Adoption of emergent technology for forest road management in New Zealand

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Abstract

A targeted survey of active forest roading managers was completed in April 2018 to better understand the characteristics of the forest industry's current road construction programme, practices used in forest road planning and management, and uptake of emergent technologies applied to forest roading problems. The 18 survey responses represented an annual harvest volume of 10.2 million m^3 and length of new road construction of 426 km.

About 180 km of this new road construction (42%) will be built on highly erodible terrain as defined by the Erosion Susceptibility Classification (ESC) system within the new National Environmental Standards for Plantation Forestry (NES-PF). Spur roads represent almost two-thirds of the new road length. In terms of road pavement construction, vibratory rollers were the most commonly used machines for compaction and total aggregate thickness (i.e. basecourse plus topcourse) averaged about 300 mm.

Respondents identified major challenges in managing their roading programmes, including planning, designing and constructing infrastructure well in advance of harvesting crews (e.g. six months) and controlling construction costs in steep terrain. On average, spur and secondary roads cost $72,000/km and $90,000/km respectively, with gravel and excavation representing the greatest cost components.

Emergent technology, such as the integration of LiDAR-based digital terrain models (DTMs) and geometric design software, is playing a key role in addressing these challenges. Managers indicated that full geometric designs were associated with particularly difficult road sections (i.e. steep and/or unstable slopes and switchbacks), and they emphasised the utility of LiDAR data and geometric design software for these situations.

Managers have also been able to test the feasibility of multiple road routes in the office with a high level of detail. They can perform complete geometric designs, and estimate earthwork volumes (a requirement under the NES-PF) and costs. While the office-based designs still require field validation, the benefits include more targeted field surveys, reduced construction costs and improved environmental performance. However, many managers indicated that few roads required a full geometric design, and in most cases marking of the road centreline was often sufficient for roading contractors to build the road.

A cut slope on a newly-constructed road that has slumped following a rainfall event in Gisborne

This study demonstrated that New Zealand's roading managers are utilising emergent technologies. Almost half (44%) of roading managers frequently used LiDAR-based DTMs to plan and design forest roads. Sixty-one percent of roading managers used a software package to aid road location planning and design. Softree RoadEng was the most commonly used program. The most common applications of unmanned aerial vehicles (UAVs) included monitoring stockpile volumes at in-forest quarries (39% of managers) and road impacts on waterways (17% of managers).

Introduction

While forest road construction occurs on a range of terrain, in New Zealand a lot of new roading is on steep and inherently erodible land (see first photo).

There has been a clear trend toward more mechanised and productive harvesting systems, which require a more secure infrastructure network to remain cost-efficient. The commencement of the NES-PF in May 2018 introduced new requirements such as detailed harvest and earthworks management plans. Concurrently, technological advancements such as LiDAR and UAVs are changing the way forest roads are planned, designed and monitored. However, little is known about the extent of emergent technology adoption by forest roading managers in New Zealand.

The objectives of this study were:

1. To document current practices used by the New Zealand forest industry to plan, design and monitor roads.
2. To highlight examples of industry adoption of emergent technologies to improve forest road management, including environmental performance.

Demographic information

A targeted survey of active forest roading managers was conducted from January to April 2018. In total, 34 managers were contacted and 18 responses were received for a response rate of 53%. The survey response represented 650,000 ha of managed plantation forest spanning the following regions: Northland, Auckland, Central North Island, East Coast, Hawke's Bay, Southern North Island, Nelson/Marlborough, West Coast, Canterbury, Otago and Southland.

Of the 18 roading managers surveyed, 15 specialised in larger commercial forests, as opposed to smaller woodlots. The companies responding to the survey represented a total annual harvest volume of 10.2 million m^3 or about one-third of New Zealand's total annual harvest volume in 2017. The associated annual road construction, including all new road construction for trucks but excluding skid trails, was 426 km. This suggests that New Zealand forest management companies oversee the construction of about 1,300 km of new forest road each year, which is consistent with previous estimates by Neilson (2012) and Fairbrother (2012).

