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Two-Stage Operations: A case study of infrastructure and survey of New Zealand Industry

An Honours project for BE(Hons), Forestry by

Tom Rendell

Supervisor: Prof Rien Visser

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Abstract

Within New Zealand, many first rotation wood-lots are coming on-line to harvest, with no infrastructure. Many of these woodlots were planted in steeper, more erodible terrain making constructing infrastructure more difficult and more costly. These costs can have a bigger impact in these in smaller wood-lots. The way to combat this issue is to reduce the amount of infrastructure needed to harvest the same area. Two-staging has been identified to reduce the amount of infrastructure needed within a forest. Two-staging is the removal of logs or stems from a harvest landing or pad which are then transported to a larger skid to be processed or stored. Two-staging operations represent an innovation proposed to combat issues surrounding harvesting of small wood-lots in steep-terrain. Despite its proposed benefits there is no consensus in the industry about what systems to use, when to use them, or what benefits you will gain from that system. There is also little information on what proportion of the industry is using two staging and for what reasons.

This study undertook a case study of an operation using a super forwarder to compare Infrastructure. Where infrastructure of the forest was measured using a GPS and then compared to a log truck to landing plan that was originally made for the forest to quantify any reduction in infrastructure the system may have achieved. This study also surveyed members of the forestry industry within New Zealand to find their motivation and deterrent to using two-stage operations.

The case study revealed the two-stage operation in the Kenderdine forest reduced roading by 2940m when compared to the original plan which was a 23% reduction. The study also found that when compare to literature the landing sizes in the Kenderdine forest were smaller. The Kenderdine landing sizes ranged from 221 – 3836 m^2 with the Superskid at 6071 m^2. This gave an average landing size of 1947 m^2 where literature found that landing size throughout New Zealand ranged from 1370-12540 m2 with an average landing size of 3900 m^2. This still indicates a reduction in average landing size of 47%.

The survey showed that there are two main groups of people using two-staging: those who perceive cost as a deterrent and those who don't. Those who perceive this deterrent generally use a two-stage system were the processing skid is not far from the pad and mostly use a skidder or shovelling system. The group that doesn't perceive this deterrent mostly use a system that involved off-highway trucks where log trucks don't enter the forest at all and are only loaded from a central skid.

The case study presented here supports the claim that two-staging with a super-forwarder can reduce infrastructure. While the results of the survey illustrate that not all parties that use two-staging understand the advantages and disadvantages of each different system. If further research was done to quantify other claimed benefits of the different two-staging systems then people in industry could be better informed to make decisions about which system is best for their application. This case study and survey represents a critical first step in understanding the current two-staging operations and their impact on New Zealand forestry.

CONTENTS

1. INTRODUCTION

Forestry is a growing, sustainable industry which provide multiple renewable products. In New Zealand it is the third biggest contributor to gross domestic product (GDP). Contributing 3.55 billion to the GDP in 2017/2018 which is 20% greater than sheep meat and wool sector as well as 45% larger than the beef sector (FOA, 2018; NZIER, 2017). Beyond GDP, forestry contributes positively by providing food, fibre, energy, and chemicals for pharmaceutical and other uses (NZIER, 2017). Specifically, it contributes to the stabilisation of erodible soils, sequesters carbon from the atmosphere (Hollinger, Maclaren, Beets, & Turland, 1993), and provides recreational areas.

Before the 1980s forestry was largely executed by the government through sizable plantation forestry (LINZ, 2019), in the late 80s and early 90s the market saw a spike in log prices. Farmers began to plant woodlots on smaller, steeper terrain on marginal and more remote land, shifting the harvesting model of New Zealand forestry (Raymond, 2012). This steep terrain has led to an increase in harvesting cost thanks to specialized machinery, difficult roadways, and detrimental environmental impacts. Many of the forests that are coming online from the 90s planting are small scale forest owners who may not be career foresters. In these smaller, steeper areas the infrastructure has larger impacts in these small forestry blocks compared to some of the larger scale plantation forests (Raymond, 2012).

Many improvements and innovations have been made to address safety and productivity in steep terrain forests. However, little research has addressed the issues surrounding infrastructure impacts in smaller woodlots (Brown, 2018; Brown & Visser, 2017). One proposed solution to the infrastructure problem in steep terrain is the extraction method of two-staging. Two-staging, which involving transporting stems or logs from the harvesting operations and a smaller landings/pad to a larger superkid to be processed or stacked into log grades, then fleeted onto highway trucks transporting them out of the forest (Ellegard, 2017). This process can be achieved in a variety of ways for example, some crews have used modified dump trucks, forwarders, stems trucks, and 8x8 ‘super forwarder’ trucks (Ellegard, 2017, 2018).

Despite these improvements and innovations, there is little information about the current state of two-staging in New Zealand forestry operations. Before moving forward, there is a need to assess what is currently being done, on what scale, and by what proportion of the industry. The aims of this study is to attempt to fill this gap in knowledge and provide insight into the motivations/deterrents for two-staging; systems being implements; and explores the implementation of one such system.

This study encompasses two parts. The first is a survey of a sample of forestry managers and contractors. This survey was aimed at gathering knowledge of the current state of two-stage operations around New Zealand and identifying some of the motivators and deterrents behind two-staging. The second part was a case study on the infrastructure implemented by a two-stage operation in the Kenderdine forest. This was to quantify any reduction the system may have achieved in infrastructure.

