

Improving Helicopter Yarding with Onboard GPS

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by
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Abstract

Despite its relatively high cost, helicopter yarding has become a common means of timber extraction where site sensitivity, access, or regulations limit the use of less costly alternatives. Although still primarily found logging salvage sites and less accessible high-value timber, helicopters are increasingly used in thinnings and/or lower value stands. The high costs associated with helicopter yarding, as well as the desire to expand the application of this system to extract lower value timber, increases the need for innovation to improve the operations.

The cost or benefit of a particular harvest prescription or innovative technique is commonly assessed with a time and motion study. Capturing time study data requires additional personnel or an imposition on the operator to record additional information. Onboard GPS can reduce or eliminate the need for additional personnel and/or operator input. It has been successfully employed in trucking and ground based forest operations to conduct gross and elemental time studies. In addition, implementation of automated evaluation program can reduce data processing time, increasing the advantage of the onboard GPS. The potential benefits of onboard GPS in helicopter yarding with a means of automated analysis could provide a rapid means of assessing and improving helicopter operations.

This research employed onboard GPS in helicopter yarding to assess the potential of developing time studies using GPS data. Three cases studies were carried out to assess the potential effectiveness of this new technology application: (a) establishing the difference between experienced and inexperienced pilots at the elemental task level, (b) establishing the impact of canopy cover on the hook time by matching the elemental time study data with post-harvest digital fish-eye photography of the canopy cover at the hook point as located by the GPS data, and (c) generating a series of productivity functions that include both a velocity and acceleration component.

Three helicopter models were sampled on a total of nine sites. An automated data processing method was developed to make the technique feasible across multiple sites and conditions. This procedure created elemental time study data, including outhaul, hook, inhaul, and unhook. Hook and unhook elements were area based using a 20 and 35

m radius respectively. Outhaul and inhaul were dependent upon time spent between the landings and hook area. Pilot, payload, and choker delivery information was applied to each corresponding turn using data commonly recorded by the co-pilot. Three of the sites have both experienced and inexperienced pilot data. Hemispherical canopy images were sampled at three sites. Percent canopy cover was measured by zenith angles, increasing by 15° increments starting with 0 - 15°. This complement of data permitted the following analysis: assessment of differences between experienced and inexperienced pilots, assessment of canopy cover on hook time, and the development of site based production models using velocity and acceleration in one set and distance in another.

The results indicate onboard GPS and the automated processing methods are suitable for creating time study data. Specifically, in all three case studies quantitative results were obtained, analyzed and opportunities for improvement identified. The time penalty suffered from using inexperienced pilots created 64 to 94% additional turn time, where total turn times for choker delivery resulted in the greatest penalty. Despite a hook point location offset, which impacted the canopy cover measurements, increasing canopy cover correlated with increased hook time at two sites for the zenith angle segment 0 – 15°. This explained up to 12% of the hook time variation. Regressions assessing production show distance, slope, and choker delivery to be significant. Turn of cycle and turn of day were commonly significant as well, typically indicating an improvement in production throughout the day. This research shows the combination of onboard GPS, the automation process, and commonly collected turn information presents a number of opportunities, enabling the assessment of a wide range of helicopter yarding conditions.

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Introduction

Forests are an important global asset. Comprising 30 percent of the terrestrial surface, nearly 4 billion hectares, forests improve water quality, produce wildlife habitat and biodiversity, sequester carbon, and provide livelihoods (FAO 2006a). Despite declining real dollar roundwood values (FAO 2006b) the forest industry encompasses up to three percent of global GDP (FAOSTAT 2003). The US holds more than seven percent of the world's forestlands with an annual net volume increase 38% greater than the volume of removals (Alvarez 2007). Forest ecosystems of the US and the domestic forest products industry are estimated to sequester 162 Tg of carbon annually (Woolbury et al 2007). This forest industry comprised 2.7 percent of US GDP in 1999 (EIA 2004).

A combination of global market forces and disincentives encourage a reduction in US forest area. While US forestland area has maintained a fairly stable level over the last century (Alvarez 2007), a two percent decline is projected by 2050 (Alig et al 2005). This decline is due to competing land uses where forests are converted to more profitable functions, primarily urban development. Development not only results in permanent reduction in the forest land base, but it causes parcelization and fragmentation, which reduces the ecological function of the remaining forestland as well as its value as a forest product resource (Deal and White 2005). An additional direct result is a reduction in carbon sequestration, water quality, and biodiversity. Further reductions in forestland are dependent upon returns from forest and agricultural land. An analysis of the southeastern US showed unchanging returns from either land use would result in conversion of forestland to agricultural cropland (Wear et al 2007). Diminishing forestland limits the ability of forest managers to capitalize on economies of scale, thus, increasing management costs.

Facing a reduction in US forestland, profitable forest management opportunities are necessary to retain long term forest cover. As indicated by Wear et al. (2007), a relative increase in returns from forestland results in increased forestland. While many argue for forest preserves or set asides, Sohngen et al (1999) showed a one percent set aside of the global forest resulted in 1.4 million hectares of additional harvest in areas previously considered inaccessible.

High harvesting costs are a common obstacle in the pursuit of profitable forest management. Keegan et al (1995) reported stump to truck costs in Montana from \$87 to \$123 per MBF for ground based systems, \$131 to \$164 per MBF for cable yarding, and \$233 per MBF for helicopter operations. More recent estimates for the eastern US require an additional \$100 per MBF for these cable and helicopter estimates. Hartsough et al. (1997) found ground based skidding to account for approximately 20-25% of the

stump to truck operation costs, helicopter yarding ranged between 65 and 78% of the stump to truck costs (Krag and Evans 2003; Dunham 2003). Considering the capital costs for harvesting equipment, these figures are not surprising. For example, ground based mechanized systems call for initial investments between \$400,000 and \$1.5 million; requiring monthly payments from \$5,000 to \$20,000 (Rickenbach and Steele 2005). However, operating and ownership costs are offset against productivity, and improvements in productivity can reduce the cost per unit volume.

Various technological advancements can be employed to improve net production or value recovery as well as reduce operating costs. However, Sedjo (1999) stated that innovations in harvesting are modest at best and barely keep up with increasing costs of harvesting. In the absence of productivity breakthroughs, the pursuit of reduced costs continues. Murphy et al (2006) used onboard harvester computers to apply adaptive and fixed proportion processing control methods to improve value recovery. Haynes and Visser (2004) used a portable computer to improve value recovery in bucking operations. Skyline operations in the western US have recently implemented radio controlled chokers to reduce labor, improve safety and increase productivity. Skog Forsk recently demonstrated a prototype hybrid forwarder; showing 20% to 50% reduction in fuel consumption (Lofroth et al 2007).

An assortment of these and other technologies can be applied to many of the harvesting systems in use today. Currently the low-cost advantage goes to mechanized ground based systems operating on sizeable, level forest tracts with large uniformly sized trees. These conditions make mechanized ground based operations the most economically efficient. This efficiency is also reflected with improved safety, where mechanization reduces the accident rate relative to manual operations (Rummer 1997; Shaffer and Milburn 1999; Roberts et al 2005). As terrain conditions become more difficult, such as increased slope, wet or low strength soil conditions, or other factors, ground based operations become more limited (Andersson and Young 1998 and others). Concerns over site disturbance or reduced operational productivity call for the implementation of alternate harvesting methods that can effectively operate in more restrictive conditions. When operational constraints increase, viable system options may move from mechanized ground based to cut-to-length operations, cable yarding, or, in the most restrictive conditions, helicopter yarding.

The high cost of helicopter yarding is somewhat balanced by its high production, reduced road construction costs, and reduced site impacts. While alternate yarding methods are terrain limited, the natural advantage of helicopter yarding is its operation above the terrain. These differences in site conditions often make direct production rate comparisons difficult, but suggested increases of 1.5 and 2.8 times that of ground based

and cable operations were proposed (Wang et al 2005). Because of the high operating costs, the helicopter logging crews and equipment are well coordinated to optimize production (MacDonald 1999). While many yarding systems are limited to relatively short distances, helicopters can economically extract timber up to a mile or more. This advantage reduces the need for road construction near the harvest site. Along with reduced road construction, Aust et al (2006) showed helicopters to have lower soil impacts relative to ground based operations, and Han and Kellogg (2000) demonstrated less stand damage with helicopters over ground based and cable operations. These low site impacts and high production rates have made helicopters increasingly important in the management of natural forest lands.

Employed since the early 1950's, helicopter yarding is incredibly versatile due to its ability to avoid many of the obstacles that encumber ground based and skyline systems (Samset 1985; Conway 1976; Burke 1973). The use of helicopters in forestry continues to expand. Where there were only a few of firms offering helicopter logging services in the early 1970's (Conway 1976), today the Helicopter Association International estimates almost 175 forestry or logging companies use helicopter logging as a principal means of yarding timber (Bruce 2003). Helicopters are a common tool for removing difficult to access high value timber as well as salvage logs resulting from fire, hurricane, and insect outbreaks. However, helicopters are increasingly used in accessible thinnings and lower value stands.

The variety of helicopters used in forest operations is also fairly extensive. Table 1 indicates the manufacturers and models used in British Columbia, Canada, where helicopter logging is common. Helicopters are typically classified or rated by payload capacity which ranges from 1134 kg for the Eurocopter Lama to 12727 kg for the Boeing CH234. The US National Interagency Helicopter Operating Guide (IHOG) categorizes helicopters by payload capacity, where the largest category, a type one aircraft, must accommodate 2268 kg or more (NIFC 2006). As the table shows, most helicopters used for logging are capable of payloads greater than 2268 kg.

Table 1. Specifications for helicopters commonly used for logging in British Columbia, Canada (Krag and Evans 2003).

Manufacturer	Model	Rated payload capacity (kg)	Engines	Engine power (kW)	Main rotor diameter (m)	Tail rotor diameter (m)
Bell	204B	1814	1	820	14.6	2.6
Bell	205A	2268	1	1044	14.6	2.6
Bell	212	2268	2	671 (each)	14.7	2.6
Bell	214B	3636	1	2185	15.2	2.6
Boeing	V-107 II	4773	2	932 (each)	15.5	n/a
Boeing	CH-234LR	12727	2	3039 (each)	18.3	n/a
Eurocopter	SA-315B Lama	1134	1	640	11	1.9
Kaman	K-1200	2722	1	1342	14.7 (×2)	n/a
Kamov	KA-32A	5000	2	1645 (each)	15.9 (×2)	n/a
Sikorsky	S-58T	2268	2	700 (each)	17.1	2.9
Sikorsky	S-61N	3629	2	1044 (each)	18.9	3.2
Sikorsky	S-61N Shortski	4084	2	1044 (each)	18.9	3.2
Sikorsky	S-64E	9072	2	3356 (each)	22	5
Sikorsky	S-64F	11340	2	3579 (each)	22	5

Describing the Helicopter Yarding Process

For the purpose of studying helicopter yarding, the process can be broken into flight cycles, turns, and elements. The basic definition for a flight cycle is leaving the service landing, flying a number of turns and returning to the service landing for a service cycle. The basic definition for a turn is leaving the log or service landing and traveling to the location of the payload (outhaul), picking up the payload (hooking), returning to the log landing with that payload (inhaul), and releasing the payload at the log landing (unhooking). Each of the four segments of the turn just described is considered an element.

A typical flight cycle can be described as follows. Beginning at the service landing the helicopter will fly to the harvest area and begin yarding logs. During the hooking element there will often be a person, the hooker, on the ground with pre-choked logs. The logs are ready to be connected to the hook at the end of the helicopters long line (Figure 1). The pilot locates the hooker and maneuvers the hook near the hooker. Then the hooker slides the chokers into the hook. The hook commonly has two slots to accept chokers (Figure 2). One is used to accommodate an estimated reasonable payload of logs and the other is used as a ‘bonus’, to target the optimal payload. This system allows the pilot to release of the ‘bonus’ side of the hook, if the payload is too heavy or if the logs become entangled in the residual stand, also known as a hangup. The pilot then lifts the logs off of the ground and clear of the forest canopy.



Figure 1. A hooker putting the chokers onto the hook in a helicopter yarding operation (hooking a turn).



Figure 2. The underside of a hook with chokers in the slots.

The inhaul element begins when the pilot flies toward the log landing. At the landing the pilot sets the logs on the ground in the drop zone and releases the chokers from the hook (Figure 3). With the load released, the pilot clears the log landing and enters the outhaul element where he flies back to the woods for another load of logs. The entire process,

outhaul, hook, inhaul, and unhook, is commonly referred to as a turn. If no problems occur, this continues for 60 to 90 minutes, until the helicopter must be refueled at the service landing. When the helicopter is flying to the service landing, being fueled or repaired, this is called the service cycle.



Figure 3. A helicopter is descending toward the drop zone to release the chokers and leave the logs at the landing (unhooking).

There are some variations to this process. Chokers are regularly delivered to the hookers with the helicopter. Coiled chokers are placed in the hook immediately following the release of the logs at the landing (Figure 4). The chokers are usually delivered to the hooker whereby the hooker will often place flagging where the chokers are desired. The locations are intended to best accommodate choking the next available set of logs. After releasing the chokers, the pilot maneuvers the hook to yard the next turn. In some instances multiple choker drops are made to multiple hookers prior to yarding the next turn. This is accomplished by using both slots in the hook to deliver chokers and having the hooker re-attach surplus coiled chokers for any remaining choker drops.



Figure 4. Coiled chokers attached to the hook are retrieved from the log landing to supply the hookers in the woods.

Advances in Helicopter Yarding

Technological advances continually improve the means to conduct forest operations. These advances are not limited to innovations in harvesting equipment, but extend to our ability to monitor performance and improve operational techniques. The initial deployment of helicopter logging encouraged advances in the field of forest operations; from harvest area planning to equipment modifications, various lessons were learned and applied. The fast pace and high cost of helicopter operations demand efficiency and create a unique proving ground for technological advances.

It is rare for a helicopter to be specifically designed for lifting external loads. As a result most helicopters are not optimized for heavy lifting. In many instances logging helicopters are adapted for external lifting operations by removing passenger seating, shelving, storage compartments, long range fuel tanks, nonessential electrical equipment and nonstructural panels (Stevens and Clarke 1974). This reduces the aircraft weight, which allows for increased payloads. The total amount of fuel carried during yarding is also optimized in an attempt to achieve a good balance between increased payload capacity and minimizing the number of fuel stops.

As in many industries, advances in materials, designs, and applications have improved helicopter yarding. A specific example of this is the use of fiberglass or composite rotor

blades. These blades provide multiple benefits over metal blades. The design characteristics improve the lift and reduce power requirements of the helicopter, as well as reducing inspection and maintenance requirements (Spring et al 1979; Carson Helicopters).

The rigging used in helicopter yarding has also improved. Remote release of the payload in helicopter logging has been possible since the early days of operations. Figure 5 shows a once common hook type that was used at the end of the longline. A similar configuration is used to attach the longline to the helicopter. Along with reducing load release times, this feature improves the safety of the operation, enabling the payload or entire longline to be disconnected from the helicopter. Today, some operations use a hook that accommodates nubbin chokers rather than eyed chokers. These slotted hooks (shown in Figure 2) allow for partial load release and can accommodate a greater number of chokers at one time. This hardware improvement increases the opportunity for payload optimization through the use of the ‘bonus’ slot. A second rigging improvement is the conversion from a wire rope to a synthetic longline. Not only is the synthetic longline lighter, but synthetic rope does not have the same tendency to store energy like wire rope (Harter et al 2004). The energy stored in wire rope longline has resulted in damage to the helicopter (Stevens and Clarke 1974) and could temporarily make the hook difficult to handle due to excessive spinning after load release.



Figure 5. Helicopter hook for eyed chokers; type used prior to nubbin choker hook.

A variation on the traditional hook is the grapple. The grapple hangs from the end of the longline. It is designed to clamp a single log in its jaws, but it is possible to gather more than one log (Figure 6). This system eliminates the need for people to work under the helicopter in the woods, which improves the safety. It also eliminates the need to return chokers to the woods. However the grapple system weighs approximately 450 kgs, while the hook system weighs approximately 60 kgs. This results in a considerable reduction in payload capacity. In addition, this system is best suited for single log turns, while the hook system can accommodate a wide variety of turn sizes. The reduced ability to

efficiently accommodate multiple logs further limits the areas where grapples can be cost effective.



Figure 6. A grapple used for helicopter yarding.

Expanding on the advantages of the grapple, is standing stem harvesting. In this scenario high value trees are climbed and manually topped and delimbed while still attached to the stump. Then the delimbed stem is nearly severed completely at the base; shortly after, the helicopter retrieves the standing stem by breaking the remaining holding wood with a horizontally mounted grapple (Cleaver 2001). This type of operation is most appropriate in very rugged terrain, where timber and visual characteristics of the site have extremely high value. Preparing the stems in this method is very labor intensive, and the yarding is limited to one tree per turn (Cleaver 2001).

While there are multiple advances outside the airframe, the use of GPS may be one of the better advances within the cockpit. For helicopter logging, GPS provides a quick means to locate new service landings, log landings, and cutting units. In these cases, project or land managers will often provide the GPS coordinates for areas of interest be they landings, cutting units, or wildlife protection zones. This information and the use of GPS allow the helicopter pilot to be certain of the proposed use for the location. Currently GPS units are not used to help manage the yarding cycle, but they aid in identifying locations among pilots, project managers, and land owners.

Since many of the helicopters used in logging often assist in wildland fire suppression, it is worth noting the use of GPS in aircraft aiding fire suppression. Automated Flight Following (AFF) is required on all type I aircraft involved in wildland fire suppression. This system is used for real time tracking of aircraft supporting the incident. The use of AFF assists in maintaining safe and efficient operations. Naturally the same system could be used by helicopter companies for tracking aircraft in operations outside of fire suppression. This could be especially helpful for companies with a sizable aircraft fleet where numerous operations and personnel are tracked across the globe, making logistical planning tasks less time consuming.

Productivity and GPS

Productivity is commonly measured and evaluated using time and motion studies. The standardized time study method was first developed by Frederick Taylor in the late 1800's (Karger and Bayhaet al 1987). This method divides a task into elements and then times each task. Various modifications to the equipment or methods can be tested to determine what provides for the best production rate. Time and motion studies can also compare different workers operating the same equipment and or doing the same task. A standard time can be established for the most efficient worker for a task, (Barnes 1980). Taylor then used these standards to implement incentive pay for workers exceeding that standard. The information on the best methods and or equipment can also be used for instruction purposes to improve production for those engaged in the task.

Prior to the development of the time study method the work force developed its own methods through trial and error (Meyers and Stewart 2002). Frank and Lillian Gilbreth developed the motion study method during the same period. By focusing on the movement involved in completing a task, wasted movements could be minimized. Today this is commonly called work simplification. The Gilbreth's techniques not only improved production but also improved the working environment with attention to ergonomics, among other things. While motion studies are commonly used in assessing human actions, they can also be applied to equipment or the movement of material in the production process (Meyers and Stewart 2002). Motion studies are intended to find the preferred means to accomplish work, while time studies are intended to establish the a standard time to perform a task (Barnes 1980). These techniques allow for the assessment and improvement of productivity in labor and capital.

The primary intent and means collecting production information has only changed slightly over time. The general goal of evaluating and improving productivity is to improve revenue or reduce costs (Barnes 1980). Whether assessing a single manual task, a machine, or a system, the general goal is to improve the performance of capital and/or labor. An additional application of time and motion studies is to estimate production in similar, but untested conditions. This allows an organization to predict costs of a new operation (Meyers and Stewart 2002). Naturally, the desire to measure productivity increases when budgets are lean, and improvements or good production estimates are necessary for survival (Karger and Bayha 1987). Just as Taylor used a watch and the Gilbreths' used motion cameras, studies today use very similar techniques. While an assortment of improvements and time keeping aids were developed, time studies still operate under the same premise of measuring time required to complete a task. Similarly, time and motion studies conducted today often use motion cameras or video tape; a recent example is the work of Mitchell and Gallagher (2007), where a chipping operation was video taped for time study analysis.

A relatively new tool used in time and motion studies is GPS (McDonald and Fulton 2005). Developed by the US Department of Defense and currently maintained by the US Air Force, GPS is a positioning, navigation, and timing system (Defense Science Board 2005). The system provides an impressive number of services; along with supplying position information that can be used for the measurement of movement and object tracking, it also provides precise time data that is used to synchronize communications, power distribution, and a multitude of electronic transactions. The system was initiated in 1960's and early 1970's, but the full constellation of satellites was not launched until the early 1990's (Pace et al 1995). This technology is still experiencing growth, and as more markets and consumers use the product, the price can be expected to decline (Theiss et al 2005). Regardless of expected price reductions, a wide variety of consumer grade GPS units are inexpensive and easy to use (Oderwald and Boucher 2003). Given the relatively new status of GPS technology, a surprising number of industries rely on it. From fishing to marketing to banking, GPS has become an integral part of commerce (Defense Science Board 2005; Theiss et al 2005).

For a slightly more detailed view of the GPS contribution's to operational efficiencies, one can consider its use in agriculture. Precision agriculture is the utilization of GPS technology to pin point the application of chemicals as well as tracking crop yield with equal accuracy (Auernhammer and Muhr 1991; Borgelt et al 1996). The resulting impact is a significant change in management; once targeting an average crop performance across a field measured in hectares, farmers now adjust treatments within plots measured in meters. The result is higher yields and reduced chemical use. Greater benefit is derived from the entire industry through greater research possibilities. Prior to precision agricultural, research was commonly conducted on experimental plots at a university. The results produced from this work represented a relatively small segment of the factors typically experienced in the industry. Using GPS technology precision agriculture provides reasonable opportunities to conduct farm wide case studies that would cover a much broader range of conditions than those at university field trials (Board on Agriculture 1997).

Just as GPS is a useful tool in agriculture, GPS serves forestry as well. With applications similar to surveying, forest applications like stand area and boundary measurements, buffer strip delineation, and locating sample plots make GPS a natural fit (Shiver and Borders 1996). While the expense and training requirements of early applications limited the use of GPS to large agencies and forestry firms, the improved accuracy, lower cost GPS units and applications make GPS use efficient for most forest managers (Oderwald and Wynne 2000; Oderwald and Boucher 2003; Bernard and Prisley 2005).

Forest operation research has also incorporated the use of GPS. When planning operations with complex site analysis, GPS data made a significant contribution to updating the GIS layers and improved logging analysis (Cavalli et al 2006). Harstela (1999) noted that GPS showed potential for updating forest management plans as well as operational field level planning. In the same work, Harstela also commented that GPS was used in equipment for transportation analysis. Earlier, Prisley and Carruth (2005) effectively used GPS in log trucks to assess travel times as well as update travel routes. Global positioning systems were put to work in Canadian strip thinning operations, where GPS measured area treated and the travel speed of the equipment (Ryans 2002). Here Ryans emphasized the cost advantage of GPS measurement methods, suggesting that \$6/ha could be saved using GPS over more conventional treatment auditing techniques.

Time studies have been linked with logging at least as far back as 1917, where James Girard said that time studies would be beneficial for loggers to improve operations (Girard 1917). Today time studies can be conducted with GPS. Onboard GPS was deployed in ground based equipment to verify the ability to conduct more precise production and site impact analysis (McDonald et al. 2000, McDonald et al. 2002). The positional data combined with knowledge of the operation and site provided a means to create a gross time study as well as an elemental time study. In this study, the GPS data were evaluated and based on travel direction, time was broken down into elemental data. This was then corroborated with a stopwatch time study. While the gross time study data correlated well with paired clock time, the elemental GPS time study showed a considerable discrepancy in the grapple element when compared to the grapple element of the stopwatch time study (McDonald et al 2000). It was suggested that the discrepancy was due to variation in element establishment methods used by the GPS positional data and the technician using the stopwatch. If both time studies used the same element trigger, perhaps this could be avoided.

Heinimann and Caminada (1996) recommend employing GPS to gather more precise data on helicopter operations. Using onboard GPS, helicopter logging flight paths can be mapped (Figure 7) allowing more in-depth analysis of the operation. While there are a number of studies on helicopter operations, prior to this work no published study has used onboard GPS technology in evaluating helicopter production.

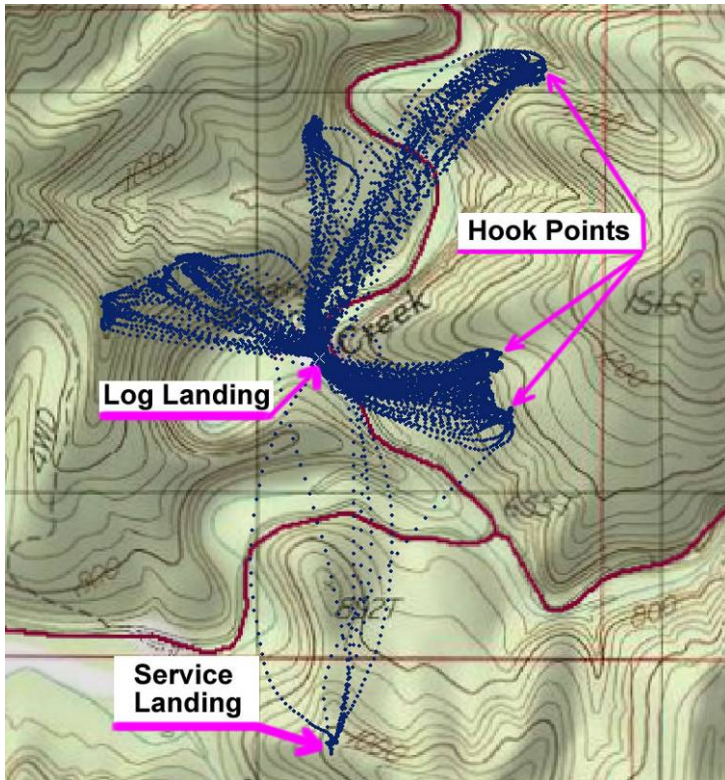


Figure 7. Mapped helicopter yarding data from an onboard GPS unit.

Productivity Factors

Because of the high cost of helicopter yarding, maximizing productivity is critical (Conway 1976). Not all of the factors presumed to impact helicopter yarding have been studied, and it is possible that not all factors are known. However, horizontal distance between the log landing and the hook point was found to be an influential factor in British Columbia (Krag and Evans 2003; Dunham 2004). Krag and Evans (2003) showed horizontal distance and difference in elevation to account for 52% of the travel empty time and 46% of travel loaded time. Naturally, accounting for travel time alone, has fewer variables than the total turn time. As a result, distance from landing to hook point alone explains less of the variability found in total turn time. For example, logging operations in Southeast Alaska showed yarding distance to account for 22% of variability in estimated total turn time (Christian and Brackley 2007).

