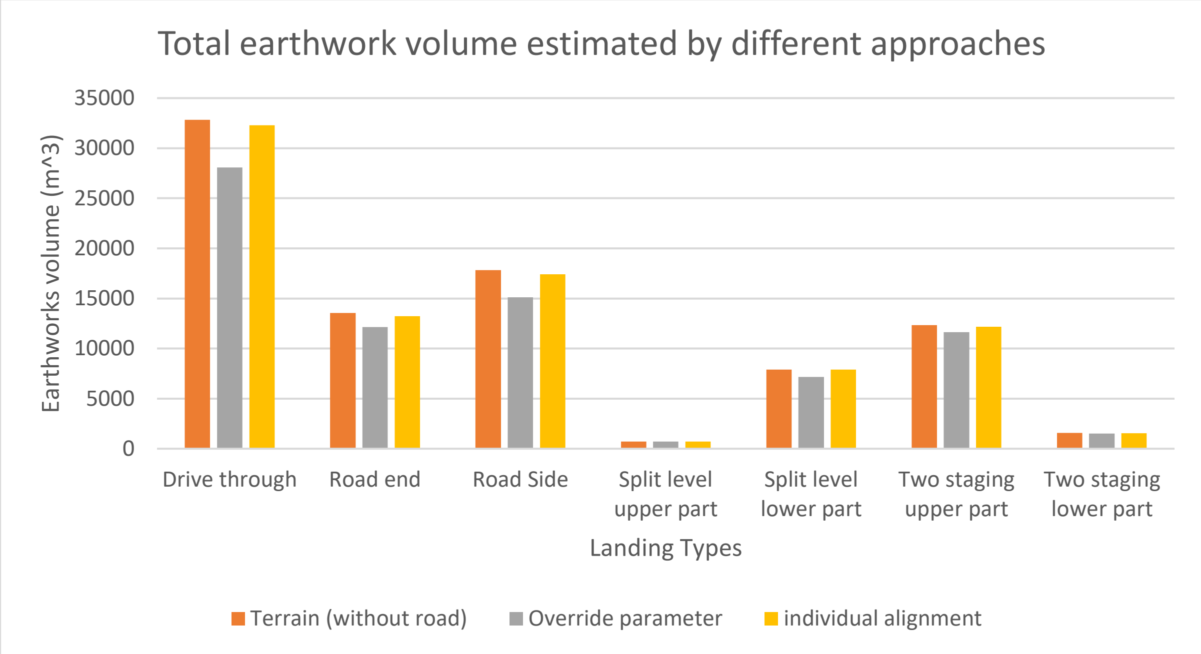


Figure 34 – Total earthworks volume estimation by different approaches

To further examine the difference, another figure showing the waste/borrow (endhaul/inhaul) situations were produced (Figure 35).