2. LITERATURE REVIEW

Since forestry has moved more to steep terrain, a recent study showed that landowners are concerned with multiple factors including protecting the environment, property damage and disruption of operations, as well as the costs associated with harvesting (Brown, 2018). The study identified value recovery concerns including confusion about tonnage delivered, stem breakage, and residue left on the property plus other issues surrounding equipment move-in costs and long transport distances to market. For example, construction of a landing typically ranges from $4000 to 7000$ (Visser 2010). On the other hand, loggers also identified some key challenges of current harvesting system as small harvest volumes, frequent moving of machinery, high harvesting costs due to tough logging conditions, and lack of infrastructure among other concerns (Brown, 2018).

The infrastructure in forest harvesting refers to the roads into the forest that connect to the landings. According to the New Zealand Forest Road Engineering Manual, produced by the NZ Forest Owners Association Inc, forestry roads can be classified into 4 categories (FOA, 2011). The first category is Arterial roads. These are typically permanent, unsealed two lane roads. They are the hub roads in a forest although they may not be in all forests. They connect to the secondary roads in a forest. Secondary roads are the second class of road and are normally constructed to a high standard, are unsealed, permanent one- or two-lane roads typically found in forests of the 1000 to 15,000 ha range (FOA, 2011). The third category is Spur roads. Typically used during harvest these roads can have heavy and intensive traffic. They are often constructed to the lowest pavement standard that can still reliably handle logging traffic and are typically one lane. The forth class of road according to the New Zealand Forest Road Engineering Manual, is Establishment tracks (FOA, 2011). These are one lane earth tracks designed to be used by light vehicles only and typically suited to 4-wheel-drive vehicles. They are used to access new areas for planting and silviculture. They are designed for low speed and often have a road width of around 2.5 m. They can be steep, up to a maximum adverse gradient of 17% (20% for short distances). Many establishment tracks are converted into secondary or spur roads once the forest has reached harvest age (FOA, 2011). New two-staging innovation aims to increase the gradeability of these roads so that they can traverse steeper terrains (Ellegard, 2018).

The other components to the infrastructure are landings. This term is not well defined and can also have other names, such as deck or skid (Geerts & Twaddle, 1984; Visser, Spinelli, & Magagnotti, 2010). Visser et al., (2010) defines a landing as an area of the forest used during times of harvest to process stems or trees extracted from the forest, store them, and then load out the logs. Ideally a landing is a flat area with all obstacles removed such as trees and stumps and can vary in size depending on operational requirements (Visser et al., 2010). Landings have always been an essential part of larger scale harvesting operations, but they can be expensive to build, and their location and size is essential to an efficient and safe operation. Landings can be broken into four categories based on their use and size (Visser et al., 2010). A ‘Pad’ which is a smaller landing, often used in two-staging. Usually used to extract the logs two then transferred to another machine to extract the log to a larger landing for processing and sorting. A ‘Skid’ which is currently the most common form of landing, services one harvesting crew for all their processing and storage needs and provides space for loading functions. A ‘Superskid’ is a large landing were stems and logs are forwarded too, often by two-stage type operation. This landing is used to concentrate the processing or cross cutting of these stems or logs and stored to be fleeted onto highway trucks. Finally, a Central Processing Yard (CPY) is the largest landing category. These typically are located close to a mill, port or railway head. They often offer more sophisticated or automated processing and are rare in New Zealand.

While infrastructure is critical to extracting timber from plantation forests, it is a high capital cost to implement. With a large proportion of the national forest estate being first rotation forest needing new infrastructure, and on steeper terrain (Raymond, 2012). This leads to a lot of infrastructure that is needed to be constructed in more challenging terrain. This terrain brings up the cost and increases the adverse environmental impacts with increased erosion (Wade, Bolding, Aust, & Lakel, 2012) and side-casting (Ellegard, 2018). Many of these forests are on more challenging terrain where the harvest volumes are smaller than the traditional large-scale forest making this capital outlay a higher proportion of the harvesting cost since there is less to harvest and offset the cost of installing infrastructure. The shift to steeper terrain also presents problems with erosion (Nosrati, Haddadchi, Collins, Jalali, & Zare, 2018) and simply being able to make roads that trucks can traverse.

One way to reduce the infrastructure needed for harvest operations is to implement a system called two staging. Two staging is where the wood is removed off the landing or pad to be sorted and stored somewhere else (Ellegard, 2017; Visser et al., 2010). Traditionally this was due to space constraints on the landing or terrain leading to the landing couldn't be negotiated by on highway log trucks (Ellegard, 2017). The secondary landing usually remained close to the first landing with log trucks still entering the forest to be fleeted with the logs. The FGR concept envisions a central sort/stack yard at the edge of the forest as close to a public roadway as possible. This could be a few hundred meters or several kilometres away (Ellegard, 2017).