Stampfer et al (2002) conducted an observational study that indicated an experienced pilot was 63% more productive than an inexperienced pilot. This research backed the supposition made by Sloan and Tollenaere (1994) when pilots new to the K-MAX showed low productivity during a yarding trial. Stampfer et al combined pilot experience, horizontal distance, choker delivery, stem volume, and harvest treatment, clearcut or patch cut, to account for 49% of the variation of total turn time (2002). While

the variance explained by Stampfer et al is comparable to that explained by Krag and Evans, the increased complexity of total turn time relative to travel time requires more explanatory variables to account for a similar level of variation. From a practical standpoint total turn time tends to be more useful because it can be used to directly measure productivity. In this instance Stampfer et al found productivity to decline with an inexperienced pilot, increasing distance, decreasing stem volume and choker delivery.

Elemental time study data of helicopter yarding can provide further insight into operational impacts or improvements. Wang et al (2005) used six elements in their analysis including fly empty, turn assembly, hook, fly loaded, release, and unchoke. Dunham (2003) used fly empty, hook up/break out, fly loaded, unhook, and in-cycle delays. These methods typically required some subjective interpretation of the operation, such as determining the correct break point between the hook or break out element and the fly loaded element. Within a case study this variation can be minimized, but when comparing between multiple case studies, under varying conditions, such as flat and steep terrain, or varying residual stand conditions, individual observers may interpret the start and end points of the individual elements differently.

All of these published studies have described components of productivity to assist in improving future operations and/or general knowledge in the field. One of the limitations of these and other studies is the use of approximated distances, where extraction distance is estimated with map distances of log landing to cutting unit, or proportional cutting unit. More precise distance measurements for each individual turn may help explain more of the variability within a particular study.

Operational Factors

The operation dependent factors for productivity are influenced by equipment and personnel. Each individual firm in the helicopter industry chooses which helicopter to use, who to employ, and level of support the operation will receive. Of course this is complicated by reality and the decisions are often constrained by available technology, labor markets, and limited capital.

Helicopter Types

Helicopters have various designs and abilities (see Table 1). The type of helicopter used will influence speed, angle of ascent, and maximum payload (Conway 1976). These factors can be influenced by modifications made to the helicopters. For example, the removal of long range fuel tanks and installing fiberglass or composite rotors to improve performance (Stevens and Clarke 1974). These modifications vary between individual helicopters of the same make and model. Additionally the condition of each ship can

impact production. If maintenance is not near ideal, vibrations and unreliability may reduce turn times.

Personnel Experience and Ability

The case study by Stampfer et al. (2002) showed that experienced pilots can have higher production rates than trainee pilots. Similarly, it is reasonable to presume that natural ability can also influence production; not all pilots will yard logs equally even with sufficient experience. Regardless of the type of aircraft, helicopter logging companies work to retain operators who are not only safe and reliable, but also efficient in optimizing the yarding process. This factor is not just limited to the pilots on helicopter yarding operations. The fallers must fell the timber with aerial extraction in mind and buck the timber with value and target payload as a priority. Hookers, who attach the payload to the helicopter, are responsible for selecting the logs that will achieve the optimal payload for the helicopter (Conway 1976). Utilization of appropriate choker routing techniques is crucial in minimizing hang-ups and aborts, which greatly increase overall average turn time and results in lower productivity. These are just a few of the many positions where the skills of the labor employed can greatly impact the operation.

Many other operational factors may also be selected such as the project manager's skills in addressing transportation and other logistical issues; however, only the above factors that directly impact the operation during the yarding cycle are addressed in this study.

Site Factors

There are many site dependent factors that influence production during the yarding cycle. These factors can be broken into three main categories: stand conditions, weather conditions, and log landing conditions.

Stand Conditions

Stand conditions influence both hook time and the payload. While there are several studies that address a variety of stand conditions, truly comprehensive studies that consider more than a few stand conditions have not been conducted.

Residual canopy cover, or canopy closure when viewed from above, limit the ability of the pilot to locate the hooker and the hooker's ability to locate the pilot. This increases the time the pilot spends to find the hook point (Burke 1973). The canopy can also interfere with the hook as the pilot attempts to get it near the hooker. This tends to be a greater issue where the tree species have more rigid limbs. Generally, when canopy cover increases wood availability, or volume to be extracted, decreases. Optimizing the payload is a key factor in achieving efficient yarding, but if wood or volume available for yarding cannot be combined to meet the target payload, then yarding production is reduced (Burke 1973; Hartsough et al. 1986). For example, if the typical log at a given site weighs

2,000 kg and the ideal payload is 3,000 kg, then the payload will routinely be 33% below the optimum. Similarly, an increase in residual trees per hectare is likely to correlate with increased canopy cover. The residual stems can act as obstacles and cause hangups, which increase hook time. Krag and Evans (2003) found patch cuts between 0.2 and 0.3 ha and single tree selection with 25% and 15% of basal area removal to have reduced production of five, 12, and 18% due to both hangups and reduced wood availability. However, in a study by Lyons and McNeel (2004), they could not separate additional confounding factors to identify a specific level of reduction .

The height of the residual stand also adds to the altitude the helicopter must lose and gain to maneuver the hook in and payload out of the stand. Because the hooker works directly below the helicopter, safety is a serious concern. The downdraft of the rotors increases the likelihood of sending broken tops and limbs onto the hooker below (Stevens and Clarke 1974; Conway 1976). The pilot is responsible for sounding an alarm on the helicopter if a dangerous situation arises. In areas where material is commonly released from overhead, the hooker and pilot will need to be more cautious which may increase the hook time.

Both the distance from the log to the hook and the log length affect the altitude the helicopter must reach to lift the load above the residual stand. If a log is more than one choker length away from the hook, then additional chokers must be used to link the log to the hook. This is commonly referred to as a strung out turn. The distance from the log to the hook may also increase the likelihood of encountering interfering stems or residual trees, that may cause a hangup or an aborted load. Each of these occurrences increase turn time (Conway 1976). Similarly, the number of logs in the load may increase the likelihood of hangups with the residual stand. Just as choker delivery was shown to reduce productivity (Stampfer et al 2002), the number of logs per turn and the log distance to the hook also influences the number of chokers needed in the operation. Increased demand for chokers is likely to result in more cycle time used in delivering chokers.

While very steep slopes are difficult to traverse for the fallers and the choker setters, it may have a positive influence on productivity of the actual yarding because the pilot can clear the load from the stand by traveling horizontally rather than vertically. Extracting the turn horizontally could reduce the effective height of the residual stand, where the distance required to clear the residual canopy is shorter horizontally compared to vertical maneuvering alone. This also allows the helicopter to lift while in horizontal motion. Lifting in horizontal motion increases the lifting ability when compared to lifting from a hover (Wagtendonk 1996). Turn times may also be improved if the slope is oriented toward the log landing, which would allow for a more direct route to the log landing.

Finally, the shape of the load can impact acceleration rate and yarding velocity due to the influence of drag (Harrington 1954; Wagtendonk 1996). Drag or parasitic drag is a function of the area and shape of object moving through the air. Increasing parasitic drag requires more horsepower to maintain the same speed (Harrington 1954). When speeds are below 65 km/hr parasitic drag has little influence on power requirements. Parasitic drag is likely to be a greater factor when yarding air speed exceeds 65 km/hr and area of the load is large. Of course load area is likely to increase when yarding whole trees or logs with limbs attached and dry or low density logs.

Weather Conditions

Weather not only limits when operations may occur, but it also influences helicopter capability during operations. The density of the air impacts both the ability of the helicopter to achieve lift and the horsepower of the engine. As the air density decreases, the ability of the helicopter to lift and the horsepower of the engine decrease. Air density is affected by pressure, temperature, and humidity

These variables result from weather conditions and altitude or elevation. Air density is commonly referred to in density altitude, which is the altitude that corresponds to the air density at standard temperature and pressure (STP) (Dykstra 1980). The temperature and pressure are commonly plotted to determine the corresponding density altitude. However, these charts exclude the impact of humidity. A pilot can compensate for a reduced air density if he can yard into the wind, because a headwind has a similar effect as increasing the air density (Wagtendonk 1996). A tailwind will have the opposite effect. Finally if the wind is too variable to count on for lift, then it will make positioning the hook more difficult and likely increase hook and, possibly, unhook time.

Log Landing Conditions

The location and layout of the log landing is a crucial factor in determining yarding productivity. The primary concern is the yarding distance, which generally is the distance from the hook point to the log landing. The difference in elevation from the hook point to the log landing may also influence turn time (Burke 1973). If the rate of elevation change is greater than 17 degrees, then the optimal angle of ascent or descent is exceeded and the pilot will fly a longer path to remain at or below the optimal angle (Krag & Evans 2003). Figure 8, modeled from the Workers Compensation Board of British Columbia, Canada, (2005) presents a sample landing configuration.

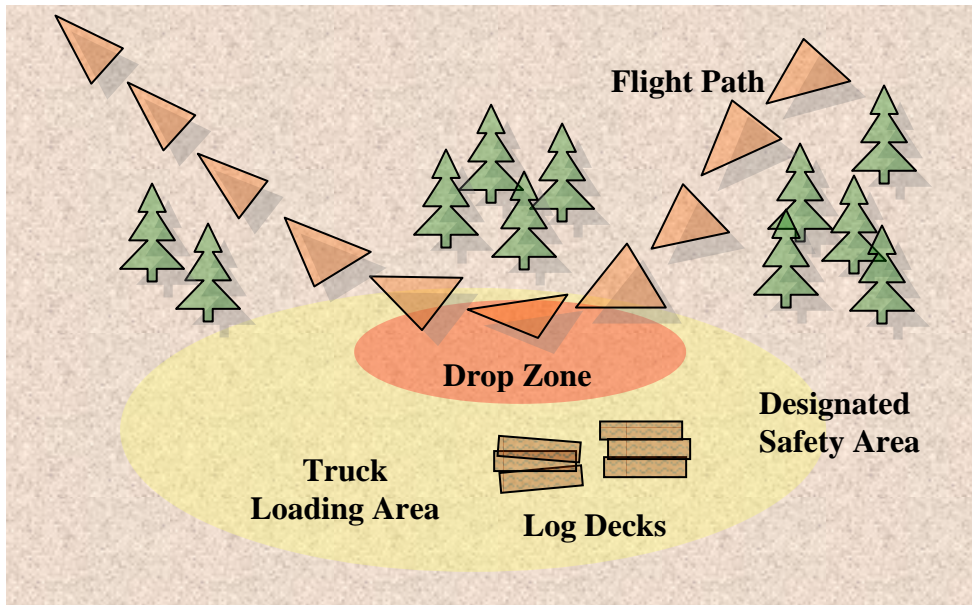


Figure 8. Helicopter landing area with flight path and other features shown.

A clear approach to the drop zone with no obstacles is also preferred to minimize turn time (Conway 1976). If the view of the landing is obscured by trees or ridges the pilot's view of the landing and the drop zone is delayed. Because helicopters fly more efficiently while in horizontal motion or with a headwind, moving vertically into and out of a drop zone will also increase turn time. If the drop zone is large and workers and equipment are at a safe distance from the intended drop area, then turn times are likely to be optimized by allowing the pilot to focus on load release and returning to the hook point. The departure route is similar to the approach route, but is likely to have less influence on turn time, since the helicopter is more responsive after the load is released.

Helipace and LogCost

As the use of helicopter yarding increased in the 1970's and early 1980's, studies were conducted to determine production rates, feasibility, and limitations of helicopter yarding. This information allowed land managers like the US Forest Service to establish informed appraisal methods for timber sales employing helicopter yarding. However, the effective application of this information is called into question as silvicultural practices and technologies change. This especially applies to clearcutting, which accounted for 31 percent of the total acres of national forest harvested in fiscal year 1989 and only 10 percent in fiscal year 1998 (USDA Forest Service Annual Report 2001). In the 1990's forest thinning increased and regeneration harvests decreased on national forest land (USDA Forest Service Annual Report 2001). While Stampfer et al (2002) demonstrated a change in production rates due to stem volume and treatment type, the majority of research on helicopter yarding that has been used in the development of these models is

derived from regeneration cuts, which commonly harvested larger timber than what is harvested today.

Helipace¹ and LogCost² are system costing models used by Bureau of Land Management and US Forest Service employees to determine economic feasibility and adjust pricing for timber harvesting on national forest land. Both of these models are freely available on the internet. Helipace, *Helicopter Logging Production and Cost Estimation*, was originally developed by the Aerial Forest Management Foundation and US Forest Service research and regional employees. Originally released in March of 1990, this software package was developed to improve the accuracy in estimating helicopter logging operations. Later updates provided new aircraft options, cost adjustments, and other features. For example, Table 2 shows the daily fixed costs and hourly variable costs, as displayed in the harvest system costing software, LOGCOST 5.2.

Table 2. Helicopter costing data from LOGCOST 5.2 (average payload, fixed cost per day, and variable cost per hour) February 2002.

Num	Helicopter Name	SL payload (lbs)	Fixed/day	Vari/hr
2	Bell 204 class	4,500	\$3,700	\$340
3	BV 107 - 61A	8,160	\$8,137	\$1,061
5	Chinook 234	22,960	\$13,662	\$3,004
6	K-MAX	4,800	\$6,750	\$840

LogCost is a spreadsheet based model that was developed by Steve Rheinberger, a US Forest Service employee with Forest Resources Enterprises. This spreadsheet allows the user to analyze multiple harvesting systems simultaneously. It predicts helicopter yarding production with methods similar to Helipace.

These two harvest system costing packages use a set time period, called a base turn time, plus an average linear yarding distance that compensates for angle of ascent and angle of descent, multiplied by a maximum velocity to predict the total turn time. The base turn time is used to account for acceleration, deceleration, hook time, and unhooking.

¹ www.fs.fed.us/r6/nr/fp/programs/helipace/helipace30.htm

² www.fs.fed.us/r6/nr/fp/FPWebPage/FP70104A/Programs.htm

Problem Statement with Opportunities

The high cost and expanding use of helicopter yarding requires efficient means to evaluate the impacts of silvicultural prescriptions, as well as assess and improve upon innovative yarding techniques. This capability would benefit all parties connected to helicopter operations, from the helicopter industry that could reduce costs, to the land managing agency that could have more economically viable forest treatment options. Gaps in our knowledge of production influencing factors create an inability to maintain accurate appraisal systems for common helicopter operations. Although individual stand, site, and economic factors influence specific system costs, it is well accepted that helicopter yarding is generally more expensive than ground based or cable yarding operations (MacDonald 1999). Consequently an error in estimating the productivity of helicopter yarding has a much greater potential to adversely impact total system cost when compared to other yarding, skidding, or forwarding operations. This type of error tends to reduce the amount forest available for harvesting, making profitable forest management increasingly difficult.

Time and motion study methods provide an effective means to evaluate and improve operations. Unfortunately, traditional methods of gathering and evaluating this data are typically complex, time consuming, and expensive (Davis and Kellogg 2005). The use of video equipment still requires a technician to play and breakout the timing data. Manual timing methods require dedicated personnel on site, and automated timing equipment data alone are often not suitable for elemental time studies. A potentially complex issue involved in time study data is born in the timing technique. In the case of elemental time studies, if the element start and end points are not clear, then discrepancies can occur and the opportunity to extrapolate and/or use study results for prediction purposes are limited. However, careful automation of the process within a digital data environment may eliminate this type of interpretive error. Given the relative success of conducting ground based elemental time studies using GPS, there is potential to achieve similar results with onboard GPS in helicopters. Currently, no studies have used onboard GPS technology for helicopter yarding.

Combining onboard GPS with a means to automate the data processing has the potential to enable operational analysis, whose detail exceeds that of previous production research with much lower costs. To date, the influence of yarding distance on helicopter logging has been estimated, generally using map measurements. Onboard GPS should provide more precise yarding distances. Velocities, acceleration rates, and flight paths are additional components that were previously unavailable for analysis but can be deduced quickly from a GPS data set. The use of GPS permits autonomous data collection suitable for elemental time studies. The absence of on site personnel and automated

processing should make this technique accessible to all operations. Just as many industries use GPS for the accurate ability to time transactions, measure movement, and track objects, it is time for this technology to be made available to fully assess and improve helicopter yarding. Given the relatively low cost of GPS units, a more objective and cost efficient means to collect this data would be difficult to find.

The development of elemental time study data by putting onboard GPS and automated processing to work should provide interesting opportunities. Just as Taylor sought to measure a fair days labor with the creation of the time study (Meyers and Stewart 2002), the findings of Stampfer et al (2002) can be further investigated by comparing the production and elements of experienced and inexperienced pilots. When a helicopter yarding organization employs a pilot new to logging work, they are likely to experience higher costs (Warren 1996; Stampfer et al. 2002). Stampfer et al showed that an experienced pilot delivered 59% more volume to the landing than an inexperienced pilot. The inexperienced pilot had a significantly lower production rate, which adversely impacts the organization. However, it was not shown where the trainee loses time. For example, a trainee may spend similar percentage of time in flight, hooking, and unhooking, or he may spend a greater percentage of time hooking and unhooking. Knowing where an inexperienced pilot is likely to need the most practice may assist the industry in selecting training regimes. If trainees are found to spend less time in flight and more time hooking, then sites with shorter haul distances may be more appropriate for training to increase the amount of time spent hooking within a given cycle. Conversely, if flight speed is significantly lower, then it may be appropriate to train a pilot at sites with longer yarding distances to increase the training time spent in route.

The elemental time study will also provide an opportunity to consider stand impacts on hook time. Where the hook element time and hook location derived from onboard GPS could be used to assess the impact of canopy cover. The stand and the stand prescription have been shown or suggested to impact production rates, where increased density of the residual stand reduces production (Krag and Evans 2003; Dunham 2003; Lyons and McNeel 2004). While the suspected impacts of canopy closure have been mentioned by a variety of sources (Jackson and Moris 1986; Burke 1973) the contribution of canopy closure has not been tested. Additionally, Heinimann and Caminada (1996) specifically recommended investigating the impacts of canopy cover on helicopter yarding. Without production research to provide an appropriate model of canopy cover and production impacts, appraisal software such as Helipace must use a best-guess to adjust for canopy conditions. Currently the model decreases the yarding production rate evenly as canopy closure rises above 50 percent. This adjustment is an untested hypothesis. For example, helicopter yarding costs for forests that would benefit from thinning may be estimated above the timber value. This makes the thinning treatment using a helicopter

economically not viable, and this best management action may not be applied. In this case an opportunity for the land managers and the timber industry is a missed opportunity.

Another clear opportunity for a GPS based study is the capture of elemental time study data with accurate yarding distances on a large number of sites with varied stand or terrain conditions. This will provide the chance to develop productivity models based upon specific distances and assess the use of velocity and acceleration as a predictive variable. The models and methods used to assess impacts on productivity should reflect current technology and the best ability to assess conditions experienced in today's yarding operations. There are few studies from the last decade that reflect the changing silvicultural practices. However, some of current models are based on clear cutting large timber, and the formulas are often simplified due to a lack of detail in the data. As a result, modifications to these formulas are produced from speculation; making the models inaccurate or inadequate. New technology allows us to more accurately measure the helicopter yarding process, thus more accurately identifying the factors that most influence productivity. In turn this allows us to better predict the production rates at future sites.

Objectives

The goal of this study is to evaluate the opportunity of using onboard GPS to improve helicopter yarding operations. To assess the potential of this technology, three specific objectives will be tested:

1. Assess the ability to identify where trainee-pilots spend a greater percentage of turn time (in flight, hooking, or unhooking elements of the turn) as compared to experienced pilots.
2. Assess the ability to determine the impacts of percent canopy cover on turn time in helicopter yarding.
3. Develop a revised method to calculate production rates using maximum velocity and acceleration, while considering the differences between line distance and flight distance.

Methods

Disclosure Limitations

Ideally a specific study design would be implemented for a research project; in this case selecting a series of helicopter systems and yarding sites most suitable to achieve desired study outcomes. However the very high cost of running a helicopter yarding operation, as well as the highly skilled crew requirements, means studies on helicopter yarding are limited to actual on-going commercial operations. Due to the highly competitive nature of the helicopter yarding industry, information regarding cooperating companies, the model of aircraft analyzed, and the location and dates of the collection period will not be released into the public domain.

Study Approach

Study Sites

Study sites (actual helicopter yarding operations) were selected for the purpose of testing our objectives. Hence, it was necessary to locate sites with various levels of canopy cover, sites where trainee pilots were being used, and for the development of productivity functions, sites with a range of operating variables.

Data were collected at a total of nine sites, working with three helicopter models, covering two payload equivalents; one with 4.5 tonne maximum payloads and one with 2.7 tonne max payload. Sites visited were those made available by helicopter logging contractors. General site characteristics were collected through personal observation and informal interviews of site workers. Stand measurements were generally not available. Pilots and mechanics provided insights into site and helicopter specific issues. Weather data was originally collected via hand held units at the log landings during the operation; unfortunately this data was lost due to a computer failure. To provide surrogate weather information, the nearest weather station data provided by the National Climatic Data Center was gathered and adjusted using adiabatic lapse rates to reflect the difference in altitude. The altitude used for adjustment was the site maximum altitude over hook circles or over log landings, whichever was greater.

While a minimum of three days at three sites per helicopter model was targeted, weather or maintenance requirements delayed some operations, eliminating the ability to gather the intended full complement of data. The 2.7 tonne max payload helicopter data only includes one site. At least three sites were sampled for each of the 4.5 tonne max payload helicopters, making a 4.5 tonne max payload total of eight sites.

GPS Data

All of the data to assess the opportunity for improving helicopter yarding using GPS were collected by mounting a GPS unit (Trimble GeoXT) onboard an operational helicopter. An external antenna was used on all but one site (Site 7), where the internal antenna was used. The antenna was located in a cockpit window, out of the pilot/copilot viewing area. Location information was primarily gathered at one-second intervals with some four and five second interval data due to GPS and user errors. The GPS data were downloaded and differentially corrected using Trimble Pathfinder Office 2.9 prior to further processing.

Based on basic GPS data, it is possible to calculate a number of useful parameters:

$$\text{Point to Point Distance} = \sqrt{((x_{i+1} - x_i)^2 + (y_{i+1} - y_i)^2 + (z_{i+1} - z_i)^2)}$$

Whereby x, y and z represent the northing, easting and vertical components of the GPS data collected at time *i*.

$$\text{Flight Distance} = \sum_{\text{hook_circle}}^{\text{landing_zone}} (\text{Point to Point Distance})$$

Whereby the *landing_zone* and *hook_circle* are defined within a GIS map.

The velocity and acceleration rate can also be determined by including the time interval in the formula. The velocity and acceleration results were linked to the last position used for the calculation.

$$\text{Velocity} = (\text{Point to Point Distance}) / \Delta t$$

$$\text{Acceleration} = \Delta \text{Velocity} / \Delta t$$

Additionally, average velocity for a given distance can be established rather than using a static rate.

$$\text{Average Velocity} = (\text{Flight Distance}) / \Delta t$$

Basic Turn and Element Data

The GPS yarding data were analyzed and coded. This project focused on work-only (productive) time. No attempt was made to code or analyze any delay time, or any other time not associated with the primary work task of the yarding cycle.

The following breakdown of time was used on all study sites:

Yarding Cycle – From the time it leaves the service landing to the time it returns to the service landing.

Yarding Turn – From the time it left the service or log landing, until the next time it leaves the log landing. The yarding turn is divided into four elements.

Turn Elements

Outhaul – From the time it leaves the service or *log landing**, until it enters the *hook circle***

Hook – Any time spent in the *hook circle*

Inhaul – From when the helicopter leaves the *hook circle* until it enters the *log landing*

Landing – Any time spent at the *log landing*.

* The ‘*service landing*’ and ‘*log landing*’ were defined with a 35 m radius around the centroid of the landing flight path positions.

** The ‘*hook circle*’ is defined as having a 20 m radius around the actual hook point.

The correct identification of the breakdown of the turn time into the individual elements proved to be more difficult than just using a fixed radii around the log landing or hook point. The primary reason is that the hook point is not fixed and must first be correctly identified and located for every turn within the data set. For this study, the elements were assigned to each post-processed position through a partially automated process. This process is described in the next section (pg 35 - Onboard GPS Data Analyses).

Payload and choker drop data were recorded by the copilot during the cycle, or relayed via radio and recorded by someone on the ground. Payloads are primarily measured to the nearest 45 kg (100 lbs) and are measured with the onboard load cell. In a few cases the copilot recorded the payload to the nearest 225 kg (500 lbs). These data were linked with each turn using the chronological order. Discrepancies in payload data, where recorded weights did not match the number of turns, could be verified using the hooker location and corresponding recorded weight.

Using an approximate fuel consumption rate, provided by the industry cooperators (600 L/hr for 4.5 tonne and 340 L/hr for 2.7 tonne helicopters) and applying that to the time from service at the end of the hook element, an adjusted payload was also calculated for each turn to reflect the relative total weight of the helicopter, fuel, and payload through

the flight cycle. Similarly, production in tonnes/hr was calculated for each turn by applying the total turn time to the payload.

Measuring Canopy Cover

Using the hook point locations from the onboard GPS, images of residual canopy cover were collected from the ground. The hook points were selected by accessibility and distribution across the site. Images were collected during the operation or within three months of the data collection period. Because the majority of the turns are from experienced pilots and to maintain the common work sampling methods, only experienced pilot data were considered in the canopy cover analysis.

The hook point was located on the ground using the Trimble GeoXT receiver. Once located, a color digital hemispherical image of the canopy was captured using a Nikon Coolpix 4500 digital camera equipped with a Fisheye converter FC-E8 and monopod with a bulls-eye bubble level. The lens height was 1.3 m when images were collected. Color images were collected on the fine setting, using 2272x1704 pixels. Percent canopy closure was calculated for each hook point using the color classification process within hemispherical image interpretation software WinScanopy version 2003c Pro. If sky conditions were not uniform, the images were then edited to allow the software to more accurately calculate percent cover. Canopy cover for the following zenith angles were produced, 0-15, 0-30, 0-45, 0-60, 0-75, 0-90, and matched to the corresponding turn data in the greater elemental analysis. Figure 9 shows the zenith angles zero and 45.