It should be noted that this survey is a snapshot; annual road construction requirements are not continuous. For example, a company managing harvesting operations in second rotation forests will require fewer kilometres of new road construction than that of first rotation forests.

Types of roads being built

Roading managers were asked to estimate the proportion of new road construction for different road standards (spur, secondary or arterial roads) as defined in the *New Zealand Forest Road Engineering Manual* (NZFOA 2011, Table 1). Of the new road construction, 63% will be lower standard spur roads and 34% will be higher standard secondary roads, with only 4% built as arterial (highest standard) roads.

Terrain erodibility

Roading managers were asked to estimate the proportion of new road construction occurring on land with varying levels of erodibility as defined by the ESC. The ESC is based on a Land Use Classification system that considers the dominant erosion process, rock type and topography. For more information visit www.mpi.govt.nz/growing-and-harvesting/forestry/national-environmental-standards-for-plantation-forestry/erosion-susceptibility-classification/.

Table 1: Total length of new truck road construction per year by road class

Road class	Total road length (km)
Spur – short term, typically defined as serving just a few landings, carrying fewer than 20 hvpd*	267
Secondary – typically services multiple operations, carrying 20-80 hvpd, but not in use all of the time	144
Arterial – typically defined as a road that is likely to always carry truck traffic, with more than 80 hvpd	15
Total	**426**

* hvpd = heavy vehicles per day

Together with risk assessment tools related to fish spawning and wilding trees, the ESC is used in the NES-PF to determine which forestry activities (e.g. afforestation, replanting, harvesting and earthworks) are permitted with certain conditions and which require a resource consent (MPI, 2018). Based on the survey response, 58% of new road construction will occur on low to moderately erodible terrain (Table 2). About 42% of new road construction will occur on high to very highly erodible terrain (180 km).

Table 2: Total length of new road construction within each erosion susceptibility class (ESC)

ESC	Total road length (km)	% of total
Low (green)	117	27%
Moderate (yellow)	130	31%
High (orange)	140	33%
Very high (red)	40	9%
Total	**426**	**100%**

Roading costs

Roading managers were asked to estimate the average cost to build roads and to consider all costs, from planning and vegetation removal through to drainage and surfacing. Spur roads cost on average $72,000/km, ranging from $10,000/km to $150,000/km. Secondary roads cost $90,000/km on average, ranging from $35,000/km to $150,000/km. The wide range in roading costs reflects variability in terrain steepness, requirements for road drainage and stream crossings, access to rock for road surfacing, and road design standards related to harvest volumes (e.g. woodlots versus larger commercial forests).

For example, in three of five cases where spur roads cost at least $100,000/km the location was Gisborne, which is characterised by steep, highly erodible terrain with long cartage distances for road surfacing materials. The lower cost spur roads (i.e. $40,000/km or less) were largely characteristic of woodlot roads or sites with pumice soils, such as in the Central North Island. Pumice soils are well-drained with a high bearing strength and construction costs are generally lower as they require little or no gravel surfacing.

To enable better understanding of roading costs, forest managers were asked to rank the following cost components (1 is most expensive, 8 is least expensive): office planning, field surveying, clearing and piling (i.e. roadline salvage), excavation, grading and compaction, gravel (or aggregate) surfacing, drainage, and stream crossings. Ranked data were averaged by road cost component for comparison (Table 3).

Table 3: Average cost ranking for different road cost components (n=18) – 1 is most expensive and 8 is least expensive

Cost component	Average rank
Gravel (or aggregate) surfacing	2.0
Excavation	2.1
Stream crossings	4.3
Grading and compaction	4.6
Clearing and piling	4.6
Drainage	4.8
Field surveying	6.8
Office planning	6.9

Gravel surfacing and excavation (i.e. earthworks requirements) had the highest rankings, indicating that they are the major drivers of road construction cost. Interestingly, for spur roads costing around $40,000/km or less (i.e. representative of woodlot roading), the greatest cost components were excavation and stream crossings.