3. TWO-STAGE OPTIONS

They are many two-stage operations currently being implemented; these vary from skid trails and off-road forwarders to modified off-highway stems trucks. Some examples of these systems are:

Skidding or shovelling

The yarder hauls stems to the pad then an excavator with a grapple shovels the stems to a processing skid nearby, or for longer distances a skidder pulls the logs to the processing skid. The logs are processed and fleeted onto on highway log trucks at this processing skid. This option is typically used in swing yarder operations where the pad is put out to the edge of a ridge or spur. For example, IFS Growth using a John Deere 848L grapple skidder for a swing yarder operation (Figure 1)

Figure 1. John Deere 848L Grapple Skidder

Super forwarder

The Super forwarder option uses modified all-wheel drive off-highway trucks of various types and configurations. This system typically involves stems being hauled to a pad and cut to length on the pad, then the logs are loaded onto the super forwarder which ferries the logs to a Superskid. This Superskid is adjacent to a public road so that on-highway log trucks do not need to enter the forest. This can mean that road standards do no need to accommodate on-highway log trucks and therefore can have a steeper grade and landings can be smaller due to less wood being stock piled and there being no need for extra room for trailers. There are many options for modified off-highway trucks being used. For instance, Forest360 using an 8x8 TATRA TERRNo1 232R80/449 forwarding truck (Ellegard, 2017) which can carry a payload of up to 30,000kg (Figure 2). While Port Blakely using a modified 8x8 Foden for a small woodlot (Figure 3). A modified 8x8 Mercedes Acros off-highway truck being used to increase productivity in the Kaingaroa Forest (Figure 4). Rosewarne Cable Loggers using a modified Bell TH304E 6x6 dump truck. This truck was modified with an extended chassis and a double bunk set up to carry logs. This machine had average travel speeds of 7km/h loaded and 8 km/h unloaded (Holmes, 2017). They truck was so successful they have since purchased a T403E Bell truck (Figure 5; Ellegard, 2017). Douglas Logging use multiple 8x8 Scania forwarding trucks that are 440hp and can carry between 20 and 25 tonne in logs (Figure 6; Ellegard, 2017).

Figure 2 Tatra 8x8 off-highway forwarding truck.

Figure 3 8x8 Ex-military Foden off-highway forwarding truck.

Figure 4 8x8 Mercedes Arocs off-highway forwarding truck.

Figure 5 Bell TH403E 6x6 modified dump truck.

Figure 6 Scania G440 8x8 modified off-highway truck.

Stems trucks

The Stems truck option of two-staging is similar to the Super-forwarder option, in that an off-highway truck transports wood from a pad to a Superskid adjacent to a public road. However, it differs from the Super-forwarder option in that the stems are not cut to length at the pad but are instead loaded directly onto the stems truck which then ferries the wholes stems to the Superskid. The stems are processed at the Superskid then stored and fleeted onto on-highway log trucks.

Button logging, for example, uses a Kenworth 904 6x4 stems truck for their two-stage operation (Figure 7).

Figure 7 Kenworth 904 6x4 truck with twin axle trailer.

4. PROBLEM STATEMENT AND OBJECTIVES

The implementation of infrastructure into steeper more erodible woodlots in New Zealand requires more cost and presents more risk to the environment. While there has been innovation in industry around this problem, there has been little research around new systems such as two-staging.

Objectives

- To survey people within the industry and gather information on two-staging. Specifically, to find what factors motivate or deterrer people involved in the two-stage operation; what type of system they are using and the size of the crew operating the two-stage system; along with their average production targets.
- To quantify the reduction in landing and roading infrastructure in the Kenderdine forest by comparing the two-stage Tatra forwarding system against the originally planned highway log truck to landing system.

5. METHODS

5.1 Case Study

The Forest360 two-stage operation consisted of a Superskid adjacent to the public road. This was used for sorting and storage of logs before they were fleeted onto logging truck to be carted out of the forest. There was a full time tracked loader at the super skid to load trucks and sort logs stacks as well as unload the two-staging machine. This machine was a Czechoslovakian 8x8 Tatra truck. The truck has a 380hp air cooled V8 engine and independent suspension to help with stability. To perform the two-staging roll in the forest this Tatra truck was modified. These modifications include attaching 4 bolsters that were widened to 3.05m (max width without a pilot to allow for easy transport) and a sliding rear tailboard to accommodate differing log lengths. The truck also had super single tyres fitted all round (in conjunction with the inside duel on the back). This increased the load rating of the vehicle and widened the track by 500mm to help increase the stability of the truck.

This truck was used to forward logs of differing sizes from various pads around the forest to the central Superskid. This operation had, at the time of this study, a tower hauler and a ground-based crew working in the forest and the Tatra was servicing both crews. This two-staging operation was being implemented in the Kenderdine forest. The forest is approximately 420ha on clay/Taranaki ash soils and is located just east of Maxwell on the Manawatu – Wanganui/Taranaki region boarder (Figure 8).

This forest was planned originally for a log truck to landing operation. However, Forest360 perceived many benefits from a two-stage operation within this forest and therefore implemented the system described above. This study aimed to investigate this two-staging operation being undertaken by Forest360. Specifically, I aimed to quantify the reduction in landing and roading infrastructure in the Kenderdine forest by comparing the two-stage Tatra forwarding system against the original highway log truck to landing system.

Figure 8. Map of Kenderdine Forest location.

To achieve my second objective, to quantify the reduction in landing and roading infrastructure in the Kenderdine forest by comparing the two-stage Tatra forwarding system against the original highway log truck to landing system, I assessed the harvest operations in the Kenderdine forest. The forest is being managed by Forest360. It is just east of Maxwell on the northern edge of the Manawatu–Wanganui region (Figure 8).