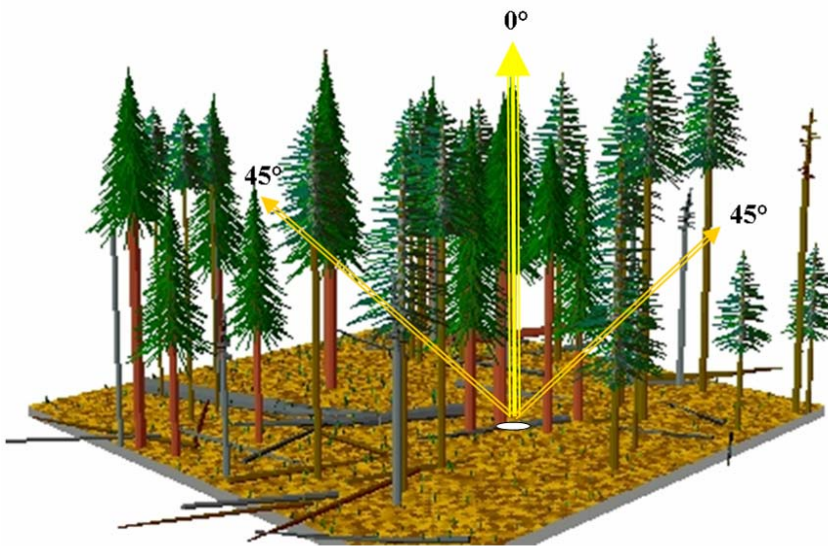


Figure 9. Zenith angles zero and 45.

Case Study 1: Pilot Experience Data

To further assess the differences of experienced and inexperienced pilots, production rates and turn elements were compared. Three of the study sites used trainee pilots, whereby a trainee pilot is defined as one that has fewer than 100 flight hours which involve yarding logs. For the analyses, each flight cycle of trainee pilot data is paired with experienced pilot data that occurred immediately before or after the trainee flight. In some instances experienced pilot data were available from both before and after the flight. The close chronological proximity was used to reduce the influence of changing conditions such as weather and the area being yarded.

Scheffe's multiple comparison procedure was conducted on hook and unhook time for the trainee and experienced pilot data. The analysis was grouped by site and the test significance level was 0.05. Other components were also tested with Scheffe's multiple comparison procedure and are summarized in the Pilot Experience Summary Table in Appendix B. Grouping analysis by site and pilot experience, stepwise selection, linear regression was conducted for outhaul time, where linear distance, percent linear slope, turn of cycle, and choker drop were explanatory variables. The same process was used for inhaul time. Linear distance, percent linear slope, turn of cycle, payload, adjusted payload, and logs were included as explanatory variables. These variables with descriptions are shown in Table 3 and specific inputs follow the table. A significance level of 0.15 was used for variable entry and inclusion.

To assess the impact on the overall productivity, stepwise linear regressions were conducted for the dependent variables total turn time and productivity. As in the previous regression analysis, a significance level of 0.15 was used for variable entry and inclusion. The variables used for both regressions are shown in Table 3; specific inputs for the dependent variables follow the table. Using these regressions, the pilot experience site means for distances, slope, adjusted payload, etc. were applied to the explanatory variables to determine the percent difference for similar yarding conditions.

Table 3. Variables for outhaul, inhaul, total turn time, and tonnes/hr regression analysis.

Type	Name	Description	Units
<i>Dependent Variable</i>	Outhaul	Time between landing & hook circles	sec
	Inhaul	Time between hook & landing circles	sec
	Turn	Time for outhaul, hook, inhaul, & unhook	sec
	Prod	Payload/turn	tonnes/hr
<i>Explanatory Variables</i>	Payload	Load cell reading of payload weight	kg
	Adj. Payload	Payload minus weight of fuel consumed	kg
	Logs	Number of logs in turn	integer
	Turn of Cycle	Count of the turns since service	integer
	Pilot Status	Experience or inexperience	0/1
	Choker Pickup	Chokers retrieved for delivery	0/1
	Choker Drop	Chokers delivered	0/1
	Outhaul Dist.	Linear dist. between landing & hook circles	m
	Outhaul Slope	Linear altitude slope between landing & hook circles	%
	Inhaul Dist.	Linear dist. between hook & log landing circles	m
	Inhaul Slope	Linear altitude slope from hook to log landing	%
<i>Analysis Group</i>	Site	Location	A/B/C
	Pilot Status	Experience or inexperience	0/1

The following four equations show which explanatory variables and block factors were considered to establish the influence on the dependent variable:

$$\text{Outhaul (sec)} = \text{fn} (\text{Site}, \text{PilotStatus}, \text{OuthaulDist}, \text{OuthaulSlope}, \text{TurnofCycle}, \text{ChokerDrop})$$

$$\text{Inhaul (sec)} = \text{fn} (\text{Site}, \text{PilotStatus}, \text{InhaulDist}, \text{InhaulSlope}, \text{TurnofCycle}, \text{Payload}, \text{AdjPayload}, \text{Logs})$$

$$\text{Turn (sec)} = \text{fn} (\text{Site}, \text{Payload}, \text{Logs}, \text{TurnofCycle}, \text{PilotStatus}, \text{ChokerPickup}, \text{ChokerDrop}, \text{OuthaulDist}, \text{InhaulDist}, \text{InhaulSlope})$$

$$\text{Prod (tonnes/hr)} = \text{fn} (\text{Site}, \text{Logs}, \text{TurnofCycle}, \text{PilotStatus}, \text{ChokerPickup}, \text{ChokerDrop}, \text{OuthaulDist}, \text{InhaulDist}, \text{InhaulSlope})$$

Case Study 2: Canopy Impact Analysis

Various sources have indicated that increasing canopy cover reduces total turn time (Jackson and Moris 1986; Burke 1973), but canopy cover has not been measured to assess this impact. Using hook point locations, canopy cover can be measured and compared to the hook element time. This information will provide insight into the impact canopy cover has on hook time.

Three sites were sampled and analyzed for canopy cover. Each site had a minimum of 30 matched images with hooks points (site 4, n=32; site 5, n=30; site 7, n=60). An initial assessment of percent canopy closure was conducted prior to incorporating additional explanatory variables.

Stepwise linear regression was used to estimate the impact of canopy cover on hook time. A significance level of 0.15 was used for variable entry and inclusion. The variables used in the regressions are shown in Table 4 and specific inputs for the development of regression equations follow the table.

Table 4. Variables for assessment of canopy closure on hook time.

Type	Name	Description	Units
<i>Dependent Variable</i>	Hook	Time within the hooking circle	sec
<i>Explanatory Variables</i>	0~15	Canopy closure for zenith angle 0-15 degrees	%
	0~30	Canopy closure for zenith angle 0-30 degrees	%
	0~45	Canopy closure for zenith angle 0-45 degrees	%
	0~60	Canopy closure for zenith angle 0-60 degrees	%
	0~75	Canopy closure for zenith angle 0-75 degrees	%
	0~90	Canopy closure for zenith angle 0-90 degrees	%
	Payload	Load cell reading of payload weight	kg
	Adj. Payload	Payload minus weight of fuel consumed	kg
	Logs	Number of logs in turn	integer
	Choker Drop	Chokers delivered	0/1
	Turn of Cycle	Count of the turns since service	integer
<i>Analysis Group</i>	Site	Location	4/5/7

The following two equations show which explanatory variables and block factors were considered to establish the influence on the dependent variable:

$$\text{Hook (sec)} = \text{fn} (\text{Site}, 0\sim15, 0\sim30, 0\sim45, 0\sim60, 0\sim75, 0\sim90)$$

$$\text{Hook (sec)} = \text{fn} (\text{Site}, 0\sim15, 0\sim30, 0\sim45, 0\sim60, 0\sim75, 0\sim90, \text{Payload}, \text{AdjPayload}, \text{Logs}, \text{ChokerDrop}, \text{TurnofCycle})$$

Case Study 3: Creating Production Equations

Production equations are useful in assessing the influence of variables during helicopter operations, as well as the assessing the operation itself. While production equations have

been developed before, these equations did not have measures of velocity and acceleration, nor did they have distance measures with the accuracy that is provided when using GPS with every turn. This information provides the opportunity to create a model that uses the components comprising the rate of travel, rather than line distance alone. Any travel element, outhaul or inhaul, contains a flight distance and a corresponding line distance. From a simplified perspective, a travel element includes an acceleration phase, a velocity plateau, and a deceleration, or negative acceleration phase. These phase measurements may produce a more accurate model, where longer distances would be expected to show higher rates of acceleration and velocity, which should influence the travel time. Because the positions comprising flight distance provide multiple records of velocity and acceleration, the maximum potential of each phase should provide suitable variables for a predictive model. Since distance information is commonly available in linear or chord distance and each of these phases are derived from flight distance, assessing the correlation between flight and line distance is necessary.

To develop production equations, stepwise linear regression was conducted on experienced pilot data at each site to assess flight distance, acceleration, deceleration, and maximum velocity for outhaul and inhaul. Regression inputs are described in Table 5 and specific inputs follow the table. These regressions were conducted to assess the use of these variables in a predictive model. Stepwise linear regression was then conducted to determine total turn time and productivity with acceleration, deceleration and maximum velocity as independent variables; these inputs are listed in full in Table 5. Stepwise regression was then conducted with the same dependent variables, total turn time and productivity, using the distance and slope as explanatory variables, shown in Table 5 with specific inputs following. A significance level of 0.15 was used for variable entry and inclusion. The cube root of distance was used when assessing acceleration and velocity to accommodate the nonlinear tendency of these components, where both acceleration and velocity are expected to plateau.

Because US Forest Service often uses payload based models to predict helicopter production rates, there is an interest in the development of a payload based model. The sampling procedure and unequal sample size do not permit suitable development of a global production model. The correct study procedure for developing such a model would include taking a random sample from all helicopter yarding operations, and each site would be sampled on the basis of a similar range of all stand and terrain parameters.

However it is possible to develop a combined model based on the data sets collected for this study. Eight of the nine sites involve a helicopter with a payload of 4.5 tonnes; therefore models were created for a 4.5 tonne payload helicopter. Stepwise regression was conducted with the dependent variables, total turn time and productivity, using the

distance and slope as explanatory variables, shown in Table 5 with specific inputs following. A significance level of 0.15 was used for variable entry and inclusion.

Table 5. Variables for total turn time and tonnes/hr regression analysis.

Type	Name	Description	Units
<i>Dependent Variables</i>	Out Flt Dist	Total between position dist for outhaul	m
	Inhaul Flt Dist	Total between position dist for outhaul	m
	Out Accel	Highest moving average outhaul acceleration	m/s ²
	Out Decel	Lowest moving average outhaul acceleration	m/s ²
	Out Max Vel	Highest moving average outhaul velocity	km/hr
	Inhaul Accel	Highest moving average inhaul acceleration	m/s ²
	Inhaul Decel	Lowest moving average inhaul acceleration	m/s ²
	In Max Vel	Highest moving average inhaul velocity	km/hr
	Turn	Time for outhaul, hook, inhaul, & unhook	sec
	Prod	Payload/turn	tonnes/hr
<i>Explanatory Variables</i>	Out CRT Dist.	Cube root of outhaul dist	m
	In CRT Dist.	Cube root of inhaul dist	m
	Out Accel	Highest moving average outhaul acceleration	m/s ²
	Out Decel	Lowest moving average outhaul acceleration	m/s ²
	Out Max Vel	Highest moving average outhaul velocity	km/hr
	Inhaul Accel	Highest moving average inhaul acceleration	m/s ²
	Inhaul Decel	Lowest moving average inhaul acceleration	m/s ²
	In Max Vel	Highest moving average inhaul velocity	km/hr
	Outhaul Dist.	Linear dist. between landing & hook circles	m
	Outhaul Slope	Linear altitude slope between landing & hook circle	%
	Inhaul Dist.	Linear dist. between hook & log landing circles	m
	Inhaul Slope	Linear altitude slope from hook to log landing	%
	Payload	Load cell reading of payload weight	kg
	Turn of Cycle	Count of the turns since service	integer
	Turn of Day	Count of the turns for the day	integer
	Choker Pickup	Chokers retrieved for delivery	0/1
	Choker Drop	Chokers delivered	0/1
	Grapple	Grapple used for yarding	0/1
<i>Analysis Group</i>	Site	Location	1 – 9

The following equations show which explanatory variables and block factors were considered to establish the influence on the dependent variable:

$$\text{OutFltDist (m)} = \text{fn (Site, OuthaulDist, ChokerDrop, TurnofCycle, TurnofDay)}$$

$$\text{InhaulFltDist (m)} = \text{fn (Site, InhaulDist, TurnofCycle, TurnofDay)}$$

OutAccel (m/s²)= fn (Site, OutCRTDist, OuthaulSlope, ChokerDrop, TurnofCycle, TurnofDay)

OutDecel (m/s²)= fn (Site OutCRTDist, OuthaulSlope, ChokerDrop, TurnofCycle, TurnofDay)

OutMaxVel (km/hr)= fn (Site OutCRTDist, OuthaulSlope, ChokerDrop, TurnofCycle, TurnofDay)

InhaulAccel (m/s²)= fn (Site, InCRTDist, InhaulSlope, Payload, Logs, Grapple, TurnofCycle, TurnofDay)

InhaulDecel (m/s²)= fn (Site, InCRTDist, InhaulSlope, Payload, Logs, Grapple, TurnofCycle, TurnofDay)

InMaxVel (km/hr)= fn (Site, InCRTDist, InhaulSlope, Payload, Logs, Grapple, TurnofCycle, TurnofDay)

Turn (sec) = fn (Site, OutAccel, OutDecel, OutMaxVel, InhaulAccel, InhaulDecel, InMaxVel, Payload, TurnofCycle, TurnofDay, ChokerPickup, ChokerDrop)

Prod (tonnes/hr) = fn (Site, OutAccel, OutDecel, OutMaxVel, InhaulAccel, InhaulDecel, InMaxVel, TurnofCycle, TurnofDay, ChokerPickup, ChokerDrop)

Turn (sec) = fn (Site, Payload, Logs, TurnofCycle, TurnofDay, ChokerPickup, Grapple, OuthaulDist, InhaulDist, InhaulSlope)

Prod (tonnes/hr) = fn (Site, Logs, TurnofCycle, TurnofDay, ChokerPickup, Grapple, OuthaulDist, InhaulDist, InhaulSlope)

Onboard GPS Data Analysis

Classic forest operations productivity research uses time and motion studies where a stopwatch, clock, handheld computer, or time stamped video is used to capture time periods for designated tasks. In elemental time studies the researcher or technician records the time interval for each previously defined element (Bjordheden and Thompson 1995). The handheld computer software program SIWORK3 has often been used as a management aid for time study field data (Spinelli et al 2002). In addition to assigning the time segments, other parameters are recorded in the field. Typically turn volume is

measured (e.g. using calipers and loggers tape at the log landing) so that productivity can be calculated relative to piece size. Other factors such as extraction distance, number of trees are also measured and recorded. Time study is commonly used to test a specific hypothesis, in which case a covariate or block factor would also be included; allowing a statistical program to test for variance and or significance.

Table 6 shows a typical completed time study data format for a helicopter yarding study. It includes four timed cycle elements (fly out, hook the load, fly in and releasing the logs at the log landing), a measured turn weight that can be combined with the time elements to calculate productivity on a per turn basis. In addition the factor extraction distance is recorded at each turn. This allows the development of a basic productivity model for the helicopter based on extraction distance. Finally a column is showing an experience covariate (Exper). This covariate would allow us to test a hypothesis that an experienced operator is more productive than an inexperienced one.

Table 6. A sample of a typical time study format for helicopter yarding.

Cycle #	Time Elements				TotCycle (s)	Payload (tonnes)	Prod (m ³ /hr)	Factor ExtrDist (m)	Covariate Exper (0/1)
	Out (s)	Hook (s)	In (s)	Unhook (s)					
1	36	44	32	25	137	3.0	75	671	0
2	29	69	37	16	151	3.1	70	687	0
3	27	58	36	15	136	3.1	78	667	0
4	28	40	33	13	114	3.3	99	672	0
5	28	37	36	14	115	2.3	68	674	0
etc	..	..	..	..	..	..	..	..	..
etc	..	..	..	..	..	..	..	..	..

Most time and motion studies in forest operations are inherently ‘complex’, where the person capturing the information is required to make many decisions. In the hypothetical study above, it is assumed the time study technician has line of sight of the operations and is able to estimate extraction distance using something like a range finder, or a map with predetermined locations marked. Otherwise multiple personnel must be used. The time study would also need to establish definite visual cues to help formalize each elemental time categories.

This study identified the opportunity to use onboard GPS as a surrogate for the standard field based time study. In addition to the time saving potential of eliminating the need for a dedicated time study technician to be on-site for the duration of the study, there are some very clear advantages, such a real-time feedback opportunities, assessment of pilot and hooker performance, turn time assessment of choker drop spatial parameters relative to hook points, assessment of alternate landing configurations and yarding techniques. These opportunities begin with an initial data set that are similar to that shown in Table 7.

Table 7. A sample of onboard GPS data.

Time	Northing	Easting	Altitude
8:20:03	292008.8	195549.7	2094.6
8:20:04	291996.6	195577.2	2101.7
8:20:05	291983.2	195606.9	2108.6
8:20:06	291978.9	195636.5	2101.1
8:20:07	291954.8	195673.2	2122.7
8:20:08	291939.7	195709.3	2131.8
8:20:09	291925.0	195746.3	2140.3
etc	..	..	..
etc	..	..	..

This rather simple information provides many time and motion opportunities. The time and positional data create the ability to calculate distance traveled over a period of time or average velocity, as well as velocity and acceleration for a given time interval. The altitude provides three-dimensional analysis. By calculating and displaying velocity and acceleration with each successive GPS data point, the task in which the helicopter is engaged can be inferred with a high level of confidence. Generally, low velocities and altitudes indicate hooking or unhooking, while high velocities and altitudes indicate outhaul or inhaul. It is also typical to find greater acceleration out of the log landing when the helicopter is not yarding logs and lower accelerations out of the hook element when the helicopter is carrying a payload. Identifying positions near the service or log landings make inferring the element in which the helicopter is engaged even clearer. As Figure 8 assists in demonstrating, plotting the positions on a map makes the identification of landings relatively easy, where the earliest positions occur at the service landing and concentrated positions occur at the log landing. With this information in mind, GPS data can be converted into elemental time study data.

Once each turn with corresponding elements are extracted from the GPS data, additional operation parameters and/or covariates can be added. Operational parameters and/or covariates should be collected sequentially to facilitate alignment with the GPS data. A time stamp is especially helpful in the event of a GPS failure, which can create a gap in the data. The time stamp improves the GPS data to operational parameter mating process and eliminates the possibility of reducing the data set due to an inability to match parameters with the remaining turn data. These parameters can include a wide variety of information, such as the specific pilot and hooker, choker drops, payload, number of logs, canopy closure or stand conditions at the hook point, etc.

Just as all measurements are subject to error, it is important to be aware of the error associated with positional data and its influence on the identification of elements. Post

processing GPS raw data can greatly reduce the positional error. However, compounding effects occur with distance, velocity and acceleration measurements. With each position, there is a level of error which is commonly expressed as horizontal and vertical confidence intervals in meters, where horizontal error is usually less than vertical error. When measuring distance between two positions this error has the potential to be increased by a factor of two; this is the combined error from each position. Because velocity is distance over time, the error found in a distance measurement is also found in the velocity calculation. When measuring distance between three positions, the potential error is increased by a factor of four. This occurs if the locations are consecutively biased in opposite extremes. This condition is shown in Figure 10, where distance A is longer through the addition of two times the error and distance B is shorter through the subtraction of two times the error. If this simply represented a total distance measurement and the positional error was the same for each position, then the errors would cancel each other and the measurement would be correct. When calculating acceleration, which is the change in velocity over time, the potential errors do not cancel out and the position error influencing the calculation has the potential to be increased by a factor of four.

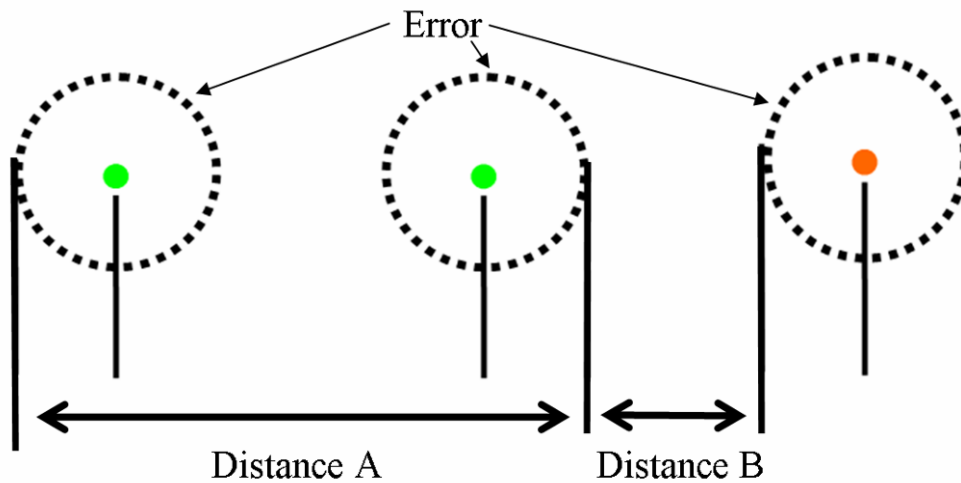


Figure 10. A representation of three GPS positions with associated error and the potential influence of error on individual and consecutive distance measurements.

Typically a worst case scenario like consecutive bias in opposite extremes is unlikely, but considering the range of percent influence that error may have on velocity and acceleration calculations is appropriate. Autocorrelation among consecutive GPS positions reduces the likelihood of these worst case scenarios under typical conditions. The factors influencing error tend to offset the positions in the same direction, because the conditions that cause the error are usually comparable over a given period. However,

this does not eliminate the occurrence of maximum potential error. Therefore, further consideration of error within the data is warranted.

According to the Trimble Office Pathfinder analysis, the post processed onboard GPS data in this work typically have a daily average 95% confidence interval of approximately |1.5| m horizontally and |2.2| m vertically. The common daily worst 95% confidence intervals are around |20| m horizontally and |25| m vertically. Given this general level of error and the influence of error on velocity, it is interesting to view some sample velocity curves from the data captured during this study. Figure 11 shows an inhaul velocity curve, which in my opinion displays a typical relatively uniform trend found in most inhaul and outhaul data.

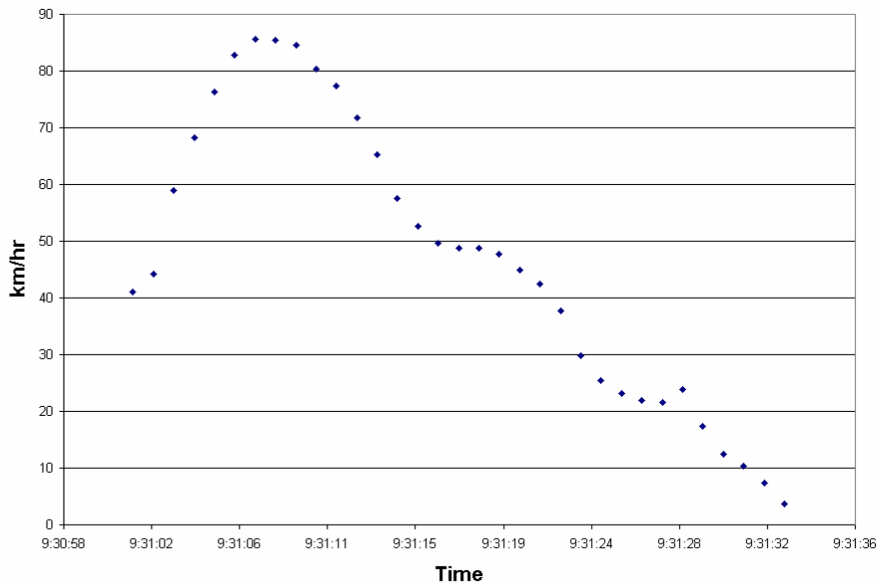


Figure 11. Inhaul velocity curve with minimal outliers at one second GPS position intervals.

The outhaul velocity curve in Figure 12 displays what in my opinion appear to be outliers that are occasionally encountered. The data point (8:22:50, 143) would be expected to fall nearer to 110 and is 30% above this expected value.

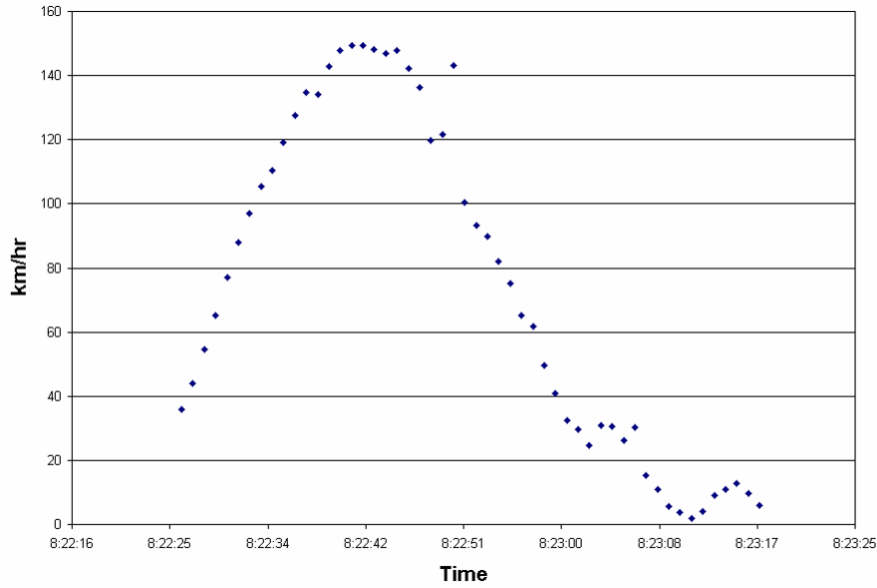


Figure 12. Outhaul velocity curve with outliers at one second GPS position intervals.

Considering the percent error for the high velocity outlier in Figure 12, further analysis of position error and potential influence on percent velocity error will provide a clearer perspective. As the distance measured increases the percentage of potential error decreases. Similarly, as velocity increases, the percentage of potential error decreases. This characteristic is shown in Figure 13. At slower speeds, the error can contribute to a much larger percent error for the distance traveled. Clearly, the high velocity outlier discussed from Figure 12 will have a position error that is well above the average.