Forest road pavement design and compaction

Vibratory rollers were the most commonly used machines for compacting the subgrade (i.e. in-situ soil and rock) and the overlying 'improved' layer, which usually consists of a single layer of basecourse aggregate and sometimes a thinner layer of topcourse aggregate. Sheepsfoot rollers were also commonly used to compact subgrades. Track rolling with an excavator or bulldozer was another common compaction technique, although it was used less extensively than vibratory rollers (see second photo). Compaction techniques will vary depending on local soil type and geology, as well as different road standards that correspond to traffic volumes, types and loads, and the duration of road use.

One company used a range of machines for compaction, including a vibratory roller and rubber-tired machines (e.g. skidders and dump trucks). In this case, they used a practical test to determine if the required level of subgrade compaction had been achieved, whether or not a loaded dump truck left an impression on the subgrade. Forest engineers will typically utilise a dynamic cone penetrometer to assess subgrade strength once it has been graded, shaped and compacted, and a Clegg hammer to assess overall pavement strength once aggregate has been spread and compacted. One company uses a minimum California Bearing Ratio (CBR) of 7% for the subgrade and 40% for the improved aggregate layer.

Summertime landing construction in Canterbury. Compaction involved track rolling the landing with a Komatsu D65 EX bulldozer (left) prior to vibratory rolling with a Sakai SV512TF (right)

Newly-constructed secondary road on the East Coast

For spur roads, the compacted thickness of the basecourse layer averaged about 220 mm, ranging from approximately 130 to 310 mm (Table 4). The upper (topcourse) layer averaged about 75 mm thick, ranging from 50 to 135 mm. Maximum particle size diameter for the basecourse and topcourse was approximately 150 and 60 mm, respectively. Interestingly, these pavement design characteristics were similar for secondary roads, showing that typically forest road managers are applying very similar standards to both road types.

Table 4: Descriptive statistics related to the compacted thickness (mm) and maximum particle size diameter (mm) used in the basecourse (aka improved layer) and topcourse layers of forest road pavements in NZ

	Basecourse		**Topcourse**	
	Layer thickness (mm)	**Maximum rock diameter (mm)**	**Layer thickness (mm)**	**Maximum rock diameter (mm)**
Spur roads				
Mean	216	151	76	59
Median	200	120	70	65
10th percentile	133	73	50	40
90th percentile	310	260	135	69
Secondary roads				
Mean	232	140	81	61
Median	225	120	65	65
10th percentile	150	73	50	43
90th percentile	324	220	141	69

The third photo shows a recently compacted forest road pavement from the East Coast. The road formation is 9 m wide and it was compacted using a 12 tonne drum roller with a vibratory option. It is common practice to use a sheepsfoot roller for the subgrade and vibratory roller for pavement. The basecourse consists of rotten rock and soil with a compacted thickness of 100 to 150 mm. The topcourse (highlighted in the inset photo) is 150 mm of crushed river run with maximum particle size of 50 mm (aka General All Passing 50 or GAP50).

Terrain maps for road planning

Roading managers were asked about the terrain maps that they use to plan and design forest roads. Of the 18 managers, 14 said that they use a map scale of about 1:5000 for preliminary planning (e.g. initial layout and route feasibility), depending on the size of the block. These maps were sourced predominantly from in-house ArcGIS systems. A few managers used Google Earth Pro and publicly available maps. For advanced road planning and design (e.g. horizontal alignment and drainage requirements) roading managers generally used a map scale of 1:5000 or finer resolution, depending on the situation.

Of the 18 managers, eight frequently use LiDAR-based DTMs in forest road planning and design (i.e. ‘often’ or ‘always’), whereas 10 of the managers do not use them very often (i.e. ‘sometimes’, ‘rarely’ or ‘never’). LiDAR-based DTM usage is highly dependent on availability (i.e. those who have them use them). Notably, four roading managers with limited LiDAR availability in their forest estates indicated that their companies have purchased or plan to purchase LiDAR data in the near future. To put these results into context, Morgenroth and Visser (2013) found that about 18% of New Zealand forest management companies were regularly using LiDAR data just five years ago.