To measure and compare the infrastructure between the two systems, I compared on the ground measurements of implemented infrastructure to that in the original plan for the forest. Next, I took a handheld GPS unit (Garmin GPSMAP 60CSX) to the Kenderdine forest in order to map the perimeter of the implemented landings and the length of the roads that are used with the Tatra forwarding system. For the purpose of this study a landing was define as any area that has been ‘built (including the removal of topsoil), compacted, flat, and contiguous (Visser et al., 2010). If a road clearly goes through the landing, that portion of the road was included in the measurement of landing area. However, if the road was besides the landing then it was be excluded. Areas prepared for vehicle parking were included if it met the above criteria of landings.

To measure the roads, I travelled around the forest roads at 18 km/h with a GPS unit in a light vehicle and measures a track. The roads measured were defined as all roads that service the landings and that logs are carried across. These GPS coordinates were uploaded as a GPX file into Easy GPS and converted into a KMZ file and then imported into ARCGIS. Then, I created a map of the Kenderdine forest in ARCGIS using LINZ as a base layer. The KMZ file was then imported to this map and editor was used to trace the GPS roads or perimeters to generate a separate shape file for each infrastructure type. This allowed me to measure the distance of all the roads and the perimeters and areas of landings for comparison with the original plan.

The two-stage operation at Kenderdine forest did not construct infrastructure throughout the whole forest. A small number of settings in the southeast section of forest had not been harvested and therefore did not have infrastructure built to them at the time of this study. Given this, the infrastructure from the original harvest plan to these settings was measured and then subtracted from

the original harvest plan. This section was mapped in the ARCGIS file outlined above and measured. This ensures that infrastructure measured on the ground was compared to the same settings from the original harvest plan.

These two quantities of infrastructure were compared to calculate the reduction in terms of percent area and absolute area (m^2). This procedure was repeated for the landings and roads individually as well as the combination to find the reduction in total infrastructure.

5.2 Survey

Two-staging operations represent an innovation proposed to combat issues surrounding harvesting of small wood-lots in steep-terrain despite its proposed benefits there is no consensus in the industry about what systems to use, when to use them, or what benefits you will gain from that system. There is also little information on what proportion of the industry is using two staging and for what reasons.

Given these gaps in two-stage knowledge, a survey was conducted to gather information about the current state of two-stage operations in New Zealand as well as why and how people are undertaking these operations. Specifically, the aim of this survey was to find what factors motivated people to use a two-stage system and what factors deter them from using a two-stage system. The survey was also used to gather information about what type of systems and machines people were using within the industry and find out what were the sizes of crews using two-staging and how productive they were.

One of the aims of the survey was to examine if the motivations for using two-stage operations were similar to the problem mentioned previously around the infrastructure impact, protection of the environment and interruption of the logging operation by (Brown, 2018; Brown & Visser, 2017). From the survey done by Brown & Visser it was found that landowners had low levels of satisfaction with value recovery (59%) and the overall economic outcome (64%). Since forestry has moved more to steep terrain, landowners are also concerned with multiple factors including protecting the environment, property damage and disruption of operations (Brown, 2018). The shift to steeper terrain also presents problems with erosion (Nosrati et al., 2018) and simply being able to make roads that log trucks can traverse. Given previously cited challenges and low satisfaction of landowners, this study aims to determine if and how two-staging operations may overcome these issues.

This information will allow forestry to identify the motivations and reasons behind two-staging as well as the barriers to it. This knowledge may provide information which could illuminate the areas that require further study. This sets up a baseline for further studies and is a step towards understanding whether two-staging is a viable operation for New Zealand forestry.

To examine the motivations and deterrents for two-staging operations in New Zealand forestry and describe the operations in terms of machinery, crew size, and productivity; I surveyed contractors and forestry managers at multiple forestry and logging companies. Surveys were conducted via phone interviews to ensure that respondents were appropriate.

Respondents were given the survey's definition of two-staging:

"Introduction: I am a university of Canterbury forest engineering student doing research into the applications of, and drivers behind two-stage operations in forestry. In this instance two-staging is defined as transporting stems or logs from a smaller landings/pad to a larger Superskid to be processed or stacked into log grades, then fleeted onto highway trucks."

Following this introduction, respondents were asked if they had been involved in two-staging and why. This provided information about their motivations and deterrents which were then categorised and recorded into a series of tick boxes. These questions were open-ended, and respondents were not provided with prompts (i.e. the tick boxes) of motivations/deterrents. Then respondents were asked a series of questions about the system they used for two-staging (i.e. swing yarder hauling stems to pad then skidder moving stems to processing yard). Subsequently, they were asked about their machinery, number of machines in their operations, number of people in their crew, and typical production target. This allowed me to assess the range of crew sizes and machinery currently by the forestry industry for two-stage operations. A blank survey is attached in Appendix.

6. RESULTS

6.1 Case Study

Kenderdine forest roads were measured using GPS to track the extent in meters of roading infrastructure for the two-staging operation (Figure 9). These roads summed to a total length of 9581 metres (Table 1). These measured roads were then compared to the original planned roading infrastructure which was not designed for two-staging operations. Original planned roads for log truck to landing configuration summed to 12521 metres (Table 2) for the section of forest now under two-staging operations. Implemented roads totalled 2940 metres less than the original plan, a 23% reduction in roading length for this section of forest (Table 3). Skid sites were also measured in the Kenderdine forest including the super skid (Table 4). These skids ranged from 221 metres squared to 3836 metres squared (Table 4), while the super skid measured 6071 metres squared. The average skid size for skids not including the super skid was 1947 metres squared, including the super skid the average skid size was 2084 metres squared (Table 5).