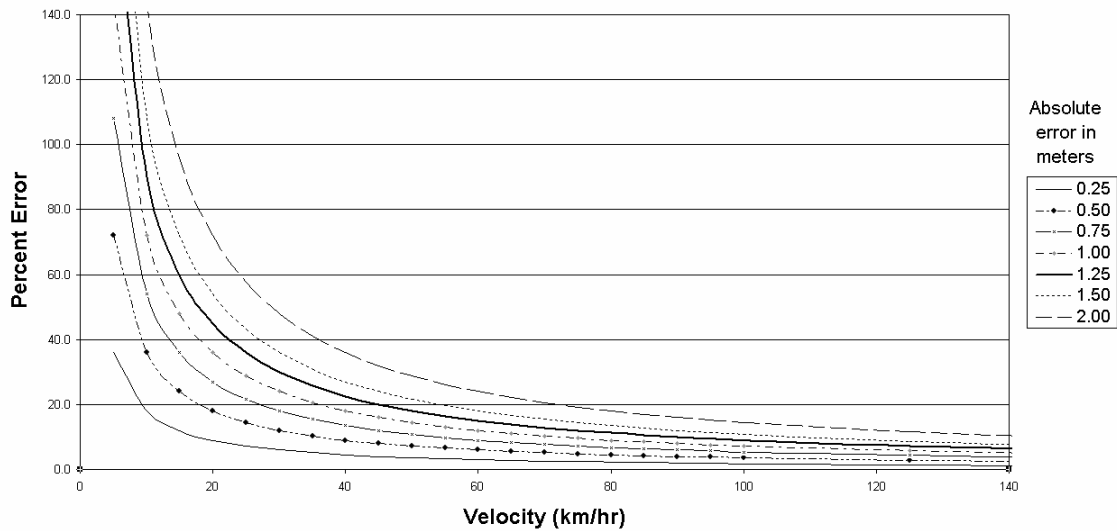


Figure 13. Potential error relative to velocity for seven position error levels.

Since the positional error potential that influences velocity is half of the error potential that could influence acceleration, plotting acceleration data should provide an indication if the acceleration calculated in this data set is influenced more heavily by error. Figure 14 provides a relatively clean inhaul acceleration plot.

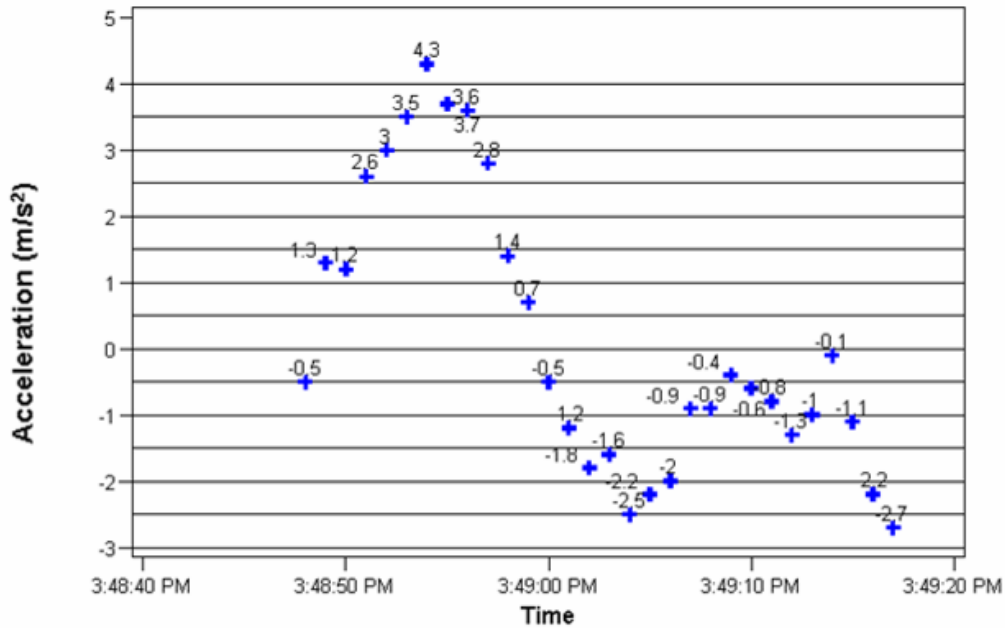


Figure 14. Chronological inhaul acceleration exhibiting minimal error at one second GPS position intervals.

In contrast, Figure 15 is an inhaul acceleration plot that appears to be heavily influenced by error. While Figure 14 in my opinion displays a smooth trend, Figure 15 suggests that considerable error is possible when calculating acceleration with GPS data. In my opinion the typical acceleration curves for the data set appear to be neither quite as smooth nor irregular as the two shown here.

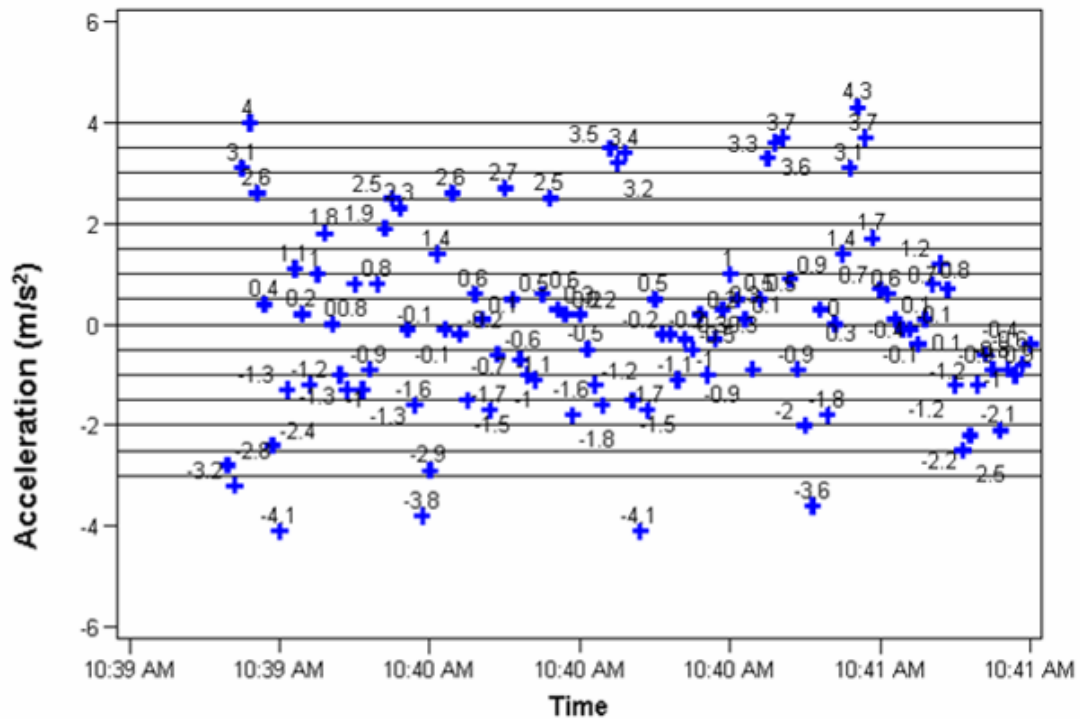


Figure 15. Chronological inhaul acceleration exhibiting substantial error at one second GPS position intervals.

The potential influence of error for acceleration is greater when the acceleration rates are low and the time interval between GPS positions is short. Figure 16 shows the proportional potential for error relative to acceleration for multiple position error levels using a one second GPS position interval. The influence of error on acceleration is quite dramatic; an acceleration rate of 3.0 m/s^2 with a position error of 0.75 m could be 100 percent error. If the GPS interval were five seconds rather than one second, this potential error would be reduced by a factor of five. This reduction is due to the error being an additive factor applied to the distance traveled prior to calculating velocity; while the change in velocity is divided by time. Conversely, quarter second GPS intervals would increase the potential error by a factor of four.

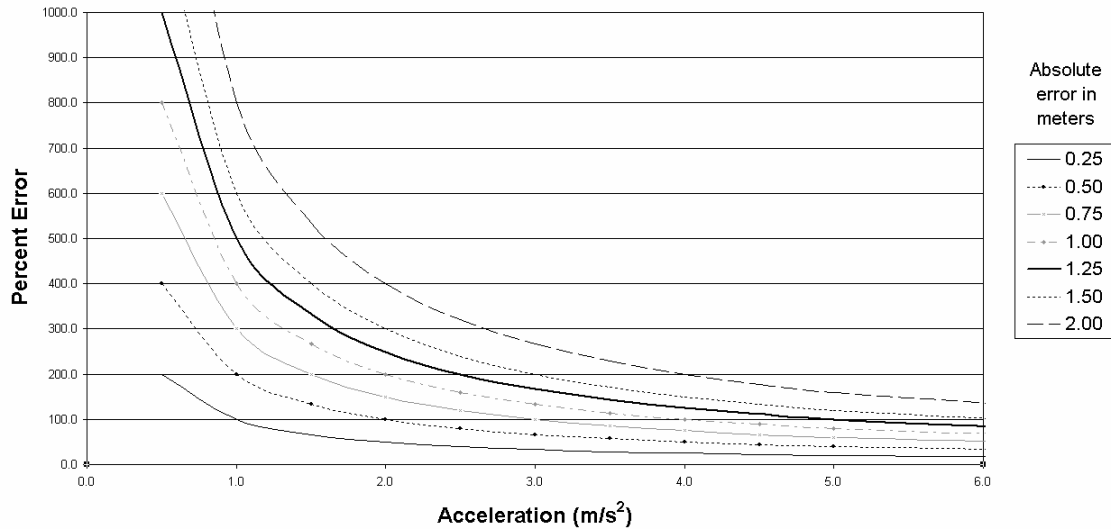


Figure 16. Potential error relative to acceleration rate for seven position error levels with one second GPS position intervals.

Considering the possibility to reduce error that influences acceleration by increasing the GPS position collection interval is appropriate. However, increasing the interval does impact the data. Five second interval data tend to exhibit a lower likelihood of erroneous positions relative to a one second collection interval. As expected, the fewer number of total points creates a smoothing effect, but this appears to have a minimal effect on the actual measurement of flight distance. When using acceleration as the screen for error, the five fold increase in time between positions requires a five fold increase in error to create a noticeable erroneous point. Instances of missing positions are likely to have the greatest impact on the five second interval data. At times when satellite availability is temporarily reduced by terrain or obstructions, a position record may not be created. In this instance the five second interval would have a 10 s gap between positions. This same condition only creates a two second gap when using a one second interval. When position record creation is intermittent extended gaps are more likely to occur with five second interval data, where no data maybe recorded for an entire element. These extended data gaps can greatly reduce the usefulness of the data. Another factor to consider is the potential to favor area based elements. The location of the antenna, in the cockpit window and below the rotors, made signal loss more likely at slower speeds, when the aircraft heading was changed. This is probably due to a combination of obstructions, such as the airframe and rotors. Because a change in aircraft heading is most likely to occur in the area based hook or unhook elements, missing values were more likely to initiate in the hook and unhook element. Since the time between positions is attributed to the earliest position among the pair, this causes data gaps near element transition to accumulate on the element where the data gap initiated, creating an artificially long initial element and short following element. If the satellite signal strength is not sufficient to create a position record prior to departing the area based

element, then the time lapse between positions is fully attributed to the area based element. This can create longer hook and unhook times and conversely shorten the inhaul and outhaul times.

Multipath interference, where the satellite signal reflects off of objects prior to reaching the GPS receiver, can reduce the accuracy of GPS data (Trimble 2002). The rotors have the potential to not only reduce the satellite signal strength, but interfere with the assumption of autocorrelation among consecutive positions. As the rotors constantly rotate over the GPS antenna, the pitch and speed of the rotor may influence the accuracy of the GPS due to increased multipath interference. While the EVEREST™ multipath rejection technology within the GPS receiver should reduce this error, it does not necessarily eliminate it. In this data set, positional error is more evident at lower speeds. This is likely to be the result of multipathing due to the combined effect of rotor pitch and speed. High positional error is especially evident just prior to take-off at the service landing, where positional errors can be as high as 30 m. Fortunately, errors of this size are easily eliminated, and due to the area based nature of the service landing, they have no impact on the elemental data. Of course, incidence of GPS record creation failure and multipath errors could be greatly reduced if an antenna could be placed above the rotors.

Semi-Automated GPS Data Processing

The data interpretation automation process is a crucial component in making onboard GPS a useful tool. As displayed earlier in Table 7, GPS data provide time, northing, easting, and altitude. Without processing, this data provides little insight into the operation. On some sites where the operation has a “terraced” quality: a unique service landing elevation, a unique and distinct log landing elevation and a unique cutting unit elevation, one may think that turns could be easily identified by merely noting the altitude changes through the data set. However, in the course of a typical day’s yarding operation it is not uncommon to collect more than 40,000 GPS positions at one second intervals. This makes the simple task of manual turn identification daunting even in the most basic operation.

Of course, the desire is not to merely provide turn times, but to provide elemental time study data for the complex operations often encountered in today’s demanding harvesting scenarios. This capability would be of little use if labeling elements and reconstructing turns required as much time to as it would to collect the data in the field. Additionally, it is useful to have a method to provide a standardized technique to evaluate data across multiple sites. This should make the evaluation of harvest prescription and new yarding techniques more reliable across sites. In the absence of an automated means to process the data, the only product of onboard GPS data would be a series of GPS data points.

The data analyses phase of this study required many iterations of attempting to improve the data automation process. The following text describes in detail the final automated process steps for converting the raw GPS data into useful time study data:

After differential correction, each day's yarding data were plotted to determine the landing coordinates. These coordinates were then entered into a program that assessed the velocity and altitude of each position beyond a 35 m radius of a landing. When landings overlapped, the positions were labeled with both landings.

When velocity outside of a landing radius dropped below 20 km/hr, the lowest altitude of the slowest positions was marked as the hook point. To reduce the influence of inaccurate positions, the hook was marked among the slowest 10% or five positions below 20 km/hr, whichever was greater (in the case of four or five second GPS position intervals, 10% or three positions were used). If the helicopter undulated above and below 20 km/hr multiple times in one turn, then multiple hook points were marked each time the helicopter dropped below 20 km/hr.

A cleanup process was then employed to reduce the occurrence of multiple hook points within a single turn. If a brief velocity increase, covering three or fewer adjacent positions, was flanked by <20 km/hr positions on both sides, the >20 km/hr positions are ignored and the lowest of the slowest 10% or five positions was then selected as the single hook point. When the GPS position interval setting was greater than one second, the cleanup process only considered the brief velocity increases of two or fewer positions. All positions outside of the 35 m radius landings and not labeled as a hook point, are then either labeled as outhaul or inhaul. If the position occurred before the final hook label and before the landing, it was labeled as outhaul. If the position occurred after the final hook label, but before the log landing, it was labeled as inhaul.

Each list of position information and labels are then manually reviewed to remove the multiple hook points within a single turn, reduce multi-landing labels to show a single landing, and to correct possible labeling errors due to GPS equipment failures, position errors, or an inappropriate velocity trigger in the hook labeling process. In the case of multiple hook points, the most likely hook point is selected; this is accomplished by comparing position, velocity, and altitude with other adjacent turns. Often, the lowest altitude hook point was selected. Overlapping landings were reduced to a single landing radius, by selecting the landing where the logs were most likely released. This was commonly the landing with the most abundant number of positions for that turn. Velocity and altitude were also considered. If the velocity between log landing visits did not exceed 20 km/hr, then no hook points were established. In these instances the hook point was entered manually using the lowest of the slowest method described above.

The bulk of the data was also manually labeled using an excel spreadsheet and velocity triggers to label the elements. The estimated hook point was manually established using velocity and the aid of the plotted positions in Trimble Office Pathfinder. When comparing the automated process to the manual process, the automated process regularly labeled the hook point within a few seconds (positions) of the manual process. This verified that the automated method would predict hook points similarly to the manual map assisted method.

After reviewing the automated hook point labeling file, the data are then run through a secondary process. In this procedure the hook points are expanded to area based hooking circles with a 20 m radius (see Figure 17). If the hook circle overlapped a landing, then the hook circle was reduced to allow one position to establish an outhaul or inhaul label between the hook circle and the landing. With this labeling process, the elements of helicopter yarding were established. Time spent traveling to a hook circle was labeled as outhaul. Time spent within the hook circle is labeled as hook. Time spent traveling away from a hook circle is labeled as inhaul. Time within a landing radius was labeled unhooking or service, depending upon the landing label. It is important to note that each hook circle is only active for a single entry for an individual turn, while landings are permanent for the entire file.

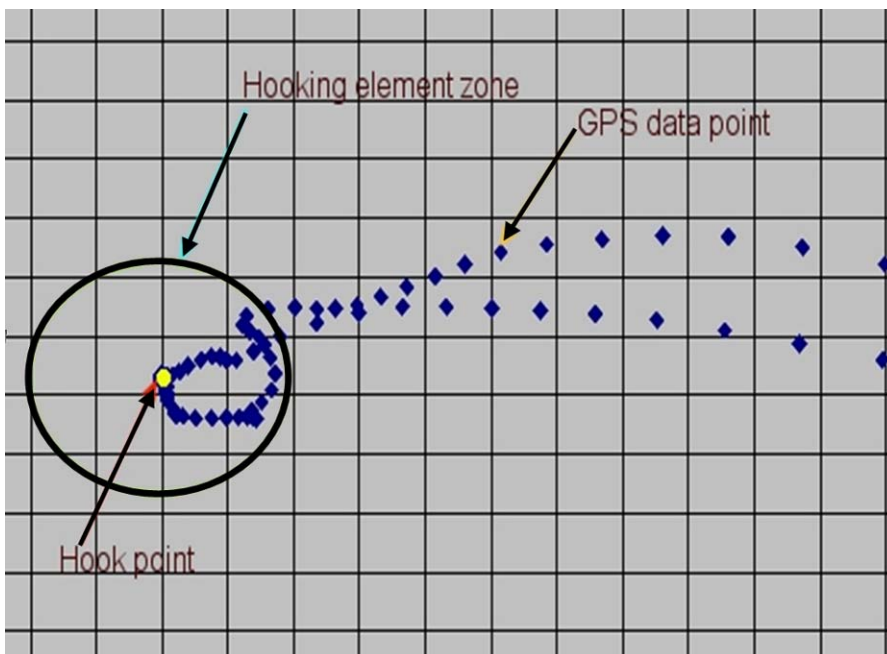


Figure 17. A grid displaying plotted onboard GPS data of hooking with a 20 m radius circle around the hook point, and a portion of outhaul and inhaul elements. Each square represents 10 m, the recording interval (Δt) is 1 sec.

The secondary process converts the lines of position data into a single lines of turn data. This turn data include time for each element (i.e. by summing all the lines from the position data file identified as belonging to that element), total turn time, elevation changes and distances from landing zone exit point to hook circle entry point and hook circle exit point to landing zone entry point. Maximum and minimum five position moving average data are also provided for acceleration, while a five position moving average velocity maximum is also provided. The five second moving average was found to most closely resemble acceleration potential, which was determined by reviewing a sample of acceleration and deceleration plots. In the case of four or five second GPS intervals, raw acceleration and velocity data were provided. This information is then combined with pilot, payload, and choker drop information. The semi-automation of both the primary and secondary processing methods were created in C++ by Ed Messerlie of the USFS San Dimas Technology and Development Center. Data compilation and configuration were conducted using Microsoft Excel 2003. These files were imported into SAS 9.1.3 and SAS Enterprise Guide 4.1 for statistical analysis.

Coinciding with the data gathering timeframe, these automation routines to convert position data to elemental time study components were developed. Particular issues addressed included erroneous positions, landing area size and shape, multiple landings, roadside landings, combined log and service landings, hooking area size, and separating choker drops from hook points. Erroneous positions are often identified by sorting the data by acceleration rate and identifying exceptionally high or low instances. Positions associated with rates greater than or equal to $|10| \text{ m/s}^2$ were eliminated. While this eliminates the bulk of the erroneous positions, which tend to occur in opposite pairs or trios, it does not eliminate all of the irregularities in the data. For instance one site exhibited a regular trajectory shift of approximately 10 m in one second. This occurred when yarding from a particular segment of the site, near a ridge, which could create strong winds or reduce satellite availability. Removing the shifted position only moved the position shift up to the proceeding position. As a result, these errors could not be eliminated without considerable reduction in positions for the specific turns.

Since a helicopter can usually approach a hooking and landing area from any direction, the processing method uses circular hooking and landing areas. Landings from all sites were reviewed with the helicopter positions plotted. The minimum diameter to accommodate landing activities on all sites without encroaching on hooking was found to be 35 m. The use of multiple landings was addressed by accommodating up to three log landings and two service landings in the routine. However, the use of progressive roadside landings created a situation where a single 35 m radius circle would not be sufficient and multiple landings would overlap. For this reason, the use of overlapping

landings was enabled. Each landing area position is labeled and positions within the overlap are marked to indicate which landings are shared. In some instances, the roadside landings shifted across cycles. When this occurred, the data were analyzed for the landing coordinates appropriate to each cycle, creating multiple files for a single day. The cycles with the correct landing coordinates were then spliced into a single file, creating one data set for the day. When log and service landings are within close proximity, log landing activity would commonly be interrupted by an incorrect service landing entry. To avoid this situation an artificial service landing position is created in the first position of the GPS data file. The data are then initially analyzed as if all activity after the artificial service landing was active logging. The service landing activity is then manually entered by noting the excessive delays and low altitude at the shared log and service landing. The service landing circle is established by determining position location relative to the service area during these instances and manually replacing the log landing label with a service landing label.

The 20 m hook circle was established by plotting a small sample of the helicopter position data. Hook points were located and common lower speed maneuvering was noted. The distance that typically included the lower speed travel was within 20 m of the hook point. Choker drops can be included within these hook circles, but they can also occur beyond the hook circle. Identifying the correct location as the hook point is an important consideration. Choker drops also commonly involve a reduced travel speed and descent, similar to the hook point. Often the choker drop requires less time, but this is not always the case. Some hooks are clean and fast, while choker drops can occasionally require more maneuvering than anticipated. The key indicator selected in the automation process was altitude. Because chokers are typically 10 m in length and durable, the pilot does not lose as much altitude as he does for hooking. Chokers do not require delicate placement, but can be dropped near the desired position. When not dropped, the pilot can use the choker length to maintain an altitude approximately 10 m greater than the long line length. In hooking, the hooker commonly grabs the hook. So the hook must typically be within two meters of the terrain. This is why the 'lowest of the slowest' method, where the lowest altitude position of the slowest velocity positions is identified as the hook point, was developed to identify the hook point. This method is not fool proof, but it was found to be very reliable for the sampled sites. In steep terrain a choker drop could occur eight meters or more below the hooker, or a positioning error could establish the choker drop as the lower point. However, if the 20 km/hr velocity trigger is reached between the choker drop and hook point, multiple hook points would be established and reviewed in the manual review process. If not, the choker drop point is incorrectly labeled as the hook point. Since the velocity trigger was not reached, the choker drop is likely to be very near the hook point.

Case Study Results

Data were successfully collected at nine different helicopter yarding sites, in six different states. The work encompasses 193 helicopter yarding cycles, or 5013 turns. The sites successfully studied are described in Table 8. Seven sites were in the Pacific Northwest with just two from the Southern Atlantic. The majority were conifer stands on steep to rolling terrain. Five were Seed Tree / Salvage operations, with the remaining four being thinning operations. None of the operations were clearcuts.

Table 8. Site descriptions.

Site	Location	Stand Type	Terrain	Harvest Type	Temp (C)/ Pressure (mmHg)
1	Pacific Northwest	Conifer	Rolling to Steep	Seed Tree/ Salvage	15 / 869
2	Pacific Northwest	Conifer	Rolling to Steep	Seed Tree/ Salvage	19 / 868
3	Pacific Northwest	Conifer	Rolling to Steep	Thinning	16 / 999
4	Pacific Northwest	Conifer	Rolling	Thinning	13 / 952
5	Pacific Northwest	Conifer	Steep	Seed Tree/ Salvage	15 / 864
6	Pacific Northwest	Conifer	Rolling to Steep	Seed Tree/ Salvage	19 / 948
7	Pacific Northwest	Mixed	Steep	Thinning	10/ 1000
8	Southern Atlantic	Hardwood	Rolling to Steep	Thinning	13 / 920
9	Southern Atlantic	Mixed	Level	Seed Tree/ Salvage	28/ 1020

Table 9 provides a summary of the number of cycles, total turns and percent choker drops at each site. On quite a few sites, delays reduced the total number of cycles sampled, but where possible additional days were spent to ensure a comprehensive data set.

Table 9. Site sampling and operation description.

Site	Days	Yarding Cycles	Avg. Turns /Cycle (#)	Choker Drops* (% of turns)
1	3	11	33.8	20.2
2	3	16	31.8	12.8
3	4	18	23.1	9.6
4	5	27	23.1	14.1
5	4	29	26.9	42.9
6	4	20	26.8	28.8
7	3	13	30.4	9.9
8	5	32	26.6	14.4
9	4	20	26.2	18.2

*Percent of total number of turns, excluding grapple cycles.

Table 10 provides a summary table for the key parameters measured, including the mean and the 5th and 95th percentile to indicate the range. The sites sampled cover a broad range of yarding conditions, with extraction distances greater than 2000 and less than 100 m, logs per turn from one to more than 17, and chord slopes between -42 and 36 percent.

Table 10. Site summary: elements, distance, & production.