Roading managers were asked to fill out a table indicating how they use LiDAR-based DTMs (Table 5).

Table 5: Uses for LiDAR-based DTMs

What are LiDAR-based DTMs used for?	Responses (no.)
Preliminary planning of new roads (i.e. initial layout, route feasibility)	10
Identification of existing roads	9
Advanced planning of new roads (i.e. road template specification, horizontal and vertical alignments, balancing earthworks, water controls)	8
Identification of stream channels	7
Identification of unstable slopes	7
Mapping Topographic Wetness Index (TWI) or Depth to Water Table (DWT) (i.e. wet areas to avoid)	1

In terms of preliminary planning, DTMs were used to locate features such as rock outcrops and archaeological sites, and to measure widths of existing roads and trails. One company used colour-coded slope maps in 10% increments (Figure 1) to identify areas where sidecast (typically up to 40% slope) or bench-and-fill road construction (typically 40% to 70% slope) was feasible, or conversely where end-haul road construction was necessary (typically >70% slope). In one case, 0.5 m contour lines were used to assess stream crossing feasibility by measuring stream channel dimensions and road approach slopes.

One manager said, ‘As we have become more efficient with using what is now very high-quality LIDAR data, I am finding that the old days of extensive forest walking and survey are not required as numerous checks are finding that the LIDAR data is extremely accurate.’ He explained that LiDAR-based DTMs are used for first (and often final) road alignments in easier terrain, while full LiDAR-based RoadEng designs are used for roads requiring substantial earthworks in steep terrain.

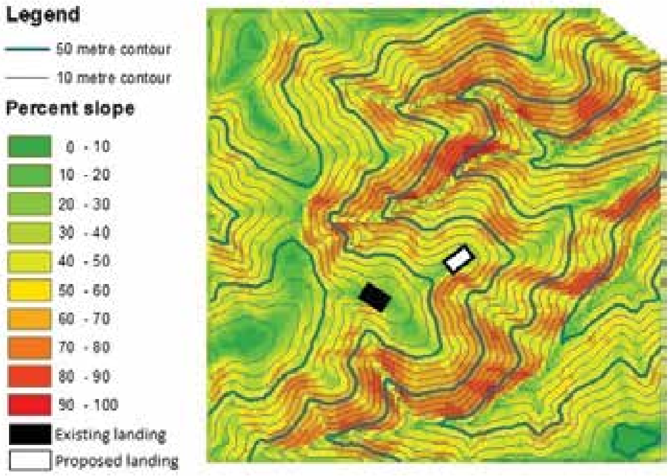

Figure 1: LiDAR data was used to create a DTM using ArcGIS and a heat map was used to depict slope steepness. In this example, a spur road is needed to connect the existing landing with the proposed landing further downslope

Forest road surveying and design

Of the 18 roading managers, 10 mainly used in-field surveys to obtain the information necessary to design and construct a road, whereas eight managers used a combination of LiDAR-based terrain models and in-field surveys. For example, one manager said that on easier terrain they run gradelines in the field, but in steeper terrain they used LiDAR data to generate RoadEng designs.

Most roading managers (15 of 18) indicated that for spur roads, few (0% to 25% of roads being built) required a full geometric design. The results were similar for secondary roads. A full geometric design was defined as applying most of the following geometric standards to produce a specific road geometric design: cut bank and fill slopes, ditch depth and width, road width and camber, curve radius, curve widening, fill widening, road slope, and sight distance.

Computer-assisted road planning and design

Sixty-one percent of roading managers use a software package to aid road location planning and design. The most popular software package was Softree RoadEng. Several roading managers emphasised its utility for road design and layout on steep and difficult sections, such as heavy earthworks requirements and switchbacks (Figure 2). While the use of RoadEng is not new, the integration of LiDAR data and RoadEng enables managers to test the feasibility of multiple road routes in the office. The benefit is that managers can allocate time that would otherwise be spent in road planning to other tasks, such as harvest planning and liaising with logging and construction crews.