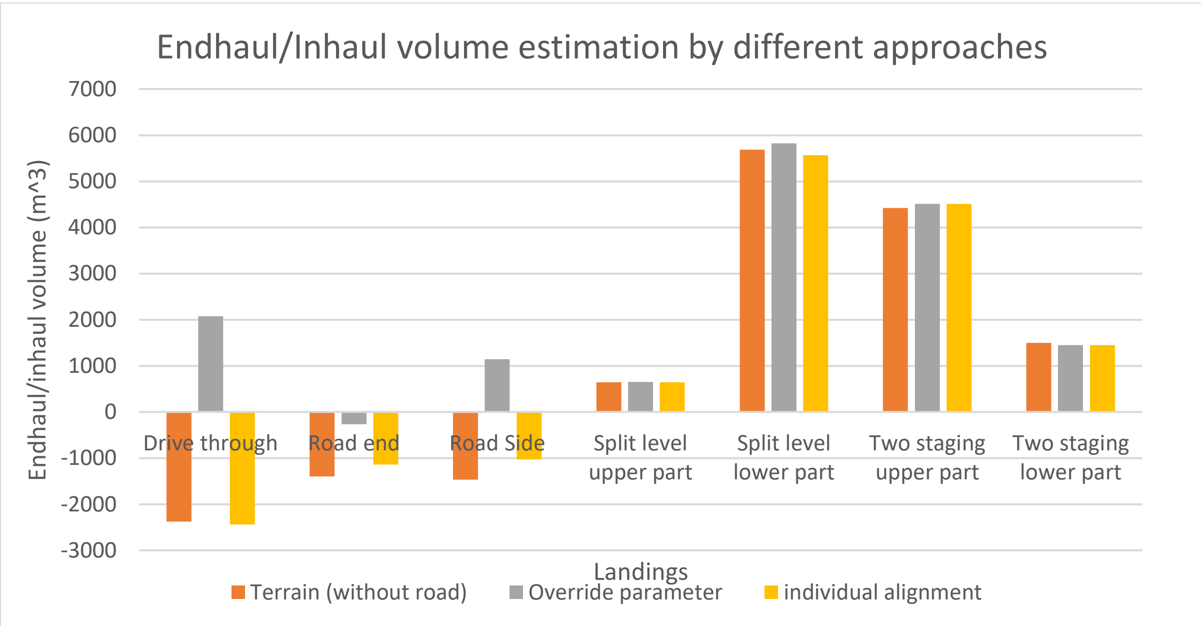


Figure 35 – Endhaul/Inhaul volume estimation by different approaches

In the figure, it could be seen that in drive through landing, road-end landing and roadside landing categories, the override parameter methods tend to underestimate the space for fill. This results could be expected as it was mentioned that the override parameter method was problematic on access edge profiles.

This result aligns to the reason explained in the cut/fill batter comparison section, which were mainly caused by the different estimation at landing centre and landing edge, and the incapability of taking the cut/batter at the start/end point into account for Method 1.

Alignment interaction in Location module

Except for the difference by the landing alignment itself, it was also found that the road or skidder track entering or exiting the road also would have influence on the cut/fill batter shape. It is also worth mentioning that in the Version 9 of RoadEng, there is no interaction between different alignments. So users are unable to take the intersection between the roads and landings into account in the Location module. The intersection between landing and road could be calculated twice if the alignments were solely designed in Location module. In order to measure such difference, small part of roads at landing level (0% grade) were designed in Location and exported back into Terrain base file to merge with the original terrain file. It was also found to have significant impact on the shape of the cut/fill batter and earthwork volume estimation, particularly when the intersection was on fill (Figure 36, example of the drive-through landing).

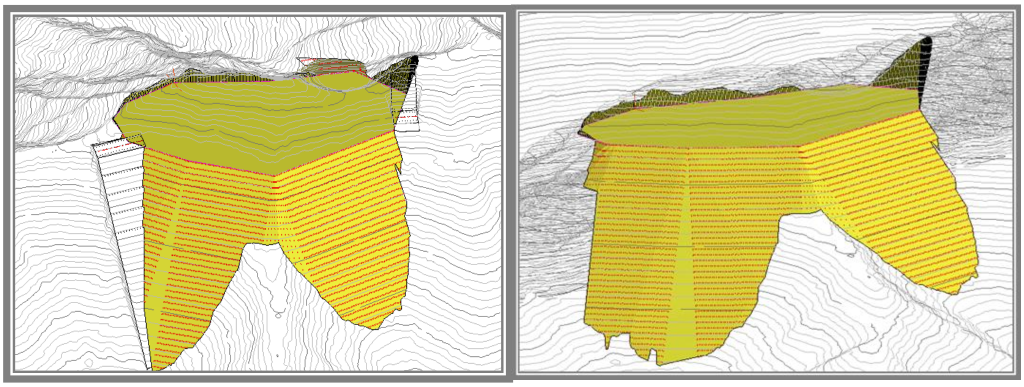


Figure 36 – cut/fill batter difference on road exiting point of drive-through landing

The difference was most significant on drive-through landing (Table 7). The total earthworks volume dropped 4300m^3 when the road was added. The earthworks also changed from waste to borrow. This was because the connection to the road was largely designed on fill, which overlaid part of the fill batter of the landing.

Table 7 – Comparison of road-included drive-through landing and road-excluded drive-through landing.