Site	Label	Mean	n	5th %	95th %
1	Outhaul (s)	33.6	372	15	65
	Hook (s)	39.6	372	20	60
	Inhaul (s)	34.2	372	20	60
	Unhook (s)	15.8	372	5	30
	Total (s)	122	372	85	170
	Outhaul Dist (m)	575	372	204	3090
	Inhaul Dist (m)	372	372	160	576
	Inhaul Slope (%)	19.8	372	-4.3	36.1
	Payload (kg)	2500	372	1590	3310
	Prod (tonnes/hr)	75.5	372	43.5	106
	Logs (#)	4.3	372	2	7
2	Outhaul (s)	32.0	504	15	55
	Hook (s)	35.0	504	15	53
	Inhaul (s)	33.3	504	10	55
	Unhook (s)	17.1	504	7	33
	Total (s)	117	504	75	165
	Outhaul Dist (m)	773	504	123	3930
	Inhaul Dist (m)	549	504	77.5	870
	Inhaul Slope (%)	-4.0	504	-12.6	21.3

	Payload (kg)	2990	501	2130	3860
	Prod (tonnes/hr)	95.8	501	59.4	142
	Logs (#)	3.8	505	1	7
	Outhaul (s)	45.7	414	19	86
	Hook (s)	51.8	414	31	77
	Inhaul (s)	47.3	414	20	76
	Unhook (s)	18.3	414	11	35
	Total (s)	160	414	96	232
3	Outhaul Dist (m)	998	414	234	2540
	Inhaul Dist (m)	835	414	226	1420
	Inhaul Slope (%)	10.5	414	-2.6	24.2
	Payload (kg)	3410	414	2360	4260
	Prod (tonnes/hr)	78.7	414	49.1	110
	Logs (#)	3.0	414	1	5
	Outhaul (s)	52.9	623	15	123
	Hook (s)	60.1	623	38	91
	Inhaul (s)	52.3	623	16	106
	Unhook (s)	21.9	623	11	43
	Total (s)	184	623	102	293
4	Outhaul Dist (m)	1400	623	122	5360
	Inhaul Dist (m)	1010	623	112	2120
	Inhaul Slope (%)	-2.9	623	-12.7	15.3
	Payload (kg)	2840	622	1810	3770
	Prod (tonnes/hr)	60.1	622	30.9	104
	Logs (#)	6.8	622	3	10
	Outhaul (s)	40.8	779	21	93
	Hook (s)	50.2	779	30	76
	Inhaul (s)	39.4	779	28	56
	Unhook (s)	22.0	779	10	40
	Total (s)	151	779	111	219
5	Outhaul Dist (m)	798	779	357	2410
	Inhaul Dist (m)	652	779	337	1060
	Inhaul Slope (%)	-23.0	779	-34.1	-16.7
	Payload (kg)	3000	779	2040	3860
	Prod (tonnes/hr)	73.9	779	40.5	106
	Logs (#)	11.8	778	7	17
6	Outhaul (s)	47.8	533	21	88
	Hook (s)	44.0	533	26	71
	Inhaul (s)	47.5	533	27	78
	Unhook (s)	21.4	533	10	45
	Total (s)	158	533	99	229

	Outhaul Dist (m)	1110	533	434	2610
	Inhaul Dist (m)	783	533	401	1230
	Inhaul Slope (%)	-15.5	533	-42.3	0.5
	Payload (kg)	3540	533	2400	4540
	Prod (tonnes/hr)	83.2	533	48.6	117
	Logs (#)	4.5	533	2	10
	Outhaul (s)	33.6	404	20	55
	Hook (s)	53.4	404	28	92
	Inhaul (s)	47.8	404	30	75
	Unhook (s)	16.1	404	8	30
	Total (s)	147	404	89	212
7	Outhaul Dist (m)	639	404	358	1010
	Inhaul Dist (m)	657	404	376	1020
	Inhaul Slope (%)	-14.6	404	-32.6	-5.9
	Payload (kg)	2170	360	1520	2720
	Prod (tonnes/hr)	54.2	360	33.7	81.2
	Logs (#)	3.1	392	1	5
	Outhaul (s)	35.0	848	13	84
	Hook (s)	48.9	848	29	72
	Inhaul (s)	35.0	848	16	71
	Unhook (s)	19.2	848	10	35
	Total (s)	136	848	89	208
8	Outhaul Dist (m)	650	848	133	1950
	Inhaul Dist (m)	454	848	118	774
	Inhaul Slope (%)	1.3	848	-25.2	30.9
	Payload (kg)	3200	848	2270	4080
	Prod (tonnes/hr)	88.4	848	49.3	132
	Logs (#)	2.3	848	1	4
	Outhaul (s)	40.7	523	27	68
	Hook (s)	32.0	523	21	46
	Inhaul (s)	49.6	523	33	71
	Unhook (s)	19.6	523	10	42
	Total (s)	140.0	523	99	198
9	Outhaul Dist (m)	1130	523	681	2510
	Inhaul Dist (m)	977	523	649	1280
	Inhaul Slope (%)	1.7	523	0.2	3.5
	Payload (kg)	3290	519	2270	4350
	Prod (tonnes/hr)	85.7	519	54.1	117
	Logs (#)	NA	0	.	.

Case Study 1: Pilot Experience

Three sites provided the opportunity to collect and analyze data involving experienced and inexperienced pilots. These sites are described in Table 11.

Table 11. Site descriptions for pilot experience data.

Site	Paired Cycles	Yarding Method	Harvest Type	Season
A	1	Grapple	Seed Tree/ Salvage	Summer
B	4	Chokers	Thinning	Summer
C	5	Chokers	Thinning	Summer

At site A, B, and C the mean experience of pilot

hook time without choker drop was 27, 48, and 50 percent respectively, of the mean inexperienced pilot for the same site. Hook times with choker drops had similar results with 37 percent for site B and 53 percent for site C. Sites A, B, and C mean experienced-pilot unhook time without choker pickup was 85, 55, and 49 percent of the inexperienced-pilot unhook time. Unhook time with choker pickup was 64 and 57 percent of inexperienced pilot time for Sites B and C. However, the unhook time for site A, a grapple operation, was not significantly different from the experienced unhook time (See Table 12).

Table 12. Mean hook and unhook times including choker influence.

Site	Element	Scheffe Significant to 0.05	Mean*	n	Pilot Status**
A	Hook	Yes	83.5	10	1
			22.7	38	0
	Unhook	No	19.4	8	1
16.5			39	0	
B	Hook	Yes	109	44	1
			51.7	137	0
	Hook (<i>Choker Drop</i>)	Yes	146	7	1
			53.7	17	0
	Unhook	Yes	30.8	44	1
			16.9	139	0
Unhook (<i>Choker Pickup</i>)	Yes	56.3	7	1	
		36.2	17	0	
	Hook	Yes	106	54	1
			52.8	152	0

	Hook (<i>Choker Drop</i>)	Yes	99	10	1
			52.3	23	0
	Unhook	Yes	36	56	1
			17.6	153	0
	Unhook (<i>Choker Pickup</i>)	Yes	60.9	9	1
			34.7	23	0

**Choker influenced means reported in italics are not significantly different from non-choker influenced means of the same pilot status. **Pilot Status of 1 = inexperienced, 0 = experienced.*

Outhaul and inhaul regressions show moderate to very strong correlations for some of the explanatory variables, with the exception of inexperienced pilot inhaul for sites A and B, which showed no correlation. Applying the appropriate site means, found in Appendix B, to these regressions further demonstrates the reduced times for the experienced pilot. The use of site means create a comparison of the similar conditions, such as distance, slope, and payload, for both pilot experience levels. The experienced pilot at site A, a grapple operation, would conduct outhaul in 66% and inhaul 57% of time needed by the inexperienced pilot. Experience pays off at site B as well, where outhaul required 78% of inexperienced time without a choker drop and 53% with a choker drop. Inhaul time was 68% of the inexperienced mean time. Site C results are similar to site B, where experienced pilot outhaul is 77% of inexperienced time and 57% with a choker drop. Inhaul for site C was 56% of the inexperienced inhaul time.

Elemental Pilot Experience Equations

The following regression equations were developed from the data set that compared pilot experience, where variables are described in Table 3:

[Eqn 1: Site A, Experienced pilot]

$$\text{Outhaul (sec)} = 15.9 + 0.0269(\text{Outhaul Dist})$$

$$\text{Adjusted } R^2 = 0.30$$

[Eqn 2: Site A, Inexperienced pilot]

$$\text{Outhaul (sec)} = 43.2 + 0.0169(\text{Outhaul Dist})$$

$$\text{Adjusted } R^2 = 0.68$$

[Eqn 3: Site B, Experienced pilot]

$$\text{Outhaul (sec)} = 8.2 + 0.0318(\text{Outhaul Dist}) + 28.6(\text{Choker Drop}) - 0.57(\text{Outhaul Slope})$$

$$\text{Adjusted } R^2 = 0.56$$

[Eqn 4: Site B, Inexperienced pilot]

$$\text{Outhaul (sec)} = 43.0 + 0.0309(\text{Outhaul Dist}) + 83.2(\text{Choker Drop}) - 2.1(\text{Turn of Cycle})$$

$$\text{Adjusted } R^2 = 0.48$$

[Eqn 5: Site C, Experienced pilot]

$$\text{Outhaul (sec)} = 23.0 + 0.0223(\text{Outhaul Dist}) + 22.8(\text{Choker Drop}) - 0.48(\text{Outhaul Slope})$$

$$\text{Adjusted } R^2 = 0.66$$

[Eqn 6: Site C, Inexperienced pilot]

$$\text{Outhaul (sec)} = 28.5 + 0.0324(\text{Outhaul Dist}) + 66.5(\text{Choker Drop})$$

$$\text{Adjusted } R^2 = 0.65$$

[Eqn 7: Site A, Experienced pilot]

$$\text{Inhaul (sec)} = 1.8 + 0.0337(\text{Inhaul Dist}) + 0.40(\text{Inhaul Slope}) + 0.00576(\text{Adj. Payload})$$

$$\text{Adjusted } R^2 = 0.46$$

[Eqn 8: Site A, Inexperienced pilot]

$$\text{Inhaul (sec)} = 53.6$$

$$\text{Adjusted } R^2 = 0.00$$

[Eqn 9: Site B, Experienced pilot]

$$\text{Inhaul (sec)} = -4.0 + 0.0359(\text{Inhaul Dist}) + 0.38(\text{Inhaul Slope}) + 0.00544(\text{Payload})$$

$$\text{Adjusted } R^2 = 0.31$$

[Eqn 10: Site B, Inexperienced pilot]

$$\text{Inhaul (sec)} = 72.1$$

$$\text{Adjusted } R^2 = 0.00$$

[Eqn 11: Site C, Experienced pilot]

$$\text{Inhaul (sec)} = 3.9 + 0.0246(\text{Inhaul Dist}) + 0.19(\text{Inhaul Slope}) + 0.00614(\text{Adj. Payload})$$

$$\text{Adjusted } R^2 = 0.71$$

[Eqn 12: Site C, Inexperienced pilot]

$$\text{Inhaul (sec)} = 14.2 + 0.0330(\text{Inhaul Dist}) + 4(\text{Logs})$$

$$\text{Adjusted } R^2 = 0.52$$

By combining the area based means, hook and unhook, and applying site wide means to the regressions for outhaul and inhaul, improvement potential can be assessed. Table 13 provides the percent of time an inexperienced pilot spends within an element or turn relative to an experienced pilot. Any number near 100 percent indicates performance equivalent to an experienced pilot. Both the highest and lowest percentages occur within site A: 368 for hook and 117 for unhook. This indicates that grapples may require minimal experience for unhooking, but significant experience for actually grabbing a log. Overall the greatest room for improvement usually occurs in the hook element.

Table 13. Inexperienced pilot time as a percent of experienced pilot time for each turn element and total turn time.

Site	Choker Delivery	Outhaul	Hook	Inhaul	Unhook	Total
A	<i>N/A</i>	156%	368%	175%	117%	181%
B	No	128%	209%	147%	147%	164%
	Yes	189%	217%	147%	155%	194%
C	No	129%	200%	179%	204%	172%
	Yes	176%	189%	179%	176%	180%

From the Pilot Experience Summary Table in Appendix B, some performance factors indicate a few of the areas where the experienced and inexperienced pilots differ in technique. Site A shows no significant difference in inhaul distance or slope between pilot experience levels, but maximum inhaul velocity (In Max Vel) is greater with the experienced pilot, at 99 km/hr, than it is with the inexperienced pilot, 59 km/hr. Site C exhibits a similar situation, where outhaul distance is not significantly different between pilot experience levels, but the experienced pilot achieves a higher mean maximum outhaul velocity (139 km/hr) while the inexperienced pilot's mean maximum outhaul velocity is 107 km/hr. The mean outhaul acceleration and deceleration rates are more extreme for the experienced pilot as well, with 3.0 m/s² and -3.0 m/s², compared to 1.9 m/s² and -1.8 m/s² for the inexperienced pilot. These trends are evident in the inhaul component of site C, as well as the outhaul and inhaul components of site B, but distances are also significantly different, which brings the distance factor into question. This issue of distance, acceleration, and velocity is further addressed in Production Analysis, the third section of the results.

Regressions for turn time and productivity (tonnes/hr) all show a strong correlation, where turn time had stronger correlations, adjusted R² = 0.70 to 0.79 and productivity adjusted R² = 0.50 to 0.64. The lower multiple coefficient of determination for productivity relative to turn time is expected to be a result of the variability in wood availability and arrangement at each hook point, which is not described with the

explanatory variables. The lowest correlations for both regressions occurs with site A, which had a small sample size for the inexperienced pilot (n=7). The time penalty for an inexperienced pilot ranged from 112.8 to 123.4 seconds per turn, while choker delivery (combining both Choker Drop and Choker Pickup) accounts for 96.7 sec at site B and 63.3 sec at site C. The negative correlation to Turn of Cycle indicates autocorrelation, in this case a performance improvement with each consecutive turn for site C. From a production perspective, inexperienced pilots reduce production by 33.1 to 42.8 tonnes/hr (PMH) and turns with choker delivery account for a 14.0 to 28.1 tonnes/hr reduction.

While it is common to develop models based on extraction or inhaul distance, outhaul distance is significant in every pilot experience regression. This is a result of using multiple landings, where the turn can start and end at different landings. Additionally, the first turn of every flight cycle is initiated from the service landing, commonly resulting in a considerably longer flight relative to the distance from the log landings.

Production Equations for Pilot Experience

[Eqn 13: Site A, Turn]

$$\text{Turn (sec)} = 22.1 + 112.8(\text{Pilot Status}) + 0.0941(\text{Outhaul Dist}) + 0.0281(\text{Payload})$$

$$\text{Adjusted } R^2 = 0.70$$

[Eqn 14: Site B, Turn]

$$\text{Turn (sec)} = 51.8 + 123.4(\text{Pilot Status}) + 0.0358(\text{Outhaul Dist}) + 58.3(\text{Choker Drop}) + 38.4(\text{Choker Pickup}) + 0.0200(\text{Payload})$$

$$\text{Adjusted } R^2 = 0.75$$

[Eqn 15: Site C, Turn]

$$\text{Turn (sec)} = 58.5 + 122.4(\text{Pilot Status}) + 0.0288(\text{Outhaul Dist}) + 0.0119(\text{Outhaul Dist}) + 40.2(\text{Choker Drop}) + 23.1(\text{Choker Pickup}) - 0.58(\text{Turn of Cycle}) + 0.0111(\text{Payload}) + 3.9(\text{Logs})$$

$$\text{Adjusted } R^2 = 0.79$$

[Eqn 16: Site A, Prod]

$$\text{Prod (tonnes/hr)} = 90.0 - 42.8(\text{Pilot Status}) - 0.0094(\text{Outhaul Dist})$$

$$\text{Adjusted } R^2 = 0.50$$

[Eqn 17: Site B, Prod]

$$\text{Prod (tonnes/hr)} = 90.6 - 33.1(\text{Pilot Status}) - 0.0105(\text{Outhaul Dist}) - 15.4(\text{Choker Drop}) - 12.7(\text{Choker Pickup})$$

$$\text{Adjusted } R^2 = 0.64$$

[Eqn 18: Site C, Prod]

$$\text{Prod (tonnes/hr)} = 87.4 - 33.4(\text{Pilot Status}) - 0.0109(\text{Inhaul Dist}) - 0.21(\text{Inhaul Slope}) - 0.0067(\text{Outhaul Dist}) - 7.7(\text{Choker Drop}) - 6.3(\text{Choker Pickup})$$

$$\text{Adjusted } R^2 = 0.58$$

This analysis has shown the penalty of using inexperienced pilots relative to experienced pilots from both an elemental as well as the turn level perspective. Here onboard GPS shows strong promise in evaluating performance.

Case Study 2: Canopy Impact

Canopy data were collected and analyzed from a subset of hook points at 3 sites. The initial canopy impact assessment, estimating hook time using stepwise regression for five zenith angles, showed correlation between 0.00 to 0.21 (See Eqn 19 -21). Site 5 was a salvage/seed tree treatment, and as a result was the most open of the three sites (See Table 14). This open characteristic reduces the overall influence of canopy closure and consequently the lack of correlation is not surprising. Site 4 showed the most uniform distribution and site 7 exhibited the least.

Table 14. Percent canopy cover summary.

Site 4				
Zenith Angle	Mean	N	5th %	95th %
0~15	30.5	34	6.48	52.0
0~30	41.8	34	22.9	56.9
0~45	49.9	34	37.6	60.1
0~60	57.6	34	49.9	64.7
0~75	66.2	34	61.5	71.7
0~90	74.3	34	69.6	79.2
Site 5				
Zenith Angle	Mean	N	5th %	95th %
0~15	4.54	30	0.00	30.0
0~30	8.90	30	0.01	39.5
0~45	14.8	30	1.60	44.4
0~60	23.5	30	8.30	53.5
0~75	34.0	30	19.3	61.4
0~90	45.0	30	30.6	70.3
Site 7				
Zenith Angle	Mean	N	5th %	95th %
0~15	36.9	63	0.23	68.3
0~30	50.9	63	17.0	73.9
0~45	62.1	63	37.6	77.4
0~60	69.4	63	50.8	81.2

0~75	75.8	63	59.6	84.6
0~90	81.1	63	67.4	87.8

Hook Time Equations from Canopy Cover

[Eqn 19: Site 4, Hook]

$$\text{Hook (sec)} = 88.74 + 0.595(0\sim15) - 1.032(0\sim45)$$

$$\text{Adjusted } R^2 = 0.21$$

[Eqn 20: Site 5, Hook]

$$\text{Hook (sec)} = 42.7$$

$$\text{Adjusted } R^2 = 0.00$$

[Eqn 21: Site 7, Hook]

$$\text{Hook (sec)} = 81.22 + 0.301(0\sim15) - 0.562(0\sim90)$$

$$\text{Adjusted } R^2 = 0.14$$

Further analysis, where the variables from Table 4 are included greatly improved the R^2 for Site 4, increasing from 0.26 to 0.64. Sites 5 and 7 had essentially no change; site 5 R^2 remained 0.00 and site 7 decreased from 0.1434 to 0.1428.

Hook Time Equations with Multiple Variables

[Eqn 22: Site 4, Hook]

$$\text{Hook (sec)} = 96.77 + 0.64(0\sim15) - 1.49(0\sim45) - 3.83(\text{Turn of Cycle}) +$$

$$0.116(\text{Payload}) - 0.108(\text{Adj Payload})$$

$$\text{Adjusted } R^2 = 0.57$$

[Eqn 23: Site 7, Hook]

$$\text{Hook (sec)} = 17.1 + 0.211(0\sim15) + 0.011(\text{Adj Payload}) + 10.3(\text{Choker Drop})$$

$$\text{Adjusted } R^2 = 0.14$$

Upon review of the independent variables for Eqn 22, it is evident that there is a potential for considerable collinearity. Of course, the percent canopy closure 0~15 is a factor of percent canopy closure 0~45, as it would be for any measure of canopy closure where the zenith angle begins at zero. Similarly, the variable, adjusted payload, is a factor of payload. The variance inflation factor (VIF) for the variables within Eqn 22 range from 2.13 to 135.37; indicating that collinearity is indeed a problem and the R^2 is artificially inflated. To reduce collinearity in the regression, two models were created independently using 0~15 and 0~45 as explanatory variables. The regression using 0~15 had the highest coefficient of determination, equaling 0.12. This was followed with stepwise

regression using only 0~15, Logs, Turn of Cycle, Payload, and Choker Drop as independent variables where 0~15 was a forced variable. The result is shown in Eqn 24.

Revised Hook Time Equation

[Eqn 24: Site 4, Hook]

$$\text{Hook} = 56.01 + 0.337(0\sim 15) - 1.7(\text{Logs}) + 7.5(\text{Choker Drop})$$

$$\text{Adjusted } R^2 = 0.18$$

Considering the relatively low multiple coefficient of determination in Eqn 23 and 24, it would seem that canopy cover plays a fairly small role in contributing to hook time. Independently, 0~15 explains 12 percent of the hook time variation for site 4 and five percent for site 7. However the offset potential in locating the hook point may be contributing to the low correlation. The GPS antenna was placed in the cockpit window. The attachment point for the long line is between 5 and 7 m away from the antenna location. This results in an instant offset of 5 to 7 m from the hook point reading. Using a 95% confidence interval on the accuracy of the GPS position for the hook point, the position could be off by an additional 1.5 m. The canopy cover locations, which were collected from the ground using position averaging for each location, have an estimated 95% confidence interval of 2.0 m without differential correction (Reynolds and Tran 2003). The possible end result is a canopy cover image that is 10.5 m from the expected hook point. Figure 18 shows the condition across a one meter grid. The impact of this offset could be reducing the ability to detect the strength of the correlation with canopy cover. Under more uniform canopy cover, such as at site 4, the offset effect may not be as confounding as it would be at a site with greater variability, such as site 7. Considering the variation explained by 0~15, 12 percent at site 4 and five percent at site 7, the proposed influence of site canopy variability is supported.

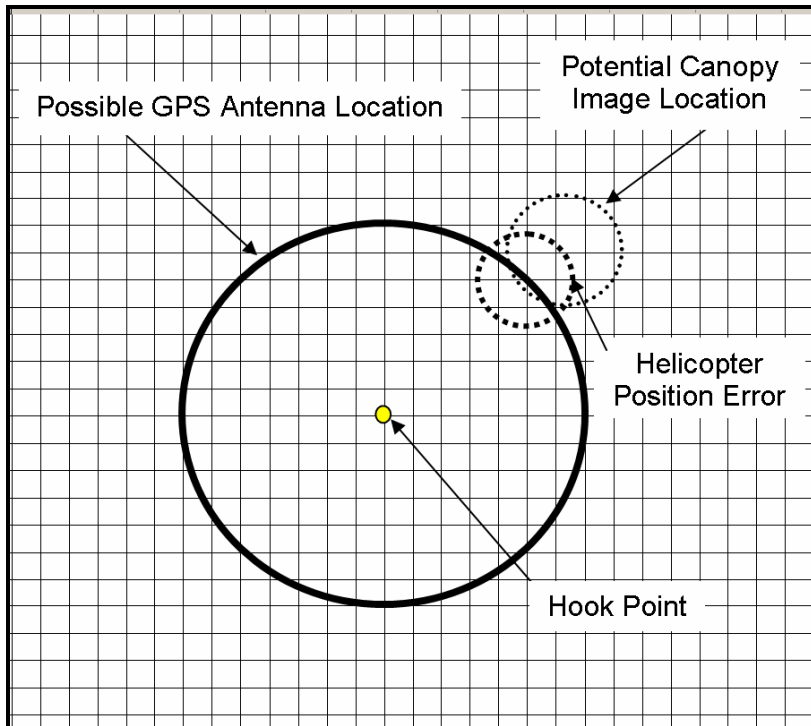


Figure 18. Canopy image location relative to hook point, projected across a one meter grid.

Case Study 3: Creating Productivity Equations

Acceleration, deceleration, and maximum velocity are measured using the differences between the positions throughout the outhaul or inhaul element. As a result these variables are a factor of the flight distance measurement, where the distance between each consecutive position is measured. However, when assessing potential helicopter operations, the linear distance is more likely to be obtainable than the flight distance. To better evaluate the use of acceleration, deceleration, and maximum velocity as explanatory variables in predictive models, the relationship between flight distance and linear distance was analyzed.

Both outhaul and inhaul flight distance displayed very high adjusted R^2 values to linear distance, ranging from 0.93 to 0.9976 and 0.81 to 0.99, respectively. Parameter estimates of linear distances typically show flight distance between two to 13 percent greater than the linear distance. Appendix C provides the complete parameter estimates with additional statistical information. The high coefficients of determination suggest that factors of flight distance, such as acceleration and maximum velocity may be correlated with linear distance.

The adjusted R^2 's for maximum velocity ranged between 0.58 and 0.85 for outhaul, and 0.62 and 0.91 for inhaul. The complete models are shown in Appendix D. This strong

relationship between the cubed root of linear distance and a maximum velocity further strengthens the potential for a mechanistic production model. However, the acceleration and deceleration adjusted R²'s are not as strong. Outhaul acceleration varied from 0.01 to 0.44 and deceleration from 0.03 to 0.37. The models for inhaul acceleration and deceleration have similar adjusted R² values, 0.10 to 0.44 and 0.08 to 0.64, respectively.

These results, shown in detail in Appendix E, indicate reduced promise of employing acceleration and deceleration as explanatory variables in a production model. This is due to the reduced ability to accurately determine some of the inputs, specifically acceleration and deceleration, for the proposed production model. In other words, if the ability to describe the variability in acceleration and deceleration is low, then our confidence in predicting acceleration and deceleration is low. Therefore, predicting acceleration and deceleration with low confidence and then using those predictions as explanatory variables in a production model results in a production model with low confidence. This occurs regardless of our ability to describe the variation in production.

If acceleration and deceleration were found with more reliability, the production models produced with those inputs may resemble those developed from the regressions resulting from those described in Table 5. Regarding total turn time, the adjusted R²'s ranged from 0.19 to 0.53. In this case the inputs were direct readings from the data, rather than estimates created from the regressions described in Appendix E. Equations 24 and 25, shown below, are samples of the total turn time regressions. Models for all nine sites can be found in Appendix F. As expected, the R²'s for productivity were lower than those calculated for turn time. These vary from 0.12 to 0.40. Two sample models, displaying those for sites 4 and 8, are shown below in equations 27 and 28.