RoadEng was used to determine road gradients that could be achieved after balancing cut and fill volumes. Design hardcopies, including the road plan, profile and cross-sections, could then be provided to supervisors and equipment operators along with GPS points that marked the location of cut points. Training resources, such as RoadEng webinars and tutorials, are available on Softree's Youtube channel (www.youtube.com/user/SoftreeSoftware). This one demonstrates how to import LiDAR data, generate a DTM, and peg out a proposed roadline (www.youtube.com/watch?v=zWFkPCyuO38&list=PLwOM-Z0fbkzckAzyGDzw9nn3wGUXo7Dcy).

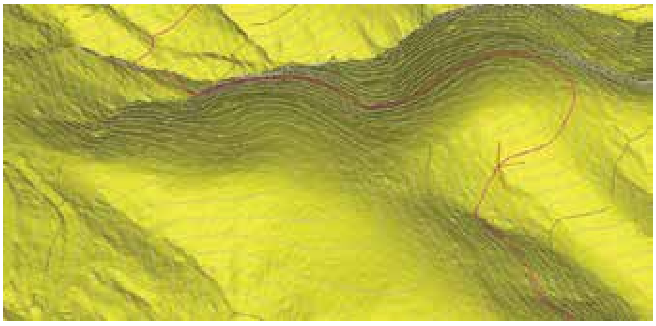

Figure 2: Three-dimensional view of a LiDAR-based DTM created using RoadEng 7. Using this DTM, the user can test the feasibility of multiple road routes in the office with a high level of detail

In another example, a roading manager used ArcGIS desktop to plan preliminary road routes, which were exported as PDFs for use in the field via a program called Paper Maps (www.paper-maps.com). Another program, Collector, was used for mapping the final as-built alignment and then this was used to update ArcGIS desktop.

Three roading managers indicated that they had at least attempted to use a cost optimisation tool; in all cases RoadEng was used. However, one manager noted, 'It's hard to find time to do it (cost optimisation) and quantify the benefit.' Conversely, another manager said that he uses a simple costing spreadsheet once he has taken the roading contractor out to the field to determine costs together.

Marking aids to road construction

Of the 18 roading managers, 14 indicated that most spur roads (>75%) require marking of the centreline only as an aid to road construction operators, which was similar for secondary roads. One manager explained, 'We have moved from steep, first rotation to easier, second rotation forests, so these numbers have changed. We also have competent equipment operators, so I am confident in marking the centreline only.' Another manager indicated that spur roads may be unmarked, saying, 'We have short spur roads here due to the terrain. We have experienced equipment operators that can make the benign grade to the skid (landing).'

Similarly, 16 of 18 roading managers indicated that few spur roads (0% to 25%) required marking of multiple components of the road formation (i.e. top of the cut slope to the bottom of the fill slope; P-Line plus cut height). This indicates that once the road location has been decided, a manager can flag the centreline and rely on operator experience to build a good road. However, the cost-efficiency of operator-based designs cannot be assessed if no-one is checking. Therefore, it would be prudent to compare full geometric designs with operator-select construction for a variety of performance indicators, such as total earthwork volume, whether or not cut and fill volumes are balanced, efficiency of machine movements, minimum switchback radius, and maximum adverse gradients achieved.

Monitoring road surface conditions and road impacts on waterways

Roading managers were asked, 'In addition to simple inspection routines, do you use any other tools (e.g. Benkelman beam, vehicle-based LiDAR) or methods (i.e. cross-sectional surveys, road user reports) to monitor the condition of the road surface (i.e. ruts, potholes, corrugations etc)?'

Of the 18 roading managers, 16 indicated that they use mostly simple inspection routines. Two managers use road user reports and requests for service. Another manager said that the trucking suppliers have an app to report road surface issues.

None of the roading managers surveyed have used UAVs or LiDAR to monitor road surface conditions as described by Pierzchala et al. (2014), Talbot et al. (2017), and Hrůza et al. (2018). However, 17% of roading managers have used UAVs to monitor road-related impacts on waterways. One manager said that a UAV is used to inspect roads following storm events.