Module	Landing type	Total earthwork volume (m^3)	Waste/Borrow (m^3)
Terrain	Drive through (with enter and exit)	28500	1400
Terrain	Drive through (without enter and exit)	32800	-2400

Other Issues encountered:

Centreline Curve:

In the initial plan, some of the alignments in the Location module were created with a curve to simulate the road travel across the skid. However, when widening the landing edge profile to achieve the desired shape as it needed to be controlled to undertake the comparison, the overriding function tends to be problematic when the shape of edge changes at the turn of alignments (Figure 37). As the width between each station user overrides would be constant, so that the edge profile would be in curve, and could be troublesome for achieving the desired shape. The problem was found in both methods in Location. It was solved by keeping the alignment straight and ensuring it starts and ends at the furthest extents of the landing.

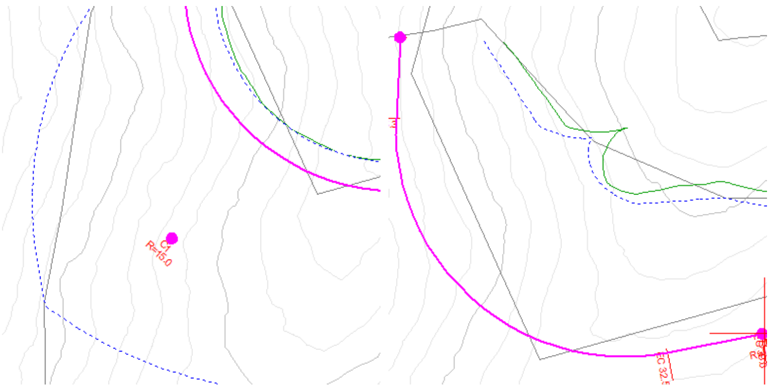


Figure 37 – Curve alignment problem

Operability

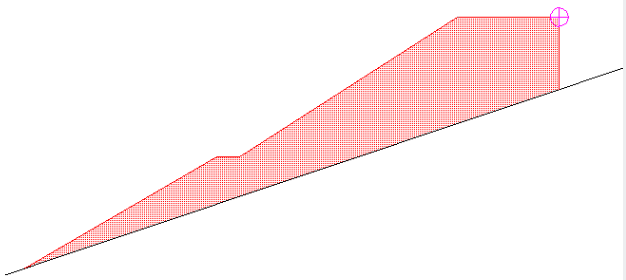
When designing infrastructure, the software should be handy and powerful to use, however RoadEng does not have specific templates for landing design. During the designing stage, some of the advantages and disadvantages from different methods were summarised:

- Override parameter method: Except for the potential of underestimating earthwork volume, and having problematic cut/fill profile. When considering the method as user's sole method for landing design, the method could be considered to be inefficient and hard to use because of the manual repetitive procedure of recording station numbers and offsets when adjusting the shape of the landing. The only advantage compared to the Individual alignment method would be that it requires only one alignment while the other requires two.

- Individual alignment method: the main advantage for this method would be the efficiency on editing landing shape and its cut/fill batter as the model updates itself once user edit the alignments by simply click and drag the stations. Once the shape was decided, it was also smooth to operate to set out the centre profile as the shape of the landing had been decided. Some disadvantages are; the method still needs to set up two different alignments and two different templates in order to use, and it is unable to interact with other alignments in Location.
- Terrain method: when considering this method as user's sole method of landing design, it requires the user has good knowledge on the location and shape of the landing. It provides accurate cut/fill shape and earthwork volume. However, determining the shape, size, area of the landing only depending on this method can be inefficient, if the user was unsatisfied on the model produced. Furthermore, the user can only apply limited specifications in terrain, unlike in location where the user can add parameters such as benching and ditches into the templates.

Cut and benched fill

RoadEng provides several functions and templates in Location module, but there was no templates that could be used to simulate cut and benched fill construction method (Figure 38). The method requires level benching on the original ground for constructing structural fill. While in Location, the bench on fill slope could not be set on the original ground under the fill. It was intended in this project to build user's own template to achieve the cut and benched fill method by using the customised template function in the Location module, however there was no clear tutorial or resource for the function. The only resource can be found was one short introductory webpage (Softree, 2017).