[Eqn 25: Site 4, Turn]

$$\begin{aligned} \text{Turn (sec)} = & 87.7 - 7.2(\text{Out Accel}) + 7.6(\text{Out Decel}) + 0.632(\text{Out Max Vel}) - \\ & 5.9(\text{Inhaul Accel}) + 0.248(\text{In Max Vel}) + 41.0(\text{Choker Drop}) + \\ & 18.6(\text{Choker Pickup}) + 0.0129(\text{Payload}) - 1.4(\text{Turn of Cycle}) + \\ & 0.173(\text{Turn of Day}) \\ \text{Adjusted R}^2 = & 0.53 \end{aligned}$$

[Eqn 26: Site 8, Turn]

$$\begin{aligned} \text{Turn (sec)} = & 93.3 - 2.8(\text{Out Accel}) + 7.1(\text{Out Decel}) + 0.523(\text{Out Max Vel}) \\ & + 32.7(\text{Choker Drop}) + 6.9(\text{Choker Pickup}) - 0.657(\text{Turn of Cycle}) \\ & + 0.034(\text{Turn of Day}) \\ \text{Adjusted R}^2 = & 0.25 \end{aligned}$$

[Eqn 27: Site 4, Prod]

$$\text{Prod (tonnes/hr)} = 86.9 + 1.3(\text{Out Accel}) - 2.8(\text{Out Decel}) - 0.165(\text{Out Max Vel}) \\ - 0.109(\text{In Max Vel}) - 10.7(\text{Choker Drop}) - 4.6(\text{Choker Pickup}) + \\ 0.514(\text{Turn of Cycle}) - 0.098(\text{Turn of Day})$$

$$\text{Adjusted } R^2 = 0.40$$

[Eqn 28: Site 8, Prod]

$$\text{Prod (tonnes/hr)} = 103.7 + 3.2(\text{Out Accel}) - 5.1(\text{Out Decel}) - 0.283(\text{Out Max Vel}) \\ - 0.126(\text{In Max Vel}) - 13.8(\text{Choker Drop}) + 0.517(\text{Turn of Cycle})$$

$$\text{Adjusted } R^2 = 0.40$$

From the sample equations it is evident that some coefficients behave as expected, where an increase in acceleration or a decrease in the negative deceleration value results in lower total turn time or more productivity. Similarly, choker drop and choker pickup increase total turn time and decrease productivity. However, increased velocity has the opposite effect, where it inflates total turn time and deflates productivity. Because the maximum velocity is closely correlated with distance, it is likely that velocity is treated as a surrogate for distance. If distance were used rather than velocity, the coefficients would be more logical. The explanatory variable, Turn of day, which was anticipated to account for more rapid production due to improved knowledge of the site conditions, shows the opposite effect. This may be due to degrading weather conditions, where warmer temperatures and/or higher wind speeds reduce efficiency slightly. Since the available weather data are rough approximates and winds aloft could not be measured, these inputs are not included in this analysis.

In order to achieve more intuitive models and eliminate the issue of predicting acceleration and deceleration, the stepwise regression analysis described in Table 5 was conducted. These coefficients of determination were greater than those calculated using velocity and acceleration variables. The total turn time adjusted R^2 's span between 0.25 and 0.59, and productivity between 0.15 and 0.41. These are only slightly higher than those associated with accelerations and velocities, but the need to predict any of those variables is eliminated in equations 29 – 46.

[Eqn 29: Site 1, Turn]

$$\text{Turn (sec)} = 48.3 + 0.0218(\text{Outhaul Dist}) + 0.0363(\text{Inhaul Dist}) + 0.374(\text{Inhaul Slope}) + 19.1(\text{Choker Drop}) + 11.1(\text{Choker Pickup}) + 0.0145(\text{Payload}) + 2.50(\text{Logs}) - 0.359(\text{Turn of Cycle}) - 0.055(\text{Turn of Day})$$

$$\text{Adjusted } R^2 = 0.44$$

[Eqn 30: Site 2, Turn]

$$\text{Turn (sec)} = 73.4 + 0.0207(\text{Outhaul Dist}) + 0.0269(\text{Inhaul Dist}) - 0.209(\text{Inhaul Slope}) + 9.4(\text{Choker Drop}) + 12.4(\text{Choker Pickup}) + 0.0066(\text{Payload}) - 0.227(\text{Turn of Cycle}) - 0.049(\text{Turn of Day})$$

$$\text{Adjusted } R^2 = 0.54$$

[Eqn 31: Site 3, Turn]

$$\text{Turn (sec)} = 70.5 + 0.0436(\text{Outhaul Dist}) + 31.7(\text{Choker Drop}) + 21.8(\text{Choker Pickup}) + 0.0142(\text{Payload}) - 0.0454(\text{Turn of Day})$$

$$\text{Adjusted } R^2 = 0.53$$

[Eqn 32: Site 4, Turn]

$$\text{Turn (sec)} = 90.0 + 0.0238(\text{Outhaul Dist}) + 0.0252(\text{Inhaul Dist}) + 0.563(\text{Inhaul Slope}) + 38.3(\text{Choker Drop}) + 16.5(\text{Choker Pickup}) + 0.0078(\text{Payload}) + 2.27(\text{Logs}) - 1.07(\text{Turn of Cycle}) - 0.159(\text{Turn of Day})$$

$$\text{Adjusted } R^2 = 0.59$$

[Eqn 33: Site 5, Turn]

$$\text{Turn (sec)} = 126.9 + 0.0403(\text{Outhaul Dist}) + 0.947(\text{Inhaul Slope}) + 10.1(\text{Choker Drop}) + 7.43(\text{Choker Pickup}) + 0.0033(\text{Payload})$$

$$\text{Adjusted } R^2 = 0.36$$

[Eqn 34: Site 6, Turn]

$$\text{Turn (sec)} = 62.5 + 0.02493(\text{Outhaul Dist}) + 0.0384(\text{Inhaul Dist}) - 0.369(\text{Inhaul Slope}) + 12.6(\text{Choker Drop}) + 5.5(\text{Choker Pickup}) + 0.0087(\text{Payload}) + 16.8(\text{Grapple})$$

$$\text{Adjusted } R^2 = 0.46$$

[Eqn 35: Site 7, Turn]

$$\text{Turn (sec)} = 86.9 + 0.0571(\text{Outhaul Dist}) + 16.4(\text{Choker Drop}) + 10.5(\text{Choker Pickup}) + 0.0092(\text{Payload}) - 0.31(\text{Turn of Cycle})$$

$$\text{Adjusted } R^2 = 0.25$$

[Eqn 36: Site 8, Turn]

$$\text{Turn (sec)} = 85.3 + 0.0309(\text{Outhaul Dist}) + 0.0336(\text{Inhaul Dist}) + 0.191(\text{Inhaul Slope}) + 32.3(\text{Choker Drop}) + 8.8(\text{Choker Pickup}) + 0.0054(\text{Payload}) - 0.406(\text{Turn of Cycle}) - 0.035(\text{Turn of Day})$$

$$\text{Adjusted } R^2 = 0.30$$

[Eqn 37: Site 9, Turn]

$$\text{Turn (sec)} = 62.4 + 0.0287(\text{Outhaul Dist}) + 0.0220(\text{Inhaul Dist}) + 8.4(\text{Choker Drop}) + 0.0100(\text{Payload}) - 0.204(\text{Turn of Cycle}) - 0.052(\text{Turn of Day})$$

$$\text{Adjusted } R^2 = 0.34$$

[Eqn 38: Site 1, Prod]

$$\text{Prod (tonnes/hr)} = 101.1 - 0.0090(\text{Outhaul Dist}) - 0.0253(\text{Inhaul Dist}) - 0.449(\text{Inhaul Slope}) - 10.9(\text{Choker Drop}) - 7.1(\text{Choker Pickup}) - 1.05(\text{Logs}) + 0.302(\text{Turn of Cycle})$$

$$\text{Adjusted } R^2 = 0.30$$

[Eqn 39: Site 2, Prod]

$$\text{Prod (tonnes/hr)} = 110.5 - 0.0103(\text{Outhaul Dist}) - 0.0305(\text{Inhaul Dist}) + 0.221(\text{Inhaul Slope}) - 7.4(\text{Choker Pickup}) - 20.6(\text{Grapple}) + 0.347(\text{Turn of Cycle}) + 0.0657(\text{Turn of Day})$$

$$\text{Adjusted } R^2 = 0.38$$

[Eqn 40: Site 3, Prod]

$$\text{Prod (tonnes/hr)} = 99.85 - 0.0134(\text{Outhaul Dist}) - 0.0101(\text{Inhaul Dist}) - 0.296(\text{Inhaul Slope}) - 10.1(\text{Choker Drop}) - 9.7(\text{Choker Pickup}) + 0.378(\text{Turn of Cycle})$$

$$\text{Adjusted } R^2 = 0.31$$

[Eqn 41: Site 4, Prod]

$$\text{Prod (tonnes/hr)} = 81.9 - 0.0057(\text{Outhaul Dist}) - 0.0122(\text{Inhaul Dist}) - 0.453(\text{Inhaul Slope}) - 9.5(\text{Choker Drop}) - 4.6(\text{Choker Pickup}) + 0.37(\text{Turn of Cycle}) - 0.087(\text{Turn of Day})$$

$$\text{Adjusted } R^2 = 0.41$$

[Eqn 42: Site 5, Prod]

$$\text{Prod (tonnes/hr)} = 72.8 - 0.0136(\text{Outhaul Dist}) - 0.0111(\text{Inhaul Dist}) - 0.246(\text{Inhaul Slope}) - 4.5(\text{Choker Drop}) - 4.7(\text{Choker Pickup}) - 1.41(\text{Logs})$$

$$\text{Adjusted } R^2 = 0.30$$

[Eqn 43: Site 6, Prod]

$$\text{Prod (tonnes/hr)} = 119.4 - 0.0103(\text{Outhaul Dist}) - 0.0238(\text{Inhaul Dist}) + 0.300(\text{Inhaul Slope}) - 3.8(\text{Choker Drop}) - 21.8(\text{Grapple})$$

$$\text{Adjusted } R^2 = 0.32$$

[Eqn 44: Site 7, Prod]

$$\text{Prod (tonnes/hr)} = 85.7 - 0.0357(\text{Outhaul Dist}) + 0.438(\text{Inhaul Slope}) - 6.7(\text{Choker Drop}) - 4.7(\text{Choker Pickup}) + 0.153(\text{Turn of Cycle})$$

$$\text{Adjusted } R^2 = 0.16$$

[Eqn 45: Site 8, Prod]

$$\text{Prod (tonnes/hr)} = 101.1 - 0.0166(\text{Outhaul Dist}) - 0.0199(\text{Inhaul Dist}) - 15.6(\text{Choker Drop}) - 5.1(\text{Choker Pickup}) + 2.55(\text{Logs}) - 5.6(\text{Grapple}) + 0.404(\text{Turn of Cycle}) - 0.0232(\text{Turn of Day})$$

$$\text{Adjusted } R^2 = 0.29$$

[Eqn 46: Site 9, Prod]

$$\text{Prod (tonnes/hr)} = 90.6 - 0.0148(\text{Outhaul Dist}) - 2.93(\text{Inhaul Slope}) - 3.8(\text{Choker Drop}) + 0.211(\text{Turn of Cycle}) + 0.046(\text{Turn of Day})$$

$$\text{Adjusted } R^2 = 0.16$$

With the exception of sites 5 and 6, the total turn time models show a reduction in turn time with increasing turns per cycle and/or turns per day. This indicates that the operation becomes more efficient over time, possibly due to pilots, hookers, and the landing crew gaining experience with site conditions and their interaction with the helicopter. This trend is also seen in productivity models; however, the turn of day shows a negative impact on production at sites 4 and 8. At the same sites, turn of cycle has a positive impact. This degradation in productivity throughout the day could be the result of lower wood availability from the area yarded later in the day or declining weather conditions.

Combined Productivity Models

While site specific models provide insights to site specific operations, there is interest in the application of a broader payload based model. The sampling procedure and unequal

sample size do not permit suitable development of a global production model, but it is possible to create a model that reflects the production across the sites sampled. In this model the variables shown in Table 5 were applied, but the 4.5 tonne payload sites were analyzed together. However, the absence of log count data for site 9 excluded it from the analysis. Two models for each variable Turn (See Eqn 47 and 48) and Prod (See Eqn 49 and 50) were created, one with and one without the explanatory variable, Logs.

[Eqn 47: Payload 4.5 tonnes with logs, Turn]

$$\text{Turn (sec)} = 80.7 + 0.0267(\text{Outhaul Dist}) + 0.0334(\text{Inhaul Dist}) + 0.223(\text{Inhaul Slope}) + 17.8(\text{Choker Drop}) + 9.1(\text{Choker Pickup}) + 0.00739(\text{Payload}) + 0.91(\text{Logs}) - 0.502(\text{Turn of Cycle})$$

Adjusted $R^2 = 0.50$

[Eqn 48: Payload 4.5 tonnes without Logs, Turn]

$$\text{Turn (sec)} = 89.2 + 0.0273(\text{Outhaul Dist}) + 0.0270(\text{Inhaul Dist}) + 0.0509(\text{Inhaul Slope}) + 18.5(\text{Choker Drop}) + 9.7(\text{Choker Pickup}) + 0.00611(\text{Payload}) - 0.464(\text{Turn of Cycle})$$

Adjusted $R^2 = 0.46$

[Eqn 49: Payload 4.5 tonnes with logs, Prod]

$$\text{Prod (tonnes/hr)} = 100.3 - 0.00992(\text{Outhaul Dist}) - 0.0155(\text{Inhaul Dist}) - 0.171(\text{Inhaul Slope}) - 7.6(\text{Choker Drop}) - 5.5(\text{Choker Pickup}) - 0.793(\text{Logs}) - 6.8(\text{Grapple}) - 0.283(\text{Turn of Cycle})$$

Adjusted $R^2 = 0.30$

[Eqn 50: Payload 4.5 tonnes without Logs, Prod]

$$\text{Prod (tonnes/hr)} = 95.9 - 0.0102(\text{Outhaul Dist}) - 0.0119(\text{Inhaul Dist}) - 0.0585(\text{Inhaul Slope}) - 8.5(\text{Choker Drop}) - 6.3(\text{Choker Pickup}) - 5.3(\text{Grapple}) - 0.283(\text{Turn of Cycle})$$

Adjusted $R^2 = 0.25$

Given the multiple coefficient of determination for Turn and Prod for each site independently, the combined 4.5 tonnes payload models account for a good portion of the variability. The inclusion of site 9 reduces this capability by between four and five percent. This is not strictly due to the absence of the variable Logs, which accounts for approximately 0.5 percent of the variability according to the semi-partial correlation. This could be due to the higher estimated average temperature relative to the other sites. Again, the Prod model has a reduced R^2 which due to the variation in wood availability and arrangement within and across the sites.

Discussion

This initial trial of onboard GPS for assessment of various helicopter yarding factors shows great promise, and with additional technological improvements, it could be possible to expand its use. Refinement and adoption of onboard GPS could provide considerable benefit to the helicopter logging industry, the land managing organizations that require their services, and the companies who contract with them.

While the data and analyses presented in the three cases studies undertaken within this project show numerous opportunities, there are limitations. This is particularly so with the automated interpretation. The protocol and software developed within the scope of this study still requires a considerable amount of expert intervention to convert the raw GPS data into accurate time study data. For example, the process of simplifying the landing and hooking maneuvers to area based circles, naturally presents a less refined perspective. It is possible for choker drops to be selected as hook points, but the potential for such misidentification was minimal with this data. Aborted turns and partially dropped turns were not considered in this analysis.

Additionally, record errors may occur due to incorrectly interpreting or entering the copilot data. Similarly, the copilot may not have recorded all of the choker drops, or may have recorded them incorrectly. The dynamic interaction between the load cell and the payload in motion requires some interpretation when recording the turn weight. For instance, Hartsough et al (1985) noted a load cell on a S-64E helicopter read an average of 519 kg high. These opportunities for error are not out of the ordinary for this type of research, and should be kept in mind when interpreting the results.

The ability to use onboard GPS in assessing relative performance was not hindered by these limitations; the simplification of hook and unhook, possibility of incorrect hook point identification, and the possibility of common recording errors. In this case the performance analyzed was that of inexperienced and experienced pilots and the impact of canopy cover. This indicates that the same technique may be used to assess the cost or benefit of harvest prescriptions or innovations in the yarding techniques. However, these data are more limited in the ability to develop precision production models, where the errors previously mentioned combined with a lack of more detailed information regarding stand characteristics, landing conditions, etc., would be needed to explain more of the variability within the data. Expanded use of onboard GPS with some further data processing refinement could address some of these issues.

Compared to more traditional means of collecting time study data, the GPS method is considerably more efficient. While technicians are typically required to operate time

sampling equipment, no on-site technicians would be required with onboard GPS. Once integrated into the operational procedure, the aircraft mechanic or pilot would simply turn on the GPS unit as part of the daily routine, and download the data at the end of the day, week, or month, depending upon field and office preferences. The time commitment to accomplish these tasks could take less than 15 minutes. Except in very rare situations, when satellite availability is quite low, the GPS can track operations regardless of location. On-site technicians do not have this luxury and require the ability to maintain line of sight with the helicopter. This line-of-site requirement often adds to the number of technicians needed. Of course, when the technician can maintain line-of-site collecting accurate distance information can be difficult. Such information is easily retrieved from the GPS data.

Back at the office, helicopter companies would need a relatively small amount of staff time to make use of the GPS system. Once a user becomes proficient in locating landings, reviewing and correcting the primary analysis, and entering data supplied by the co-pilot, creation of a final elemental data file is relatively quick. In its present form, a typical day's worth of elemental flight data could be created in approximately two hours. More complex conditions, such as progressive roadside landings, may require more time. There are numerous opportunities to benefit from the methods demonstrated as well as means to expand upon them.

Currently many operations require the copilot to record turn weights, log count, choker drops, the hooker for each turn, as well as other operational information in hard copy. This information is then sent to the main office for record keeping. If this data were recorded electronically, and synchronized with the onboard GPS, the methods used in this work could be readily transferred with minimal manual input. Time once spent reviewing general production rates could be used to consider means to improve each turn. This would readily allow assessment of extended flight cycles to enhance productivity through the greater familiarity of the site and conditions. Alternately, data could be transferred and analyzed in real-time, where suggestions for improvements could be made on the 'fly'. While this research did not focus on differences between experienced pilots, the opportunity exists to conduct detailed pilot comparisons, as was conducted with the experienced and inexperienced pilots. Similarly, hookers could be compared as well. Continual demonstration of ideal payloads and short hook times would indicate significant savings to the company. The specific methods of the hookers could be investigated more thoroughly to improve performance throughout the company. The information from both experienced pilots and hookers could be use to improve company training as well as providing a target for incentive pay.

All three segments of this study utilized the ability to identify turns with choker delivery. This was not limited to complete turns that included choker delivery, but split the components of the process into the choker pickup, which occurred at the landing and the choker drop, which occurs in outhaul or within the hooking circle. This method provides more insight into the factors impacting choker delivery. Because the release of chokers is controlled by an electrical switch in the cockpit, attaching an inductive loop to the wire between the switch and the hook would allow the choker release, as well as payload release to be recorded without modifying the current equipment. Tying this information directly to the GPS would create more detailed information on choker drop and payload release locations and timing. Considering various drop distances from the hook point this information would serve to more accurately account for the cost of choker delivery. Additionally, the payload release data would also permit more detailed landing analysis, which could be combined with general layout and equipment information. Choker and payload release could also be tracked through continual recording of load cell readings with a GPS position link. This method would also allow monitoring of breakout forces. For an extremely in depth study of landing operations, all crew members and equipment could be equipped with GPS units to assess the influence of crew and equipment locations on landing efficiencies.

Although the canopy analysis component of this work accounted for a relatively small portion of the variability in hook time, establishing the hook point from the hooker, rather than the helicopter would allow a more accurate hook point location for canopy cover assessment. Combining a greater level of stand data, with location information may provide a more thorough understanding of hook time. Conversely, the payload data could be associated with each hook point to better assess the influence of micro-site characteristics on log weight. Payload associated hook point data could also be provided to the land management agency to correlate with timber cruise data from that sale. Along with verifying the cruise, it would allow the consideration of adjustments to future timber cruise or appraisal applications, such as adjusting anticipated helicopter payload given species, slope and aspect of a site.

While sites within this work cover a broad range of yarding sites, distances, and conditions, operations will occur beyond this range and bring into question the use of these regressions for such an application. For this reason, the mechanistic approach is of interest, where total turn time is calculated with speed and distance. However, as discussed earlier, the accuracy of acceleration and deceleration measures are problematic with the GPS configuration used in this analysis. The accuracy issue may be the cause for poor correlation to acceleration and deceleration, which reduces their predictive value in a mechanistic model. Alternatively, acceleration and deceleration characteristics of a specific helicopter make may not be appropriate inputs for such a model. Given the area

based approach used in this analysis, hook and landing circle entrance and departure speeds can vary greatly. In some instances, acceleration peaked before inhaul or outhaul was initiated. Factors such as landing layout, stand conditions, weather, and pilot abilities may have greater influence on acceleration. Future research may verify this with improved antenna placement, or alternate means of measuring the acceleration function. This could result in a more reliable mechanistic model.

As the pilot experience and production analysis showed, the models for total turn time regularly possessed a higher multiple coefficient of determination than productivity measured in tonnes/hr. While tonnes/hr is a common measure in forest operations, in helicopter logging, this variation is not as easily explained. This is likely to be a result of the variation in wood availability, wood weight variability, and log arrangement at the hook point. Through the incorporation of technologies like GPS in future research, this variability may be explained.

Additionally, the productivity functions in this study focused on work time only or productive machine hours (PMH), excluding any delays outside of the yarding cycle. For instance when mechanical problems with the hook required the helicopter to return to the service landing, the time lost on this aborted turn and the flight to the service landing was excluded from the production analysis. While this may seem to limit the usefulness of the work in terms of predicting average productivity rates, Spinelli and Visser (2008) demonstrated the utility of applying standardized delays to PMH. Because delays occur erratically both in terms of location and duration, and are often dependent upon operational factors, such as hot versus cold decking, natural forest stands or plantations, and terrain type, Spinelli and Visser suggest that applying delay factors to PMH allow for the development of standardized production studies where delay is independently added to improve site specific analysis. This method is quite appropriate for helicopter yarding, where the inoperable weather conditions, varying by location and season, frequently cause yarding delays.

Conclusion

This research implemented onboard GPS in helicopter yarding to assess the potential of using GPS data to develop time studies and improve operational analysis. Covering six states, three helicopter models were sampled, including a total of nine sites. Eight of these sites involved helicopters with maximum payloads of 4.5 tonnes. One site involved a 2.7 tonne maximum payload helicopter. Yarding operations were varied and included choker and grapple yarding, experienced and inexperienced pilots, one to 20 log turns, and extraction distances from 55 to 3100 m. This variety made the development of an automated GPS data processing method challenging, but a semi-automated process was successfully developed. As a result this technique is suitable for a broad range of scenarios.

The GPS data are broken into elemental time study components, comprising outhaul, hook, inhaul, and unhook. The hook point and landing locations were area based with 20 and 35 m radii, respectively. The outhaul and inhaul elements were determined by the time spent outside of and in route to either area based element. Location and time information provided in the GPS data enable time, distance, velocity, and acceleration calculations. With this information each turn is then combined with the data typically recorded by the copilot, commonly including payload, number of logs, choker drops, pilot, and hooker, which readies the data for analysis. Three aspects of this data were analyzed to consider the suitability of employing onboard GPS.

Three of the sampled sites used both experienced and inexperienced pilots. Each yarding cycle with an inexperienced pilot was paired with a chronologically adjacent yarding cycle from an experienced pilot. These data were then compared to assess the elemental and turn based differences in productivity. The time study data indicate a 64 to 94% increase in total turn time compared to experienced pilots with choker delivery and grapple operations showing the larger percentage increases. From the elemental perspective, the inexperienced pilots spent 89 to 117% more time in hook and 168% more time in hook with a grapple. The inexperienced pilot showed only 17% more time in unhook with a grapple, while choker operations ranged between 47 and 104% more time in unhook. The outhaul and inhaul elements showed a lower percentage time difference than the hooking elements. While inexperienced pilots are not as proficient as experienced pilots in any element, they tend to show the greatest discrepancy in the hook element. On the whole, the inexperienced pilots could improve most in the hook elements and conducting choker drops. When operational factors permit it, inexperienced pilots may improve more rapidly if they work in operations with shorter yarding distances where choker drops are frequent. This successful analysis validates the

use of onboard GPS and the data processing method in assessing techniques or innovations in helicopter yarding.

Hemispherical canopy images were collected at three sites to determine percent canopy cover and assess its impact on hook time. A subset of hook point locations determined from the onboard GPS were located on the ground. The percent canopy cover measurements started with zenith angles 0 - 15° and increased by 15° increments to 0 - 90°. Although an artifact in the GPS antenna location in the helicopter created offset in locating the hook point on the ground, the 0 - 15° canopy cover measurement accounted for up to 12% of the variation in hook time. Not surprisingly the most open of the sampled sites had no correlation with canopy closure. These results validate the previous supposition that the canopy closure impacts hook time. While the elimination of the offset or identifying the hook points from the ground may provide more robust analysis, this investigation supports the idea that onboard GPS can be used to evaluate the impacts of stand prescriptions.

The experienced pilot data were used to develop regressions for total turn time and productivity in tonnes/hr at each site. Two approaches were used in developing these regressions. The first approach used maximum acceleration, deceleration, and velocity as explanatory variables. The second method used the more traditional distance and slope measures as explanatory variables. Although outhaul and inhaul flight distance correlated well to linear distance, the acceleration and deceleration did not show strong correlation to distance, which indicated that these would not provide suitable explanatory variables in a production equation. The more traditional means for developing production equations showed moderate strength multiple coefficients of determination. For seven of the nine sites total turn time models had a higher correlation than productivity, indicating that variability due to wood weight and wood availability creates additional complexity in production models. The variables turn of cycle and turn of day often resulted in improved production, indicating better knowledge of the site over time improve the operation. The precision of the production models developed from onboard GPS and commonly recorded data was lower than preferred, but could improve with the incorporation of additional site related inputs.

This research demonstrated some of the opportunities of onboard GPS in helicopter yarding and the data processing method developed. The level of detail available through this technique is unprecedented for published helicopter yarding investigations. While more site specific information is needed to improve the precision of production models, the data can be used to create clear evaluations regarding the impacts of various harvest prescriptions, pilot ability, and yarding methods. Through deployment of this method helicopter companies will not only be able to assess operational efficiencies, but will

have rapid means of assessing new techniques. With results in hand they would be encouraged to innovate and could readily measure the success or failure of those innovations.