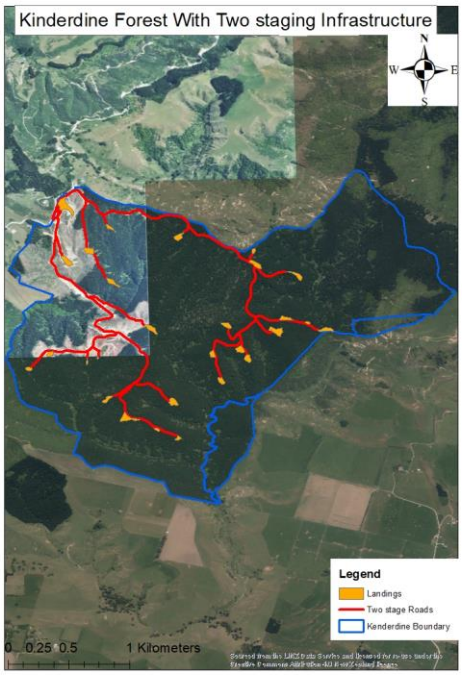

Figure 9 Map of the Kenderdine forest with roads and landings as measured with GPS.

Table 1 The length of roads in the Kenderdine forest measured by GPS (in metres).

Kenderdine GPS measured roads	
Road	Road length (m)
1	212
2	2564
3	173
4	455
5	15
6	151
7	299
8	501
9	53
10	100
11	623
12	219
13	249
14	711
15	563
16	304
17	634
18	431
19	318
20	181
21	503
22	322
total	9581

Table 2 Original planned roads for log truck to landing configuration (in metres). Planned road not used is the roading planned into the setting that have not been harvested yet and there is no two-staging infrastructure.

Conventionally planned road length	
Road type	road length (m)
Total road upgrade	2800
Total road new easy	6995
Total road new difficult	5240
Planned road not used	-2514
Total	12521

Table 3 . The difference in roading of the two-stage operation compared to the original log truck to landing plan.

Two-Stage roading difference	
Roading difference (m)	-2940
Percentage reduction	-23%

Table 4 Areas of the landing sites of the Kenderdine forest including the Superskid measured with a GPS (in metres squared).

Kenderdine Skid areas	
Skid	Area (m^2)
Super skid	6071
1	2443
2	625
3	2020
4	3836
5	1721
6	1580
7	2005
8	2394
9	2067
10	2339
11	2605
12	854
13	2200
14	2179
15	1368
16	961
17	714
18	3772
19	1689
20	2645
21	2648
22	1040
23	1425
24	541
25	221
26	2199
27	2523
28	3099
29	2743
Total	62528

Table 5 Average size of the skid sites measured in the Kenderdine forests both including and excluding the Superskid.

Average skid sizes	
Average skid size excluding superskid (m^2)	1947
Average Skid size includeing Superskid (m^2)	2084

From the results it can be seen that the two-stage system used in the Kenderdine forest reduced the roading infrastructure by 23%. Often in small wood lots, roading represents a large cost; therefore, this result is a large reduction in roading infrastructure and would translate into a cost saving. This reduction in roading could also represent a reduction in environmental risk as less soil is being disturbed to construct the roads and less impervious surface which would prevent infiltration of rainfall.

The landing sizes of this operation were found to range from 221- 3836 m^2 with the Superskid at 6071 m^2. This gave an average landing size of 1947 m^2. When compared to a study by Visser on landing size in whole-tree harvesting they found that landing size throughout New Zealand ranged from 1370-12540 m^2 with an average landing size of 3900 m^2 (Visser et al., 2010). Comparing these landing sizes with those found in the Kenderdine study shows a 50% landing size reduction if the Superskid is not included. This means the more landings the Superskid services the smaller the relative impact of the Superskid. Even if the Superskid is included in the average landing area this only increases the landing area average to 2084 m^2. This still indicates a reduction in average landing size of 47%. This means even with the Superskid, this two-staging operation has less infrastructure than standard operations.

6.2 Survey

Survey respondents included 15 people representing current managers or contractors at multiple forestry and logging companies through New Zealand. All those surveyed indicated that they had experience with two-staging. Following are highlighted responses and general patterns, for specific details from each respondent see Appendix.

Productivity targets were reported by most of the respondents except respondent A. They ranged from 120 to 600 tonnes per day (Table 6). Most crews ranged between 250 and 350 tonnes per day targets, with 8 crews in this range (Table 6**Error! Reference source not found.**). There was a large gap in responses above this until respondent E cited a daily target of 600 tonnes or more. A couple of crews cited targets of 120 tonnes per day, although one respondent stated that this low target was due to the market price drop. In addition to motivations, respondents to the survey also differed in the number of people and machines used in their operations (Table 6**Error! Reference source not found.**). Respondent A did not provide this information. The remaining respondents varied between 5 to 12 people. The machines used ranged from 5 to 14. There was little pattern between crew size and number of machines in that crew, but this did reveal that two-staging operations are being used across this range of sizes.

Table 6 Productivity, number of machines and number of crew members for each of the respondents two-stage operations.