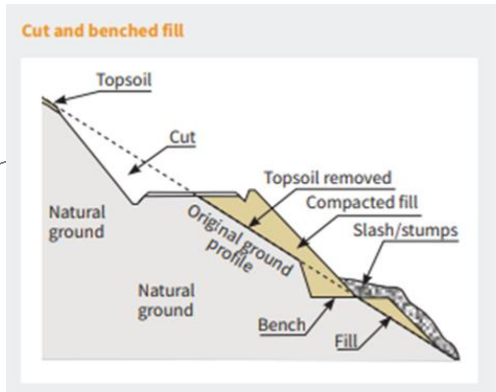


Figure 38 – Bench in fill template in loaction module (left) versus cut and benched fill construction method (right)

Recommendations for users:

From the results and analysis, it could be concluded that Override parameter was the least practical method for landing designs, not only because of the estimation but also its repetitive and inefficient procedure. For all five types of landing, the individual alignment method was found to be the handiest when accessing cut/fill batter as it updates itself every time a positon or elevation of a station was changed, and user can easily set the centre profile according to the edge profile. However, some errors could be expected as it requires the user line up the centre and edge profile manually. On the other hand, as mentioned before, location module was unable to take the intersection with other alignment into account.

The recommended procedure for landing design was to design the landing in Location first to confirm the elevation and shape as they were control points for the roading infrastructure. After the roading infrastructure is finished, export them to Terrain and merge with the original terrain model. The landing design obtained from Location module can then act as a referencing shapefile for shape, area and elevation for design in Terrain module. This could effectively avoid respectively adjusting for specifications in Terrain and taking account of influence on other infrastructures intersecting with the landing.

However, the Override parameter method was not completely out-performed by the other two methods. Such a method would be easy to use on easy terrains where the landing shape can be approximately rectangular.

Feedback on the software:

As discussed in previous sections, there are three potential improvements on the current version (Version 9) of the software:

1. Graded pad function in Terrain module can be only applied with basic functions, developer should consider add functions similar to Location templates in Terrain for more advanced and detailed design
2. Alternatively to 1, the software may consider to adding graded pad functionality into the Location module, and improve interaction between alignments so that the design could be done within one module.
3. Enhance tutorial and resource on advanced functions such as customising templates for cut/fill bench design. Although RoadEng contains benched design that is similar to the one described in Forest Road Engineering Manual and Forest Practice Guide(s). As RoadEng has been growing towards the main software for geometric design for forestry industry. The software should seek for perfection according to users needs.

Limitation and future direction

In this study, the comparison was solely on the software itself. The project has not include the comparison between real life construction and design to check the constructability of the RoadEng design. However, in this project, the potential methodology for comparison between designed landing and real life construction was also given. The trial attempt of the methodology is shown in Figure 39.

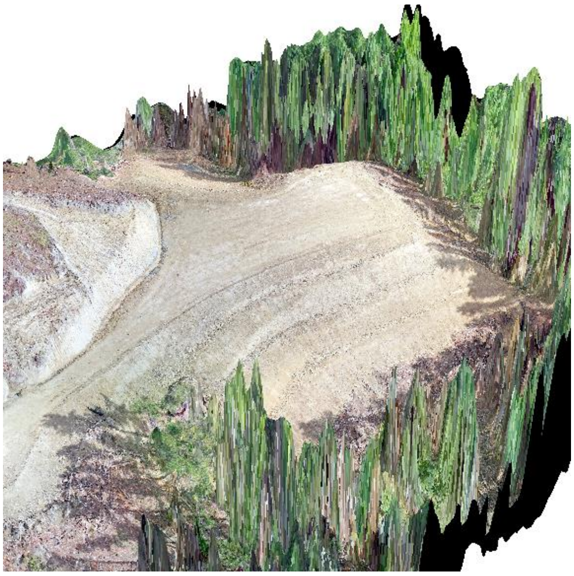


Figure 39 – 3D model of the landing in ArcGIS

The 3D model was produced using a DJI Mavic Pro 2. A total number 105 photos were shot and was input into DroneDeploy to produce an photogrammetry-based point cloud. The drone surveyed photo was taken in one of AFL's landing in Kopua Forest. As the landing was built before AFL started using RoadEng, there is no referenced design in RoadEng for this landing.

The landing was designed in RoadEng to compare with the surveyed one. The designed landing shape was input into ArcGIS to compare with the constructed one (Figure 40). To fit the cut/fill batter situation, the size of the design (2599.2m^2) was designed 23% bigger than the actual construction (2000.9m^2). This is due to the contractor pushing the original ground that was higher than the landing level, to the side to see the extraction routine, while the edge would be in cut condition in software. So the landing edge needed to be extended to be higher than the ground level.