References

- Alig, R.J., D.J. Lewis and J.J. Swenson. 2005. Changes in land use, forest fragmentation, and policy responses. P 81-84 in Proc. of Emerging issues along urban/rural interfaces: Linking science and society, Laband, D.N. (ed.). Atlanta.
- Alvarez, M. 2007. The state of America's forests. Society of American Foresters, Bethesda, MD. 68 p.
- Andersson, B. and G. Young. 1998. Harvesting coastal second-growth forests: summary of harvesting system performance. Forest Engineering Research Institute of Canada Tech. Rep. No. TR-120. 47 p.
- Auernhammer, H., and T. Muhr. 1991. GPS in a basic rule for environment protection in agriculture. P. 394-402 in Proc. of 1991 symposium automated agriculture for the 21st century, American Society of Agricultural Engineers.
- Aust., W.M., T.C. Fristoe, P.A. Gellerstedt, L.A.B. Giese, and M. Miwa. 2006. Long-term effects of helicopter and ground-based skidding on site properties and stand growth in a tupelo-cypress wetland. *For. Ecol. and Mgmt.* 226:72-79.
- Barnes, R.M. 1980. Motion and time study: Design and measurement of work. John Wiley & Sons. New York 689 p.
- Bernard, A.M., and S.P. Prisley. 2005. Digital mapping alternatives: GIS for the busy forester. *Jour. of For.* 103(4):163-168.
- Bjordheden, R., and M.A. Thomposon. 1995. An international nomenclature for forest work study. P. 190-215. in Proc *IUFRO 1995 S3:04 XX World Congress, Caring for the forest: Research in a changing world*. Field, D.B. (ed.). Tampere, Finland.
- Board on Agriculture. 1997. Precision agriculture in the 21st century: Geospatial and information technologies in crop management. National Academy Press, Washington D.C. 168 p.
- Borgelt, S.C., J.D. Harrison, K.A. Sudduth, and S.J. Birrell. 1996. Evaluation of GOS for applications in precision agriculture. *App. Eng. Agr.* 12(6):633-638.
- Bruce, Bob. 2003. Helicopter logging's bumpy ride: using helicopters to thin forests instead of fighting fires. *Timber West* July/Aug.
- Burke, D. 1973. Helicopter logging: Advantages and disadvantages must be weighed. *J. For.* Sept. 574 – 576.
- Carson Helicopters. Carson composite main rotor blade. Available online at [www.carsonhelicopters.com/composite blades.htm](http://www.carsonhelicopters.com/composite_blades.htm); last accessed Mar. 9, 2008.
- Cavali, R., S. Grigolato, and D. Lubello. 2006. Planning logging systems through site analysis. P. 319-330 in Proceedings of the international precision forestry symposium, Ackerman, P.A., D.W. Langin, and M.C. Antonides (eds.). Stellenbosch University, Stellenbosch.

- Christian, L.E., and A.M. Brackley. 2007. Helicopter logging productivity on harvesting operations in southeast Alaska, using ecologically based silvicultural prescriptions. *WJAF* 22(2):142-147.
- Cleaver, D. 2001. Standing stem harvesting. P. 280-284 in Proc. Int. Mt. Logging and 11th PNW Skyline Symp 2001. Seattle, USA
- Conway, S. 1976. *Logging Practices: Principles of Timber Harvesting Systems*. Miller Freeman Publications, USA. 416 p.
- Davis, C.T., and L.D. Kellogg. 2005. Measuring machine productivity with the multiDat datalogger: a demonstration on three forest machines. USDA For. Serv. Gen. Tech. Rep. PSW-GTR-194. 10p.
- Defense Science Board. 2005 Task force on the future of the global position system. Available online at www.acq.osd.mil/dsb/reports/2005-10-GPS_Report_Final.pdf; last accessed Mar. 9, 2008.
- Deal, R.L., and S.M. White (eds.). 2005. Understanding key issues of sustainable wood production in the Pacific Northwest. USDA For Serv. Gen. Tech. Rep. PNW-GTR-626. 76p.
- Dunham, M. T. 2003. Helicopter logging with the Bell 214B: group and single-tree selection in low-volume coastal cedar stands. *FERIC, Vancouver, B.C. Advantage Report* 4(33): 1-19.
- Dunham, M. T. 2004. Helicopter logging with the Bell 214B: retention and clearcut harvesting in the southern interior of British Columbia. *FERIC, Vancouver, B.C. Advantage Report* 5(38): 1-24.
- Dykstra, D.P. 1980. Density altitude as a performance standard for helicopter research in forestry. *Transactions of the ASAE*. 23(3):541-545.
- Energy Information Administration. 2004. Forest products industry analysis briefs economic profile and trends. Available online at www.eia.doe.gov/emeu/mecs/iab98/forest/profile.html; last accessed Mar 9, 2008.
- FAO. 2006a. Global Forest Resources Assessment 2005: Progress towards sustainable forest management. FOA Forestry Paper 147. UN FAO-FRA
- FAO. 2006b. Global Forest Resources Assessment 2005: 15 key findings. UN FAO-FRA.
- FAOSTAT. 2003. Forestry trade issues in the WTO: Factsheet for the sixth WTO ministerial conference, Hong Kong 3. UN FAO Rome. 2 p.
- Girard, J.W. Forest service stumpage appraisals. 1917. *J. For.* 15(6):708-725.
- Han, H-S., and L.D. Kellogg. 2000. Damage characteristics in young Douglas fir stands from commercial thinning with four timber harvesting systems. *WJAF* 15(1):27-33.
- Harrington, R.D. 1954. National advisory committee for aeronautics. Langley aeronautical laboratory Tech. Note 3234. P. 8.

- Harstela, P. 1999. The future of timber harvesting in Finland. Available online at <http://dev.hil.unb.ca/Texts/JFE/July99/harstela.html>; last accessed March 8, 2008.
- Hartsough, B.R., M.B. Lambert, and J.A. Miles. 1985. Airship logging: parameters affecting load factors. *Trans. of Amer. Soc. of Ag. Eng.* 28(5):1363-1370.
- Hartsough, B. R., Lambert, M. B., and Miles, J. A. 1986. Simulating changes to helicopter logging operations. *Trans. ASAE* 28(5): 1228 – 1231.
- Hartsough, B. R., Drews, E. S., McNeel, J. F., Durston, T. A., and Stokes, B. J. 1997. Comparison of mechanized systems for thinning ponderosa pine and mixed conifer stands. *For. Prd. J.* 47(11/12): 59 - 68.
- Harter, J., J. Garland, and S. Pilkerton. 2004. Synthetic rope properties and end connector concepts for use in timber harvesting applications. *Proc. 2004 Int Mt. Logging Conf. Vancouver, B.C. Canada.*
- Hayes, H.J.G., and R.J.M. Visser. 2004. An applied hardwood value recovery study in the Appalachian region of Virginia and West Virginia. *Intern. Jour. For. Eng.* 15(1):25-31.
- Heinimann, H. R., and Caminada, L. 1996. Helicopter logging in Switzerland: analysis of selective logging operations. Paper presented to the Mountain Logging and Pacific Northwest Skyline Symposium, May 12 -16 in Campbell River, Canada
- Jackson, B.D., and R.A. Morris. 1986. Helicopter logging of bald cypress in southern swamps. *South. Jour. App. For.* 10:92-95.
- Karger, D.W., and F.H. Bayha. 1987. *Engineered work measurement.* Industrial Press, New York. 503 p.
- Keegan, C.E., C.E. Fiedler, and D.P. Wichman. 1995. Costs associated with harvest activities for major harvest systems in Montana. *For. Prod. J.* 45(7-8): 78-82.
- Krag, R., and Evans, C. 2003. Helicopter logging on the Queen Charlotte Islands: productivities and costs of a Sikorsky S-64E Skycrane in clearcuts, patch cuts and single-tree selection cuts. *Forest Engineering Research Institute of Canada, Vancouver, B.C. Advantage Report* 4(19): 1-40.
- Lofroth, C., P. Jonsson, B. Norden, and H von Hofsten. 2007. Hybrid forwarder achieves considerable reduction in fuel consumption. *Skogforsk Results* No. 3.
- Lyons, C.K., and J. McNeel. 2004. Partial retention and helicopter turn volume. *For. Prod. J.* 54(1):58-61.
- MacDonald, A.J. 1999. *Harvesting systems and equipment in British Columbia.* FERIC HB-12. 199 p.
- McDonald, T. P., Carter, E. A., and Taylor, S. E. 2002. Using the global positioning system to map disturbance patterns of forest harvesting machinery. *Can. J. For. Res.* 32: 310-319.
- McDonald, T.P., and J.P. Fulton. 2005. Automated time study of skidders using global positioning data. *Comp. and Elec. in Ag.* 48:19-37.

- McDonald, T.P., S.E. Taylor, and R.B. Rummer. 2000. Deriving forest harvesting machine productivity from positional data. Presented at the 2000 ASAE Annual International Meeting, Paper No. 005011, ASAE.
- Meyers F.E., and J.R. Stewart. 2002. Motion and time study for lean manufacturing. Prentice Hall, Upper Saddle River, NJ. 370 p.
- Mitchell, D., and T. Gallagher. 2007. Chipping whole trees for fuel chips: a production study. *South. J. Appl. For.* 31(4):176-180.
- Murphy, G., M. Acuna, and D. Amishev. 2006. Adaptive control of bucking on harvesters: target and timing effects. *For. Prod. Jour.* 56(11/12): 79-83.
- National Interagency Fire Center. 2006. Interagency Helicopter Operations Guide. Available online at www.nifc.gov/ihog/; last accessed Mar. 9, 2008.
- Pace, S., G.P. Frost, I. Lachow, D.R. Frelinger, D. Fossum, D. Wassem, and M.M. Pinto. 1995. The global positioning system: assessing national policies. Rand Corporation, USA. 390 p.
- Oderwald, R.G., and B.A. Boucher. 2003. GPS after selective availability: how accurate is accurate enough? *J. For.* 101(4):24-27.
- Oderwald, R., and R.H. Wynne. 2000. Field applications for statistical data and techniques. *J. For.* 98(6):58-60.
- Prisley, S.P., and J.S. Carruth. 2005. GPS speeds data collection on GIS road networks. Available online at <http://gis.esri.com/library/userconf/proc95/to050/p040.html>; last accessed March 8, 2008.
- Reynolds, R., and E. Tran. 2003. Trial of a GeoXT GPS receiver under forestry conditions. *Advantage* 4(34):1-2.
- Rickenbach, M., and T.W. Steele. 2005. Comparing mechanized and non-mechanized logging firms in Wisconsin: implications for a dynamic ownership and policy environment. *For. Prod. Jour.* 55(11):21-26.
- Roberts, T., R.M. Shaffer, and R.J. Bush. 2005. Injuries on mechanized logging operations in the southeastern United States in 2001. *For. Prod. Jour.* 55(3):86-89.
- Rummer, B. 1997. Safety and health concerns in forestry operations. American Pulpwood Association, Inc. Tech Paper 97-P-4. 5 p.
- Ryans, M. 2002. Tracking silvicultural operations with GPS. Forest Engineering Research Institute of Canada, *Advantage* 3(18):1-10.
- Samset, I. 1985. Winch and cable systems. Marinus Nijhoff/Dr W. Junk, Boston. 539 p.
- Sedjo, R.A. 1999. Land use change and innovation in US forestry. P. 141 -174 in *Productivity in natural resource industries: Improvement through innovation.* Simpson R.D. (eds.). Resources for the Future, Washington D.C.
- Shaffer, R.M., and J.S. Milburn. 1999. Injuries on feller-buncher/grapple skidder logging operations in the southeastern United States. *For. Prod. J.* 49(7/8):24-26.
- Shiver, B.D., and B.E. Borders. 1996. Sampling techniques for forest resource inventory. John Wiley & Sons, New York. 356 p.

- Sloan, H., and J. Tollenaere. 1994. Technology advances in helilogging; a case study of the KMAX in Appalachian hardwoods. in *Proceeding of Advanced technology in forest operations: Applied ecology in action*. Council on Forest Engineering. Portland, OR.
- Sohngen, B., R. Medelsohn, and R. Sedjo. 1999. Forest management, conservation, and global timber markets. *Amer. Jour. Ag. Econ.* 81(1):1-13.
- Spinelli, R., B.R. Hartsough, P.M.O. Owende, and S.M. Ward. 2002. Productivity and cost of mechanized whole-tree harvesting of fast-growing eucalypt stands. *Int. J. For. Eng.* 13(2):49-60.
- Spinelli R., and R.J.M. Visser. 2008. Analyzing and estimating delays in harvester operations. *Int. J. For. Eng.* 19(1):35-40
- Spring, S.C., J.R. Niemann, and G.W. Grady. 1979. Preliminary airworthiness evaluation CH-47C with fiberglass rotor blades (with T55-L-712 engines). Available online at <http://handle.dtic.mil/100.2/ADA069891>; last accessed March 8, 2008.
- Stampfer, K., H. Gridling, and R. Visser. 2002. Analyses of parameters affecting helicopter timber extraction. *Intern. Jour. For. Eng.* 13(2):61-68.
- Stevens, P.M., and E.H. Clarke. 1974. Helicopters for logging characteristics, operation, and safety considerations. USDA For. Serv. Gen. Tech. Rep. PNW-20. 18 p.
- Theiss, A., D.C. Yen, and C-Y. Ku. 2005. Global positioning systems: an analysis of applications, current development and future implementations. *Comp. Stand. and Inter.* 27:89-100.
- Trimble 2002. Mapping systems general reference. Trimble. Part number 24177-03-ENG Revision A. pp. 1-114.
- United States. Department of Agriculture, Forest Service. 2001. National Summary: Forest Management Program Annual Report, Fiscal Year 1998 (Preliminary Version) Washington D.C.
- Wagtendonk, W. J. 1996. Principles of helicopter flight. Aviation Supplies and Academics, New Castle, WA 167 p.
- Wang, J., S.T. Grushecky, and J. McNeel. 2005. Production analysis of helicopter logging in West Virginia: a preliminary case study. *For. Prod. Jour.* 55(12):71-76.
- Warren, George. 1995. The business of helicopter logging. Proceedings of the National Institute for Occupational Safety and Health, Helicopter Logging Safety Workshop, May 1 – 2, in Ketchikan Alaska.
- Wear, D.N., D.R. Carter, and J. Prestemon. 2007. The U.S. south's timber sector in 2005: a prospective analysis of recent change. USDA For. Serv. Gen. Tech. Rep. SRS-99. 44p.
- Woodbury, P.B., J.E. Smith, and L.S. Heath. 2007. Carbon sequestration in the U.S. forest sector from 1990 to 2010. *For. Ecol. and Mngmt.* 241:14-27.
- Worker's Compensation Board of B.C. 2005. Safe work practices for helicopter operations in the forest industry. WCB Publications, British Columbia.

Appendix A

Safety Plan for Field Work

Safety is a high priority. The injury rate for workers in the forest industry is above average in the U.S. The fast pace of helicopter logging increases the need for everyone near the operation to remain alert to hazardous situations. The research activity should not increase the risks associated with these operations. Special attention must be directed to limiting the distractions for those working on the operation. The data collection crew will strictly adhere to all instructions provided by industry cooperators.

Those involved with data collection will wear appropriate personal protective equipment. While in the forest or at the log landing this protective equipment will include high top, nonskid boots, a hard hat, and a high visibility vest. Eye and hearing protection will also be worn when near helicopter operations. Due to the high level of activity at log landings it is important to observe the operation before approaching. This will reduce the chances of the data collectors or their vehicles from entering dangerous areas and restricting the movement of equipment. No one will enter the drop zone. The appropriate direction to approach a helicopter will be confirmed with company personnel. It is important to stay outside of the helicopters flight path whether in the forest, on roads, or at one of the landings. When in the cutting unit, special attention must be directed to snags, limbs, loose tops, etc. that may fall due to rotor wash or a slight breeze. Radio communication will be maintained with both trucks on the haul roads and the helicopter operation.

Appendix B

Pilot Experience Summary Table								
Site	Pilot Status	N Obs	Variable	Mean	N	5th Pctl	95th Pctl	Signif. Diff.
A	0	39	Hook (s)	22.74	38	5	54	X
			Unhook (s)	16.54	39	10	40	
			Total (s)	101.71	38	70	170	X
			Outhaul Dist (m)	654.11	39	46.2	930.2	X
			Outhaul Accel (m/s ²)	2.1	39	-0.8	5	
			Outhaul Decel (m/s ²)	-1.59	39	-3.8	0.2	
			Out Max Vel (km/hr)	98.71	39	30.7	150.3	
			Inhaul Dist (m)	529.77	39	53.6	850.4	
			Inhaul Slope (%)	-3.6	39	-13.1	12.4	
			Inhaul Accel (m/s ²)	2.21	39	0.4	5.4	
			Inhaul Decel (m/s ²)	-0.83	39	-2.1	0.8	
			In Max Vel (km/hr)	98.74	39	33	147.3	X
			Payload (kg)	2300.72	36	1814	3221	
			Logs (#)	1	39	1	1	
			Prod (tonnes/hr)	83.4	36	36.06	130.66	X
B	0	155	Hook (s)	51.95	154	31	79	X
			Unhook (s)	19.03	155	10	37	X
			Total (s)	160.73	155	99	233	X
			Outhaul Dist (m)	983.93	155	476.1	2490	X
			Outhaul Accel (m/s ²)	2.95	155	1.6	4	X
			Outhaul Decel (m/s ²)	-1.94	155	-2.8	-1	
			Out Max Vel (km/hr)	130.39	155	82.5	191	
			Inhaul Dist (m)	821.36	155	273.2	1417.8	X
			Inhaul Slope (%)	11	155	-2.8	23.4	
			Inhaul Accel (m/s ²)	1.91	155	1	2.9	X
			Inhaul Decel (m/s ²)	-1.69	155	-2.4	-0.9	X
			In Max Vel (km/hr)	100.78	155	53.3	141	X
			Payload (kg)	3445.56	155	2540	4309	X
			Logs (#)	3.1	155	1	5	
			Prod (tonnes/hr)	78.1	155	50.51	102.36	X
B	1	51	Hook (s)	113	51	65	170	X
			Unhook (s)	34.33	51	18	67	X
			Total (s)	281.33	51	100	407	X
			Outhaul Dist (m)	1240.01	51	552.9	2564.5	X

			Outhaul Accel (m/s²)	2.45	51	1.4	3.6	X
			Outhaul Decel (m/s²)	-1.79	51	-3.4	-0.7	
			Out Max Vel (km/hr)	130.21	51	69.4	194.4	
			Inhaul Dist (m)	949.79	51	543.1	1436.9	X
			Inhaul Slope (%)	8.3	51	-4.4	21.7	
			Inhaul Accel (m/s²)	1.43	51	0.7	2.7	X
			Inhaul Decel (m/s²)	-1.03	51	-1.9	-0.4	X
			In Max Vel (km/hr)	83.53	51	48.5	130.1	X
			Payload (kg)	3263.1	50	2495	3992	X
			Logs (#)	3.42	50	2	6	
			Prod (tonnes/hr)	41.55	50	26.5	56.14	X
C	0	176	Hook (s)	52.71	175	37	75	X
			Unhook (s)	19.85	176	10	39	X
			Total (s)	155.9	176	94	231	X
			Outhaul Dist (m)	1210.11	176	72	3474	
			Outhaul Accel (m/s²)	3.01	176	0.2	4.6	X
			Outhaul Decel (m/s²)	-2.96	176	-4.8	-0.9	X
			Out Max Vel (km/hr)	138.73	176	31.2	233.1	X
			Inhaul Dist (m)	847.09	176	58.7	2147.3	
			Inhaul Slope (%)	-3.68	176	-17.7	16.2	X
			Inhaul Accel (m/s²)	2.73	176	0.7	4.5	X
			Inhaul Decel (m/s²)	-1.86	176	-3.2	-0.3	X
			In Max Vel (km/hr)	107.28	175	25.9	182.9	
			Payload (kg)	2821.81	176	1814	3810	
			Logs (#)	7.01	176	3	11	
			Prod (tonnes/hr)	70.04	176	37.74	111.64	X
1	65	Hook (s)	104.5	64	64	155	X	
		Unhook (s)	39.49	65	18	74	X	
		Total (s)	267.8	65	130	437	X	
		Outhaul Dist (m)	1288.73	65	40.1	5439.6		
		Outhaul Accel (m/s²)	1.87	65	0.2	3.5	X	
		Outhaul Decel (m/s²)	-1.82	65	-3.3	-0.5	X	
		Out Max Vel (km/hr)	107.21	65	17.8	220	X	
		Inhaul Dist (m)	671.13	64	59.4	1747.5		
		Inhaul Slope (%)	1.71	64	-23.7	35.4	X	
		Inhaul Accel (m/s²)	1.57	64	0.3	3.9	X	
		Inhaul Decel (m/s²)	-1.3	64	-3.7	-0.3	X	
		In Max Vel (km/hr)	62.77	63	16.1	123.3		
		Payload (kg)	2699.92	65	1814	3719		
		Logs (#)	6.69	65	1	10		
		Prod (tonnes/hr)	36.77	65	22.69	61.06	X	

Site Summary Statistics for Pilot Experience					
Site	Variable	Mean	N	5th Pctl	95th Pctl
A	Outhaul Dist (m)	799.57	50	61.2	3972.7
	Outhaul Slope (%)	10.4	48	-3.9	21
	Inhaul Dist (m)	532.89	46	91.8	848.1
	Inhaul Slope (%)	-2.69	46	-11.7	12.4
	Payload (kg)	2289.32	53	1814	3039
	Adjusted Payload (kg)	2048.09	46	1493	2710
	Logs (#)	1	56	1	1
B	Outhaul Dist (m)	1048.54	206	478.7	2536.3
	Outhaul Slope (%)	-6.67	206	-19.7	4.6
	Inhaul Dist (m)	853.16	206	469.2	1423.2
	Inhaul Slope (%)	10.33	206	-3.4	22.3
	Payload (kg)	3401.06	205	2495	4173
	Adjusted Payload (kg)	3140.68	205	2256	3919
	Logs (#)	3.18	205	1	6
C	Outhaul Dist (m)	1231.73	241	57.1	4751.4
	Outhaul Slope (%)	7.04	241	-9.5	32.4
	Inhaul Dist (m)	800.16	240	59.05	2117.85
	Inhaul Slope (%)	-2.24	240	-19.25	20.55
	Payload (kg)	2788.94	241	1814	3765
	Adjusted Payload (kg)	2473.23	241	1456	3519
	Logs (#)	6.93	241	3	10

(Site B inexperienced pilot averaged 13.5 turns per cycle).

Appendix C

Dependent Variable: Out Flt Dist
Site 1

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	123588183	41196061	14617.4	<.0001
Error	368	1037129	2818.28560		
Corrected Total	371	124625312			

Root MSE	53.08753	R-Square	0.9917
Dependent Mean	526.59489	Adj R-Sq	0.9916
Coeff Var	10.08128		

Parameter Estimates											
Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits	
Intercept	1	-6.05198	6.25630	-0.97	0.3340	0	.	.	0	-18.35456	6.25060
Outhaul Dist	1	1.08968	0.00522	208.66	<.0001	0.99628	0.99078	0.98459	1.00810	1.07941	1.09995
Choker Drop	1	39.54259	6.87597	5.75	<.0001	0.02741	0.00076747	0.00074790	1.00452	26.02146	53.06371
Turn of Day	1	-0.16925	0.06998	-2.42	0.0161	-0.01153	0.00013229	0.00013229	1.00513	-0.30685	-0.03165

Dependent Variable: Out Flt Dist
Site 2

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	256458324	128229162	102960	<.0001
Error	501	623958	1245.42608		
Corrected Total	503	257082283			

Root MSE	35.29059	R-Square	0.9976
Dependent Mean	709.76448	Adj R-Sq	0.9976
Coeff Var	4.97216		

Parameter Estimates											
Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits	
Intercept	1	-0.63505	2.31925	-0.27	0.7843	0	.	.	0	-5.19171	3.92161
Outhaul Dist	1	1.02664	0.00227	452.91	<.0001	0.99920	0.99753	0.99375	1.00467	1.02219	1.03110
Choker Drop	1	13.96598	4.86541	2.87	0.0043	0.00633	0.00003992	0.00003992	1.00467	4.40685	23.52511

Dependent Variable: Out Flt Dist
Site 3

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	163313526	54437842	13223.3	<.0001
Error	411	1692014	4116.82184		
Corrected Total	414	165005540			

Root MSE	64.16246	R-Square	0.9897
Dependent Mean	1007.06819	Adj R-Sq	0.9897
Coeff Var	6.37121		

Parameter Estimates											
Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits	
Intercept	1	-41.94120	8.91663	-4.70	<.0001	0	.	.	0	-59.46910	-24.41331
Outhaul Dist	1	1.10019	0.00560	196.59	<.0001	0.99720	0.98892	0.96423	1.03129	1.08919	1.11120
Choker Drop	1	54.34943	10.67654	5.09	<.0001	0.02544	0.00065988	0.00064654	1.00079	33.36200	75.33687
Turn of Cycle	1	1.12047	0.43769	2.56	0.0108	0.01299	0.00016350	0.00016350	1.03144	0.26008	1.98086

Dependent Variable: Out Flt Dist

Site 4

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	818096370	409048185	19690.3	<.0001
Error	619	12859178	20774		
Corrected Total	621	830955549			

Root MSE	144.13229	R-Square	0.9845
Dependent Mean	1315.03939	Adj R-Sq	0.9845
Coeff Var	10.96030		

Parameter Estimates											
Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits	
Intercept	1	34.16221	8.91793	3.83	0.0001	0	.	.	0	16.64914	51.67528
Outhaul Dist	1	1.03282	0.00521	198.33	<.0001	0.99167	0.98358	0.98341	1.00001	1.02259	1.04305
Choker Drop	1	102.61572	16.66178	6.16	<.0001	0.03079	0.00094826	0.00094826	1.00001	69.89525	135.33620

Dependent Variable: Out Flt Dist
Site 5

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	207721084	103860542	14288.8	<.0001
Error	776	5640498	7268.68325		
Corrected Total	778	213361582			

Root MSE	85.25657	R-Square	0.9736
Dependent Mean	804.54904	Adj R-Sq	0.9735
Coeff Var	10.59682		

Parameter Estimates											
Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits	
Intercept	1	-31.64394	6.47286	-4.89	<.0001	0	.	.	0	-44.35032	-18.93755
Outhaul Dist	1	1.11018	0.00657	168.91	<.0001	0.98787	0.97304	0.97201	1.00398	1.09728	1.12308
Choker Drop	1	24.17320	6.18453	3.91	0.0001	0.02286	0.00052047	0.00052047	1.00398	12.03281	36.31359

Dependent Variable: Out Flt Dist
Site 6

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	386505960	96626490	7195.80	<.0001
Error	531	7130368	13428		
Corrected Total	535	393636328			