Respondent	Number of People	Number of Machines	Productivity t/day
A	NA	NA	NA
B	6	6	180
C	5	5	120
D	9	5	256
E	12	14	600+
F	9	5	256
G	8	6	120
H	7	6	280
I	7	9	220
J	10	7	320
K	9	8	320
L	8	5	180
M	9	6	300
N	7	10	300
O	10	5	350

The respondents to the survey identified several motivations to using two-staging in their forestry operations (Figure 10. Responses motivation and deterrents of two-staging survey.Figure 10). These motivations included over coming terrain restrictions, increasing productivity, improving value recovery, because of location/access issues, environmental reasons and safety reasons. There was also a prevision to record any ‘other’ factor that may have motivated a participant to use two-staging. Many of the people surveyed gave multiple reasons for using two-stage operations. Despite several options for deterrents, those who indicated that there was a deterrent only identified cost as the downside (Figure 10).

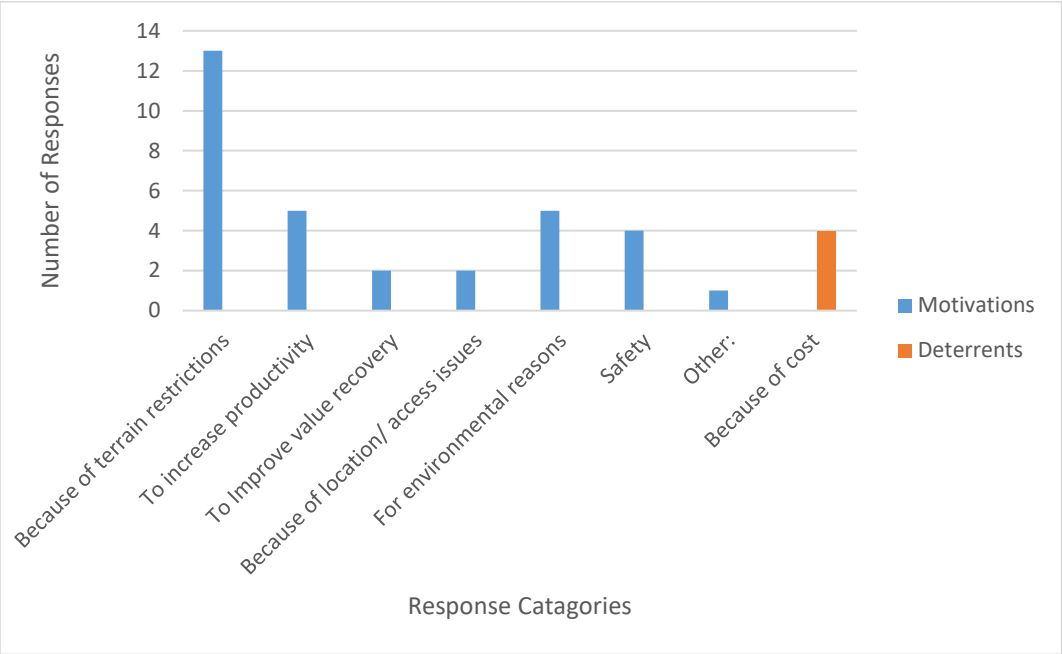

Figure 10. Responses motivation and deterrents of two-staging survey.

From those that indicated that extra cost was a deterrent to two-staging, they also stated that their only motivation was due to terrain restrictions. These respondents represent one group within the data set. Three out of four respondents in this group used a skidder or shovelling machine for their two-staging operation, while the fourth used a Volvo all-wheel drive truck. Those who selected cost as a deterrent made up the majority of people who used either a skidder or a shovelling machine for two-staging. In total 5 people used a skidder or a shovelling machine while 10 people used an off-highway truck of some description.

The other group of respondents (11 out of 15), did not mention extra cost as a deterrent but had multiple motivations, except for respondent B, for using two-staging (Figure 10). This group also used various methods of two-staging to complete their operations. Those who did not mention cost as a deterrent can be further divided into two groups: those who cited terrain as a motivation (9 respondents) and those who did not (2 respondents), though terrain was not necessarily the only motivation.

The majority of those who cited terrain as motivation, used off high-way trucks for their operations; however, two respondents in this group used skidders. The respondents in this group used: grapple skidder, ex-military 8x8 modified Foden off-road truck (Figure 3); 8x8 Mercedes AROCS truck modified with log bolsters (Figure 4); a system of two specialized log trucks swapped at either end; 6 wheel drive Mercedes off-road truck; skidder; bullet train off road truck; Kenworth 904 off-road truck with two-axel trailer operating as a full stems truck (Figure 7); and Tatra 8x8 modified forwarding truck (Figure 2). All the off-road trucks used are not standard equipment and were modified for the role. Additionally, respondents were asked for specific machine information about their system; these responses varied extensively in their level of detail (see Appendix).

The two respondents who did not cite terrain as a main motivation and did not cite cost as a deterrent for two-staging, instead cited motivations of location/access issues, to improve value recovery, to improve productivity, and to improve safety. Within this group, respondent B stated no road access as

their only motivation for using two staging. This respondent used an off-highway log truck for two-staging. While respondents from other groups also stated no road access, these other respondents cited multiple motivations including terrain restrictions and used other trucks (a converted Bell articulated dump truck (Figure 5) and purpose-built trucks) to complete their operations.