Figure 40 – Percentage slope of the actual landing

The landing with same shape and elevation as the constructed one was also designed in RoadEng Terrain (Figure 41).

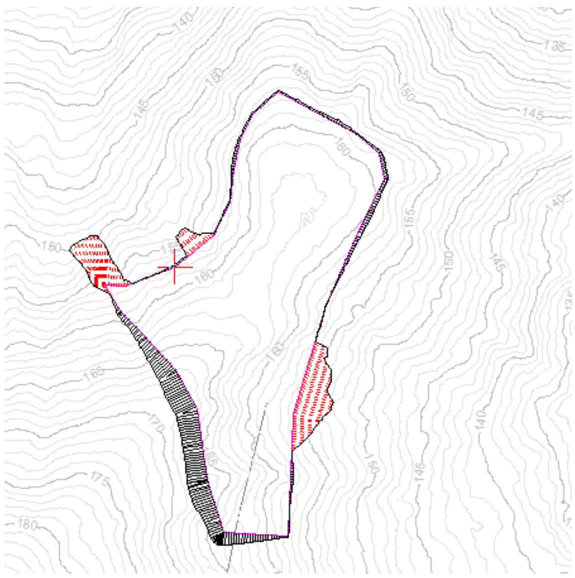


Figure 41 – Actual landing shape design in terrain

The earthwork volume on the landing excluding the cut and fill batter was also calculated in both ArcGIS and RoadEng, and was found to be 8926.4 m^3 in RoadEng and 5935m^3, which has 33.5% volume difference. The error could be explained by many factors such as the accumulation of offsets in coordinates between the two terrain models. The second factor was that in RoadEng the surface was set to be completely flat, while it is unlikely to achieve in the field condition. The third reason was the calculation algorithm was different in each software package. In RoadEng, the results the volume calculation was based on TIN, while in ArcGIS, the volume was estimated using 1 x 1 m pixels. The combination of those factors might explain the difference between two software.

Although the results did not prove the constructability of the software based design. It show the potential for drone survey on supervising the quality and specification of the construction if the landing was designed according to the RoadEng design. With the extensive application of RoadEng, comparison can be done if any company starts applying the designs in real construction. However, this part only provides a concept and direction for the possible approach for comparing the design and construction. The methodology still needs to be improved if any personnel wish to continue researching the constructability of RoadEng produced landing design.

6. Conclusion

This work was aimed to analyse and compare three different approaches for landing design in both RoadEng Terrain and Location modules. In the study, approaches were applied on five types of landing to access the performance on estimating earthwork volume, cut/batter shapes and the operability of each approach. The study location was in Okiwa Forest owned by AFL and using the 1 m LiDAR data in Gisborne area provided by Gisborne District Council.

The study had found that of all the methods, the override parameter produced the most different results from the others. The method tends to underestimate the earthworks volume and misses areas on fill batter. The issues were found to be mainly associated with the calculation mechanism as the templates were applied perpendicular to the centre alignment. Because of such mechanism, it was found when the edge had similar angle to the contour and was close to perpendicular to the alignments, the method would produce different estimations. It was also found that when the alignment was not in straight line, widening the width of alignment was found to be problematic to achieve the desired shape as the width between each station user overrides would be constant, so that the edge profile would be in curve, and could be troublesome for achieving the desired shape. The problem was found in both methods in Location. It was solved by keeping the alignment line straight and ensured it was starting and ending at the furthest extents of the landing.

The Individual alignment method and Terrain method were found to have similar results. However, it was also found in Location module, different alignments could not interact with each other. However the alignment was able to be exported back into Terrain from Location to account for intersection of the road infrastructure, and has found to be influential on the design particularly when the road enters or exits the landing on fill.

Furthermore, it was found that the cut and fill benching method was unable to be achieved. The method requires level benching on the original ground for constructing structural fill. While in Location, the bench on fill slope could not be set on the original ground under the fill.

It is recommended to use the Individual alignment method as a rough design, then export the alignment into the Terrain module to take road intersection into account, as the most suitable solution for steep terrain. The Override parameter method would be best suited for gentle terrain, where the landing does not need to be designed with a complex shape.

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