Application of emergent technologies to roading problems

Managers were asked to list examples of emergent technologies that they were interested in applying to their tasks in road planning, design and management. The integration of LiDAR data and geometric design software (Neilson, 2012), as well as the use of UAVs to monitor quarry stockpile volumes (Arango & Morales, 2015), generated the most interest, which is not surprising as these are the main emergent technologies being used by New Zealand's forest roading managers to date. For example, seven respondents used UAVs to estimate stockpile volumes at in-forest quarries and borrow pits (see fourth photo).

Other UAV applications included surveying bench heights for safety reasons and estimating solid rock volumes available for blasting calculations to create a quarry plan.

Also, three managers discussed the utility of displaying an advanced road alignment on a tablet computer in the cab of an excavator or bulldozer. The tablet would show the final road design, DTM and corresponding location of the machine to facilitate road construction in the correct location and to minimise earthworks. Finally, managers expressed interest in using UAVs to collect LiDAR data in woodlots and to measure cut and fill volumes after road construction.

Example of an in-forest quarry in Canterbury

Challenges in managing a forest roading programme

Roading managers were asked to describe the biggest challenges they face in managing a forest roading programme. A summary of the common themes is provided below:

- **Keeping ahead position**

  Ideally, companies will attempt to clear the roadline and build roads during the summer and at least six months ahead of planned harvesting activities. This helps to promote a natural firming of the road. However, harvesting crews may be forced to shift to green infrastructure on short notice due to windthrow or wildfires that require salvage logging. Also, changing market conditions could cause a shift in harvesting position and this so-called 'just-in-time' roading can result in a greater risk of road failure
- **Roadline salvage**

  Several managers discussed the challenge of managing resources to gain efficiency in constructing roads while the road line salvage crew is simultaneously clearing the wood
- **Cost control**

  Examples include efficient use of machines and accuracy of contractor payment systems
- **Managing clean-up of storm events**

  For example, in regions such as the Bay of Plenty, Gisborne and Nelson/Marlborough
- **Contractor labour skills**

  Managers noted that it can be hard to keep the good contractors around. It is important to note that this finding contrasts with the practice of marking road centrelines and relying on operator skill to build a good road

- **Supervising construction related to quality control and environmental compliance**

  This includes checks to ensure that construction has met design specifications related to benching and compaction, sidecast containment, road grades and switchback radius

- **Gravel resources**

  For example, access to sufficient volumes of quality aggregate

- **Steep terrain road construction**

  For example, when 70% to 80% of road construction is end-haul, things can get expensive quickly and finding suitable dump sites for spoil material can be difficult. An additional challenge in steep terrain is upgrading poorly engineered (legacy) roads and trails, which may require extensive regrading, realignment, or retaining walls to fix collapsing fill sections.

Conclusions

The survey responses from 18 currently active forest roading managers in New Zealand were used to provide a detailed snapshot of the industry's current road construction programme, practices used in road planning and management, and uptake of emergent technology. The survey response represented an annual harvest volume of 10.2 million m^3, roughly one-third of New Zealand's annual cut in 2017. The corresponding length of new road construction was 426 km. As such, this study estimates that companies are currently building about 1,300 km of new roads each year, two-thirds of which are lower standard spur roads that provide on-highway truck access to landings during harvesting operations. About 42% of this new road construction is planned to occur on highly erodible terrain.

Roading managers desire ready access to highly-detailed terrain information to ensure that the road systems they plan and design are stable, safe and cost-efficient. Most notably, this study showed that 44% of roading managers frequently use LiDAR-based DTMs in combination with in-field surveys to provide the information necessary to design and construct forest roads. The integration of LiDAR-based DTMs and road design software enables managers to test route feasibility, complete geometric designs, balance cut and fill volumes, and estimate construction costs efficiently. One manager said, 'I would say that having accurate LiDAR-generated coverages is the biggest jump forward in forest planning that has occurred in the last 20 years.'

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