Beyond these general group patterns of motivations and deterrents, this survey also revealed some important cases which I will describe in more detail. A specific case in the response from respondent E cited motivations of productivity and value recovery as well as safety. Since terrain was not a motivation, the respondent wanted to facilitate more space by using a two-stage machine. They yarded to a 40x40 skid then two-staged logs to 90x35 skid. This allowed them to keep the hauler productive and reduce stacks in the hauler's vicinity. Two-staging facilitated more space for log stacks which hold approximately 1500-2000 tonne on average per day. This also allowed for easy change of grade cuts leading to the ability to cut more grades and flexibility in the cut plan. The respondent also cited safety as a motivation stating that it eliminates the man to machine interaction.

Respondent C was the only respondent to cite 'other' as a motivation, though this was in addition to terrain restrictions and increased productivity. They stated that the amount of wood coming out of the forest was not worth the cost of the roading infrastructure for a small setting. Two-staging represented a viable alternative. By using ex-military 8x8 modified Foden off-road truck (Figure 3) which required minimal roading to minimize the cost of roading infrastructure. This respondent thought this system increased their productivity by keeping the primary pad relatively clear and the harvesting crew more productive.

7. DISCUSSION

7.1 Case Study

Forest360 indicated a need to reduce environment risk in the Kenderdine forest. One of these environmental risks was the risk of landing collapse after harvest potentially effecting waterways. The smaller landing size seen in the Kenderdine forest would help in mitigating this risk as less area has to be disturbed to make these landings and there is less fill batter. This smaller landing size may also increase the options of landing placement within the forest. This could potentially lead to less landings in general if wood could be pulled to more optimal locations.

This case study is subject to weaknesses and limitations. These include the fact that this study will only analysis one forest operation using the Tatra forwarding system. It uses an 'original' harvest plan to quantify the Infrastructure that would be used by the log truck to landing scenario. This has weaknesses as one foresters harvest plan may be different to the next due to personal preferences and differences of thinking. Therefore, it's not a direct comparison of two systems implemented in the same forest, rather a proposed system versus and actual implemented system. Another limitation is the accuracy of the handheld GPS unit.

One element that came up over the course of this study but was outside of its scope was drainage effects. BMPs for roading state that as road gradients increase the number of culverts increase also. However, with the ability to increase the road grade with a super forwarder the road can crest the

ridgeline in a lot of situations. This means that the road doesn't cut across a catchment so the only water it is moving is from the road surface.

The results of this case study show that there were large reductions of infrastructure compared to the original harvest plan and previous studies. This reduction shows that this two-stage system can help address the problems of infrastructure in small wood lots identified by Raymond (2012). Forest360 was not only successful in reducing infrastructure, but the operators also identified other perceived benefits of the system, i.e. productivity, value recovery, and safety. However, these benefits remain outside the scope of this study but represent viable avenues for further research.

7.2 Survey

From the surveys collected in this study there appear to be two groups of people who use a two-stage system: those who are forced to and those who choose to. Those who were forced to tended to not see any other benefit apart from getting around terrain issues and therefore associate an extra cost of two-staging as a deterrent. For example, one respondent said that 80% of their operations were two-staging; however, a new harvest coordinator wants to stop two-staging to move away from the extra cost. This perception is in direct contrast to a recent benchmarking study by Visser that shows the two staging can decrease the logging rate of a tower hauler by $1.42/tonne (Visser, 2017). However, these respondents used a more traditional two-staging system where the processing skid was not far from the hauling pad and were just getting a better position for their hauler and not getting the other benefits from two-staging. On the other end of the spectrum, were those who saw multiple benefits from two-staging. This group did not associate the extra cost of two-staging as a deterrent. This group predominantly used off-highway trucks where the Superskid was close to the edge of the forest for loading logs out. This system was expected to reduce infrastructure and environmental risk. This shows there is a link with the system type and perceived costs.

Most of the people who perceived extra cost also reported using a shovelling or skidder system for their operation. While most of those who say multiple benefits used off-highway trucks, except for two responders who used skidders, one of these respondents was looking into using a Tatra forwarding system. While this pattern suggests that different systems of two-staging may provide different benefits or costs, further investigation is needed to understand this link.

Many of the respondents who listed multiple benefits aside from terrain cited increased productivity, increased value recovery, reduction of infrastructure, reduction of environmental risk, and increased safety from two-staging. All these point toward the risks involved with using a new system is less than the risks of causing harm to the environment, having un-productive crews, or being unable to service debt of their machines. However, some people only see the cost, suggesting a barrier which prevents people from utilizing two-stage operations. Lack of knowledge about these systems may be contributing to this barrier. Despite this reluctance, all the respondents to this survey have been involved in two-staging operations which indicates there must be a need for these types of systems.

Another factor contributing to this barrier may be the lack of standardized or off the shelf machinery for some of these two-stage operations. Most of those who claimed multiple benefits used off-highway trucks. These trucks needed to be modified, often needing bolsters to be fabricated and attached. These modifications are an extra cost to an often already depreciated machine, and if the operation were not a success then the markets for these non-standard machines may be small and unknown, making salvage costs and machine costing difficult. Whereas a traditional machine, such as a grapple loader or

skidder, is more commonly used in forestry allowing for easier resale and costing of these machines. Therefore, modification and fabricating specialized machine represents more capital risk. More knowledge about two-staging operations and their associated risks and benefits may help break down some of these barriers. Also, if more companies start two-staging, there would be a bigger market for these modified machines.

Each system of two-staging has different risks and benefits. For example, one respondent claimed that his two staging of full stems to a Superskid was an ideal system as it allowed for good roading and control of water which helped mitigation of environmental risks. However, there was one major problem, the accumulation of all the forest slash at one central Superskid. This poses a fire risk and has cause major fires in the past. It also makes the slash management of the forest difficult. This risk could also provide an opportunity. If there was a market established for this biomass to be used hog fuel or chip, its location at a central Superskid could aid in pickup making it more viable for a market to collect and thereby reducing fire risks for the contactor. The Tatra system can also control for environmental risks by using good roads but do not pose the risk of accumulated slash. These represent some examples of the benefits and risks associated with different systems as well as potential mitigation opportunities.

This study highlights some of the motivations and deterrents for two-staging operations in New Zealand forestry. It shows trends in benefits and types of systems used as well as establishing a baseline for further studies. This survey collected 15 respondents which represents a small part of the forestry industry and additional surveys will help paint a more complete picture of people's motivations for and barriers to using two-staging. Additionally, these conclusions are based on people's responses to a survey and have not been investigated or researched to support their claims. Further studies are required to determine how these perceived benefits translate into productivity gains or infrastructure reduction as well as the impact on the environment. By informing contractors and managers about how each two-staging system works they could make more informed decisions about which system is most applicable to their forest and will allow them to get the benefits they desire.

8. CONCLUSIONS

The case study presented here shows a large reduction of infrastructure in the Kenderdine forest when compared to the original plan and the study on landings by Visser. This confirms the claims around the Tatra two-stage system being able to reduce the infrastructure within a forest in steeper erodible terrain. This will result in a cost saving as less infrastructure has to be built to harvest the same amount of land and more land is left as productive for the next rotation.

The survey study showed that there are two main groups of people using two-staging, those who perceive cost as a deterrent and those who don't. Those who perceive this deterrent generally use a two-stage system were the processing skid is not far from the pad and mostly use a skidder or shovelling system. The group that doesn't perceive this deterrent mostly use a system that involved off-highway trucks where log trucks don't enter the forest at all and are only loaded from a central skid.

Interestingly, one respondent claimed his stems truck operation was the only way to two-stage as it allowed him to control water flows and erosion better, yet they had large environmental risks of slash

fires at their Superskid and slash management issues. Respondents using other off-highway truck systems also claimed these environmental benefits but processing at the pad removed this fire risk and large slash management problem. This indicates that if more information was available about the different types of systems and their benefits contractors and managers could make more informed decisions about what type of system wold suit their application.

One prominent outlier of the survey was respondent E. This respondent was the only one that wasn't restricted by location or terrain. Instead their motivations were safety, productivity and value recovery. This crew was very productive with a daily production target of 600+ tonne/day. This example shows that the benefits of this system may stretch beyond the motivations of terrain difficulty in steep woodlots and into other areas of forestry.

Further studies into the other benefits of two-staging will help managers and contractors to select a system that is applicable to their operation. With more information and certainty, the risks involved with using a two-staging system will be better understood and this could reduce the barriers stopping people from gaining the full benefits from two-staging. More research into things like productivity and value recovery as well as reduction of environmental risk would clarify these perceived benefits and help quantify them.

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10. REFERENCES

Brown, K. (2018). *Harvesting woodlots in NZ: What do small-scale Landowners and loggers think?* Paper presented at the 2018 Forest Engineering Conference, Rotorua, New Zealand.

Brown, K., & Visser, R. (2017). A survey of New Zealand farm forest owners who recently harvested. *New Zealand tree grower, 38*(3).

Ellegard, J. (2017, 1 june 2017). The 2-stage Challenge. *New Zealand Logger*.

Ellegard, J. (2018). Breaking Out. *New Zealand Logger*.

FOA. (2011). New Zealand Forest Road Engineering Manual.

FOA. (2018). Facts and Figures 2017/18.

Geerts, J., & Twaddle, A. A. (1984). method to assess log value loss caused by cross-cutting practice on the skidsite. *New Zealand Journal of Forestry*.

Hollinger, D., Maclaren, J., Beets, P., & Turland, J. (1993). Carbon sequestration by New Zealand's plantation forests. *New Zealand Journal of Forestry Science, 23*(2), 194-208.

Holmes, L. (2017). *Review of the Madill 124 Swing Yarder*. Retrieved from

LINZ. (2019). Crown Forest Land. Retrieved from https://www.linz.govt.nz/crown-property/types-crown-property/crown-forest-land

Nosrati, K., Haddadchi, A., Collins, A. L., Jalali, S., & Zare, M. R. (2018). Tracing sediment sources in a mountainous forest catchment under road construction in northern Iran: comparison of Bayesian and frequentist approaches. *Environmental Science and Pollution Research, 25*(31), 30979-30997.

NZIER. (2017). *Plantation Forestry Statistics*. Retrieved from

Raymond, K. (2012). Innovation to increase profitability of steep terrain harvesting in New Zealand. *New Zealand Journal of Forestry, 57*(2), 19-23.

Visser, R. (2017). Benchmarking Harvesting Cost and Productivity - 2016 Update. *Forest Growers Research*.

Visser, R., Spinelli, R., & Magagnotti, N. (2010). Landing size and landing layout in whole-tree harvesting operations in New Zealand.

Wade, C. R., Bolding, M. C., Aust, W. M., & Lakel, W. A., III. (2012). Comparison of Five Erosion Control Techniques for Bladed Skid Trails in Virginia. *Southern Journal of Applied Forestry, 36*(4), 191-197. doi:10.5849/sjaf.11-014

11. APPENDIX