Root MSE	115.88006	R-Square	0.9819
Dependent Mean	1123.97631	Adj R-Sq	0.9817
Coeff Var	10.30983		

Parameter Estimates											
Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits	
Intercept	1	-34.68898	15.21273	-2.28	0.0230	0	.	.	0	-64.57350	-4.80447
Outhaul Dist	1	1.10936	0.00669	165.78	<.0001	0.99308	0.98126	0.93752	1.05194	1.09621	1.12250
Choker Drop	1	36.41785	11.30455	3.22	0.0014	0.01896	0.00037493	0.00035403	1.01529	14.21073	58.62498
Turn of Cycle	1	1.45065	0.64021	2.27	0.0239	0.01388	0.00011473	0.00017515	1.10026	0.19301	2.70830
Turn of Day	1	-0.21681	0.10814	-2.00	0.0455	-0.01222	0.00013711	0.00013711	1.08970	-0.42925	-0.00436

Dependent Variable: Outhaul Dist
Site 7

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	14367092	3591773	1127.21	<.0001
Error	266	847588	3186.41984		
Corrected Total	270	15214680			

Root MSE	56.44838	R-Square	0.9443
Dependent Mean	642.64022	Adj R-Sq	0.9435
Coeff Var	8.78382		

Parameter Estimates											
Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits	
Intercept	1	42.64884	13.22112	3.23	0.0014	0	.	.	0	16.61749	68.68020
Outhaul Dist	1	1.02244	0.01559	65.57	<.0001	0.96831	0.94135	0.90052	1.04119	0.99174	1.05314
Choker Drop	1	29.34637	11.36913	2.58	0.0104	0.03770	0.00113	0.00140	1.01847	6.96144	51.73130
Turn of Cycle	1	-0.75947	0.35725	-2.13	0.0344	-0.03219	0.00133	0.00094646	1.09498	-1.46287	-0.05606
Turn of Day	1	-0.12506	0.08286	-1.51	0.1324	-0.02240	0.00047709	0.00047709	1.05211	-0.28820	0.03808

Dependent Variable: Outhaul Dist
Site 8

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	265065406	132532703	9839.19	<.0001
Error	848	11422456	13470		
Corrected Total	850	276487862			

Root MSE	116.05980	R-Square	0.9587
Dependent Mean	648.41704	Adj R-Sq	0.9586
Coeff Var	17.89894		

Parameter Estimates											
Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits	
Intercept	1	-0.73001	6.24921	-0.12	0.9070	0	.	.	0	-12.99575	11.53573
Outhaul Dist	1	1.09280	0.00779	140.24	<.0001	0.97968	0.95479	0.95818	1.00167	1.07751	1.10810
Choker Drop	1	110.65525	12.36483	8.95	<.0001	0.06252	0.00390	0.00390	1.00167	86.38598	134.92451

Dependent Variable: Outhaul Dist
Site 9

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	68833753	68833753	7377.47	<.0001
Error	521	4861068	9330.26557		
Corrected Total	522	73694821			

Root MSE	96.59330	R-Square	0.9340
Dependent Mean	1096.80478	Adj R-Sq	0.9339
Coeff Var	8.80679		

Parameter Estimates											
Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits	
Intercept	1	57.71554	12.81373	4.50	<.0001	0	.	.	0	32.54261	82.88848
Outhaul Dist	1	0.99393	0.01157	85.89	<.0001	0.96646	0.93404	0.93404	1.00000	0.97120	1.01666

Dependent Variable: Inhaul Flt Dist
 Site 1

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	8274079	8274079	1607.17	<.0001
Error	370	1904842	5148.22274		
Corrected Total	371	10178922			

Root MSE	71.75112	R-Square	0.8129
Dependent Mean	408.62742	Adj R-Sq	0.8124
Coeff Var	17.55906		

Parameter Estimates										
Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits
Intercept	1	-11.50535	11.12055	-1.03	0.3015	0	.	.	0	-33.37276 10.36207
Inhaul Dist	1	1.12819	0.02814	40.09	<.0001	0.90159	0.81286	0.81286	1.00000	1.07286 1.18353

Dependent Variable: Inhaul Flt Dist
Site 2

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	31264703	31264703	52489.7	<.0001
Error	502	299009	595.63540		
Corrected Total	503	31563712			

Root MSE	24.40564	R-Square	0.9905
Dependent Mean	565.03631	Adj R-Sq	0.9905
Coeff Var	4.31931		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits	
Intercept	1	15.71763	2.63260	5.97	<.0001	0	.	.	0	10.54536	20.88990
Inhaul Dist	1	1.00100	0.00437	229.11	<.0001	0.99525	0.99053	0.99053	1.00000	0.99242	1.00959

Dependent Variable: Inhaul Flt Dist
 Site 3

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	75081304	75081304	28032.7	<.0001
Error	412	1103480	2678.34903		
Corrected Total	413	76184784			

Root MSE	51.75277	R-Square	0.9855
Dependent Mean	889.16039	Adj R-Sq	0.9855
Coeff Var	5.82041		

Parameter Estimates										
Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits
Intercept	1	-19.22090	5.99207	-3.21	0.0014	0	.	.	0	-30.99975 -7.44204
Inhaul Dist	1	1.08738	0.00649	167.43	<.0001	0.99273	0.98552	0.98552	1.00000	1.07462 1.10015

Dependent Variable: Inhaul Flt Dist
Site 4

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	368114735	368114735	40338.5	<.0001
Error	621	5667029	9125.65000		
Corrected Total	622	373781763			

Root MSE	95.52827	R-Square	0.9848
Dependent Mean	1088.73258	Adj R-Sq	0.9848
Coeff Var	8.77426		

Parameter Estimates										
Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits
Intercept	1	57.93947	6.40222	9.05	<.0001	0	.	.	0	45.36685 70.51209
Inhaul Dist	1	1.01688	0.00506	200.84	<.0001	0.99239	0.98484	0.98484	1.00000	1.00694 1.02683

Dependent Variable: Inhaul Flt Dist
Site 5

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	42994308	42994308	7761.53	<.0001
Error	777	4304125	5539.41379		
Corrected Total	778	47298432			

Root MSE	74.42724	R-Square	0.9090
Dependent Mean	687.46393	Adj R-Sq	0.9089
Coeff Var	10.82635		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits
Intercept	1	7.75232	8.16311	0.95	0.3426	0	.	.	0	-8.27204 23.77668
Inhaul Dist	1	1.04198	0.01183	88.10	<.0001	0.95342	0.90900	0.90900	1.00000	1.01876 1.06520

Dependent Variable: Inhaul Flt Dist
 Site 6

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	70424526	70424526	5373.11	<.0001
Error	534	6999061	13107		
Corrected Total	535	77423587			

Root MSE	114.48518	R-Square	0.9096
Dependent Mean	883.02929	Adj R-Sq	0.9094
Coeff Var	12.96505		

Parameter Estimates											
Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits	
Intercept	1	-56.80925	13.74210	-4.13	<.0001	0	.	.	0	-83.80445	-29.81405
Inhaul Dist	1	1.19976	0.01637	73.30	<.0001	0.95373	0.90960	0.90960	1.00000	1.16760	1.23191

Dependent Variable: Inhaul Flt Dist
 Site 7

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	28212015	28212015	12682.8	<.0001
Error	402	894218	2224.42284		
Corrected Total	403	29106233			

Root MSE	47.16379	R-Square	0.9693
Dependent Mean	725.23812	Adj R-Sq	0.9692
Coeff Var	6.50321		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits
Intercept	1	10.58761	6.76572	1.56	0.1184	0	.	.	0	-2.71300 23.88823
Inhaul Dist	1	1.08715	0.00965	112.62	<.0001	0.98452	0.96928	0.96928	1.00000	1.06817 1.10613

Dependent Variable: Inhaul Flt Dist
Site 8

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	47356794	47356794	11924.7	<.0001
Error	847	3363695	3971.30495		
Corrected Total	848	50720490			

Root MSE	63.01829	R-Square	0.9337
Dependent Mean	511.73333	Adj R-Sq	0.9336
Coeff Var	12.31467		

Parameter Estimates											
Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits	
Intercept	1	22.91140	4.97147	4.61	<.0001	0	.	.	0	13.15355	32.66925
Inhaul Dist	1	1.07721	0.00986	109.20	<.0001	0.96627	0.93368	0.93368	1.00000	1.05784	1.09657

Dependent Variable: Inhaul Flt Dist
Site 9

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	25988338	25988338	8680.89	<.0001
Error	521	1559739	2993.74132		
Corrected Total	522	27548077			

Root MSE	54.71509	R-Square	0.9434
Dependent Mean	1017.32715	Adj R-Sq	0.9433
Coeff Var	5.37832		

Parameter Estimates										
Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits
Intercept	1	44.54507	10.71141	4.16	<.0001	0	.	.	0	23.50220 65.58793
Inhaul Dist	1	0.99545	0.01068	93.17	<.0001	0.97128	0.94338	0.94338	1.00000	0.97447 1.01644

Appendix D

Dependent Variable: Out Max Vel
Site 1

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	275184	137592	614.42	<.0001
Error	366	81961	223.93849		
Corrected Total	368	357145			

Root MSE	14.96457	R-Square	0.7705
Dependent Mean	79.58509	Adj R-Sq	0.7693
Coeff Var	18.80324		

Parameter Estimates											
Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits	
Intercept	1	-51.55605	4.00110	-12.89	<.0001	0	.	.	0	-59.42408	-43.68802
Out CRT Dist	1	18.09229	0.51998	34.79	<.0001	0.87274	0.74567	0.75908	1.00342	17.06975	19.11482
Outhaul Slope	1	0.41487	0.06592	6.29	<.0001	0.15786	0.02484	0.02484	1.00342	0.28524	0.54450

Dependent Variable: Out Max Vel
Site 2

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	714035	178509	364.22	<.0001
Error	496	243094	490.10924		
Corrected Total	500	957130			

Root MSE	22.13841	R-Square	0.7460
Dependent Mean	109.96607	Adj R-Sq	0.7440
Coeff Var	20.13204		

Parameter Estimates											
Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits	
Intercept	1	-53.33975	4.75611	-11.22	<.0001	0	.	.	0	-62.68435	-43.99515
Out CRT Dist	1	18.53050	0.50165	36.94	<.0001	0.84974	0.72872	0.69870	1.03344	17.54487	19.51613
Outhaul Slope	1	0.46914	0.12039	3.90	0.0001	0.08927	0.00769	0.00778	1.02490	0.23260	0.70567
Grapple	1	-11.69056	3.79798	-3.08	0.0022	-0.06995	0.00415	0.00485	1.00854	-19.15267	-4.22844
Turn of Cycle	1	0.31287	0.09593	3.26	0.0012	0.07451	0.00545	0.00545	1.01915	0.12439	0.50135

Dependent Variable: Out Max Vel
 Site 3

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	501619	167206	401.96	<.0001
Error	412	171383	415.97721		
Corrected Total	415	673002			

Root MSE	20.39552	R-Square	0.7453
Dependent Mean	126.60361	Adj R-Sq	0.7435
Coeff Var	16.10975		

Parameter Estimates											
Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits	
Intercept	1	-21.84180	7.64521	-2.86	0.0045	0	.	.	0	-36.87029	-6.81331
Out CRT Dist	1	15.74531	0.68582	22.96	<.0001	0.74171	0.71649	0.32579	1.68863	14.39717	17.09346
Outhaul Slope	1	0.82136	0.14151	5.80	<.0001	0.18557	0.02311	0.02082	1.65378	0.54318	1.09953
Turn of Cycle	1	0.42280	0.13863	3.05	0.0024	0.07697	0.00575	0.00575	1.03034	0.15029	0.69530

Dependent Variable: Out Max Vel
Site 4

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	2147618	536905	881.08	<.0001
Error	610	371717	609.37232		
Corrected Total	614	2519335			

Root MSE	24.68547	R-Square	0.8525
Dependent Mean	138.74634	Adj R-Sq	0.8515
Coeff Var	17.79180		

Parameter Estimates											
Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits	
Intercept	1	-48.28021	4.38275	-11.02	<.0001	0	.	.	0	-56.88732	-39.67310
Out CRT Dist	1	18.31096	0.31383	58.35	<.0001	0.93643	0.84148	0.82346	1.06491	17.69465	18.92727
Outhaul Slope	1	0.35423	0.12277	2.89	0.0040	0.04546	0.00294	0.00201	1.02616	0.11312	0.59534
Turn of Cycle	1	0.72550	0.12877	5.63	<.0001	0.09080	0.00731	0.00768	1.07368	0.47262	0.97838
Turn of Day	1	-0.03763	0.02179	-1.73	0.0847	-0.02734	0.00072125	0.00072125	1.03647	-0.08042	0.00517

Dependent Variable: Out Max Vel
Site 5

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	510163	127541	361.84	<.0001
Error	773	272465	352.47677		
Corrected Total	777	782627			

Root MSE	18.77436	R-Square	0.6519
Dependent Mean	131.22494	Adj R-Sq	0.6501
Coeff Var	14.30701		

Parameter Estimates											
Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits	
Intercept	1	55.96772	6.48497	8.63	<.0001	0	.	.	0	43.23749	68.69795
Out CRT Dist	1	14.32303	0.50397	28.42	<.0001	0.63611	0.47227	0.36378	1.11231	13.33373	15.31234
Outhaul Slope	1	-2.28828	0.12165	-18.81	<.0001	-0.41099	0.17454	0.15937	1.05988	-2.52708	-2.04948
Turn of Cycle	1	0.24642	0.08599	2.87	0.0043	0.06360	0.00390	0.00370	1.09374	0.07762	0.41523
Turn of Day	1	0.01886	0.01183	1.59	0.1114	0.03406	0.00114	0.00114	1.01418	-0.00437	0.04209

Dependent Variable: Out Max Vel
Site 6

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	631401	126280	484.04	<.0001
Error	528	137749	260.88883		
Corrected Total	533	769150			

Root MSE	16.15205	R-Square	0.8209
Dependent Mean	134.41292	Adj R-Sq	0.8192
Coeff Var	12.01674		

Parameter Estimates											
Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits	
Intercept	1	24.52507	4.69534	5.22	<.0001	0	.	.	0	15.30124	33.74891
Out CRT Dist	1	12.71246	0.38689	32.86	<.0001	0.72620	0.74699	0.36621	1.44003	11.95243	13.47249
Outhaul Slope	1	-0.65640	0.05519	-11.89	<.0001	-0.28991	0.00521	0.04798	1.75152	-0.76481	-0.54799
Grapple	1	-64.19219	4.82374	-13.31	<.0001	-0.37059	0.06510	0.06007	2.28635	-73.66827	-54.71611
Turn of Cycle	1	0.25784	0.08928	2.89	0.0040	0.05578	0.00196	0.00283	1.09976	0.08245	0.43324
Turn of Day	1	-0.03411	0.01549	-2.20	0.0281	-0.04343	0.00164	0.00164	1.14691	-0.06455	-0.00368

Dependent Variable: Out Max Vel
 Site 7

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	175106	43776	235.11	<.0001
Error	398	74107	186.19732		
Corrected Total	402	249212			

Root MSE	13.64541	R-Square	0.7026
Dependent Mean	116.60397	Adj R-Sq	0.6996
Coeff Var	11.70236		

Parameter Estimates											
Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits	
Intercept	1	33.81022	11.32975	2.98	0.0030	0	.	.	0	11.53658	56.08385
Out CRT Dist	1	11.53339	1.06048	10.88	<.0001	0.49073	0.63074	0.08837	2.72504	9.44855	13.61824
Outhaul Slope	1	-1.06038	0.11955	-8.87	<.0001	-0.39837	0.06435	0.05878	2.70000	-1.29541	-0.82535
Turn of Cycle	1	0.15647	0.07326	2.14	0.0333	0.06037	0.00474	0.00341	1.06919	0.01245	0.30048
Turn of Day	1	0.03272	0.01689	1.94	0.0534	0.05426	0.00280	0.00280	1.05001	-0.00048409	0.06593

Dependent Variable: Out Max Vel
 Site 8

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	1123810	224762	699.16	<.0001
Error	844	271324	321.47370		
Corrected Total	849	1395134			

Root MSE	17.92969	R-Square	0.8055
Dependent Mean	105.72188	Adj R-Sq	0.8044
Coeff Var	16.95930		

Parameter Estimates											
Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits	
Intercept	1	-38.75144	3.29447	-11.76	<.0001	0	.	.	0	-45.21776	-32.28512
Out CRT Dist	1	18.17464	0.33266	54.63	<.0001	0.88009	0.78679	0.68779	1.12616	17.52170	18.82758
Outhaul Slope	1	0.25485	0.03837	6.64	<.0001	0.10313	0.01155	0.01017	1.04640	0.17954	0.33017
Grapple	1	-4.85811	1.61699	-3.00	0.0027	-0.04630	0.00175	0.00208	1.03078	-8.03190	-1.68432
Turn of Cycle	1	0.29930	0.07657	3.91	0.0001	0.06118	0.00306	0.00352	1.06293	0.14902	0.44958
Turn of Day	1	-0.03788	0.01179	-3.21	0.0014	-0.04973	0.00238	0.00238	1.04015	-0.06102	-0.01473

Dependent Variable: Out Max Vel
 Site 9

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	130549	32637	184.54	<.0001
Error	518	91611	176.85432		
Corrected Total	522	222160			

Root MSE	13.29866	R-Square	0.5876
Dependent Mean	161.82753	Adj R-Sq	0.5845
Coeff Var	8.21780		

Parameter Estimates											
Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits	
Intercept	1	2.25090	6.17938	0.36	0.7158	0	.	.	0	-9.88882	14.39062
Out CRT Dist	1	15.37319	0.57881	26.56	<.0001	0.77527	0.56186	0.56157	1.07031	14.23608	16.51030
Outhaul Slope	1	1.34804	0.34420	3.92	0.0001	0.11171	0.01294	0.01221	1.02205	0.67183	2.02424
Turn of Cycle	1	0.11918	0.07548	1.58	0.1150	0.04617	0.00365	0.00198	1.07430	-0.02910	0.26746
Turn of Day	1	0.04048	0.01191	3.40	0.0007	0.09715	0.00919	0.00919	1.02661	0.01708	0.06388

Dependent Variable: In Max Vel
Site 1

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	108972	21794	239.72	<.0001
Error	366	33276	90.91807		
Corrected Total	371	142248			

Root MSE	9.53510	R-Square	0.7661
Dependent Mean	66.95968	Adj R-Sq	0.7629
Coeff Var	14.24006		

Parameter Estimates											
Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits	
Intercept	1	-11.85418	4.70987	-2.52	0.0123	0	.	.	0	-21.11597	-2.59239
In CRT Dist	1	15.60924	0.47883	32.60	<.0001	0.83617	0.69199	0.67920	1.02941	14.66763	16.55085
Inhaul Slope	1	-0.12617	0.03785	-3.33	0.0009	-0.09017	0.00007852	0.00710	1.14514	-0.20061	-0.05173
Payload (kg)	1	-0.01027	0.00106	-9.67	<.0001	-0.25765	0.06149	0.05972	1.11149	-0.01236	-0.00818
Logs	1	-1.14806	0.29935	-3.84	0.0001	-0.09725	0.00940	0.00940	1.00601	-1.73672	-0.55940
Turn of Cycle	1	0.10566	0.04790	2.21	0.0280	0.05642	0.00311	0.00311	1.02390	0.01145	0.19986

Dependent Variable: In Max Vel
Site 2

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	472853	78809	660.61	<.0001
Error	494	58932	119.29632		
Corrected Total	500	531785			

Root MSE	10.92229	R-Square	0.8892
Dependent Mean	92.25868	Adj R-Sq	0.8878
Coeff Var	11.83876		

Parameter Estimates											
Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits	
Intercept	1	-55.02195	4.66483	-11.80	<.0001	0	.	.	0	-64.18730	-45.85660
In CRT Dist	1	19.61216	0.47337	41.43	<.0001	0.98700	0.86769	0.38507	2.52981	18.68210	20.54222
Inhaul Slope	1	0.20278	0.06284	3.23	0.0013	0.07688	0.00204	0.00234	2.53030	0.07931	0.32625
Payload (kg)	1	-0.00364	0.00099171	-3.67	0.0003	-0.05734	0.00318	0.00302	1.09023	-0.00558	-0.00169
Logs	1	-0.85624	0.30261	-2.83	0.0049	-0.04394	0.00296	0.00180	1.07508	-1.45079	-0.26168
Turn of Cycle	1	0.16632	0.04889	3.40	0.0007	0.05326	0.00528	0.00260	1.09293	0.07026	0.26238
Turn of Day	1	0.04623	0.00773	5.98	<.0001	0.09234	0.00803	0.00803	1.06173	0.03105	0.06141

Dependent Variable: In Max Vel
Site 3

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	292561	73140	567.00	<.0001
Error	407	52501	128.99455		
Corrected Total	411	345062			

Root MSE	11.35758	R-Square	0.8479
Dependent Mean	100.79490	Adj R-Sq	0.8464
Coeff Var	11.26801		

Parameter Estimates											
Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits	
Intercept	1	-16.91679	5.80557	-2.91	0.0038	0	.	.	0	-28.32944	-5.50414
In CRT Dist	1	16.04935	0.50040	32.07	<.0001	0.89661	0.81409	0.38455	2.09050	15.06566	17.03304
Inhaul Slope	1	-0.18576	0.08426	-2.20	0.0280	-0.06088	0.00249	0.00182	2.03992	-0.35139	-0.02013
Payload (kg)	1	-0.00866	0.00095996	-9.02	<.0001	-0.18013	0.02891	0.03042	1.06682	-0.01055	-0.00677
Turn of Cycle	1	0.19398	0.07719	2.51	0.0124	0.04913	0.00236	0.00236	1.02226	0.04225	0.34572

Dependent Variable: In Max Vel
Site 4

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	1460534	365134	1634.52	<.0001
Error	612	136714	223.38845		
Corrected Total	616	1597248			

Root MSE	14.94619	R-Square	0.9144
Dependent Mean	111.73809	Adj R-Sq	0.9138
Coeff Var	13.37609		

Parameter Estimates											
Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits	
Intercept	1	-25.00068	3.86175	-6.47	<.0001	0	.	.	0	-32.58457	-17.41679
In CRT Dist	1	16.90619	0.21117	80.06	<.0001	0.95898	0.90404	0.89646	1.02586	16.49149	17.32089
Payload (kg)	1	-0.00583	0.00103	-5.65	<.0001	-0.06782	0.00354	0.00447	1.02915	-0.00786	-0.00381
Turn of Cycle	1	0.27693	0.07617	3.64	0.0003	0.04351	0.00132	0.00185	1.02380	0.12735	0.42651
Turn of Day	1	-0.08231	0.01312	-6.27	<.0001	-0.07525	0.00551	0.00551	1.02826	-0.10807	-0.05655

Dependent Variable: In Max Vel
Site 5

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	482415	160805	1187.44	<.0001
Error	771	104410	135.42176		
Corrected Total	774	586826			

Root MSE	11.63709	R-Square	0.8221
Dependent Mean	99.26568	Adj R-Sq	0.8214
Coeff Var	11.72317		

Parameter Estimates											
Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits	
Intercept	1	-73.95717	7.39720	-10.00	<.0001	0	.	.	0	-88.47821	-59.43614
In CRT Dist	1	23.05060	0.55964	41.19	<.0001	0.82929	0.81119	0.39149	1.75667	21.95199	24.14921
Inhaul Slope	1	0.48005	0.10476	4.58	<.0001	0.09123	0.00347	0.00485	1.71746	0.27440	0.68570
Payload (kg)	1	-0.00429	0.00075745	-5.67	<.0001	-0.08785	0.00742	0.00742	1.04054	-0.00578	-0.00281

Dependent Variable: In Max Vel
Site 6

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	308838	51473	145.35	<.0001
Error	527	186633	354.14248		
Corrected Total	533	495471			

Root MSE	18.81867	R-Square	0.6233
Dependent Mean	109.61779	Adj R-Sq	0.6190
Coeff Var	17.16754		

Parameter Estimates											
Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits	
Intercept	1	-24.00826	9.81377	-2.45	0.0148	0	.	.	0	-43.28718	-4.72934
In CRT Dist	1	17.15667	0.80621	21.28	<.0001	0.75525	0.57212	0.32369	1.76222	15.57289	18.74046
Inhaul Slope	1	0.35725	0.06954	5.14	<.0001	0.19897	0.01592	0.01886	2.09871	0.22064	0.49385
Grapple	1	-21.35116	6.68984	-3.19	0.0015	-0.15086	0.01505	0.00728	3.12571	-34.49318	-8.20913
Payload (kg)	1	-0.00463	0.00137	-3.38	0.0008	-0.09575	0.00748	0.00818	1.12069	-0.00732	-0.00194
Logs	1	1.11879	0.35934	3.11	0.0019	0.09504	0.00735	0.00693	1.30366	0.41287	1.82471
Turn of Day	1	-0.04810	0.01748	-2.75	0.0061	-0.07627	0.00541	0.00541	1.07540	-0.08245	-0.01375

Dependent Variable: In Max Vel
Site 7

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	172865	43216	325.95	<.0001
Error	349	46272	132.58355		
Corrected Total	353	219136			

Root MSE	11.51449	R-Square	0.7888
Dependent Mean	89.54944	Adj R-Sq	0.7864
Coeff Var	12.85825		

Parameter Estimates											
Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits	
Intercept	1	-66.08230	6.32149	-10.45	<.0001	0	.	.	0	-78.51532	-53.64928
In CRT Dist	1	20.72260	0.59862	34.62	<.0001	0.89049	0.76043	0.72503	1.09372	19.54524	21.89997
Payload (kg)	1	-0.00993	0.00174	-5.70	<.0001	-0.14386	0.02230	0.01967	1.05197	-0.01336	-0.00651
Logs	1	-1.11660	0.44774	-2.49	0.0131	-0.06304	0.00393	0.00376	1.05615	-1.99721	-0.23599
Turn of Cycle	1	0.12283	0.06458	1.90	0.0580	0.04749	0.00219	0.00219	1.03043	-0.00418	0.24984

Dependent Variable: In Max Vel
Site 8

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	698973	116495	487.05	<.0001
Error	840	200917	239.18747		
Corrected Total	846	899890			

Root MSE	15.46569	R-Square	0.7767
Dependent Mean	84.47863	Adj R-Sq	0.7751
Coeff Var	18.30722		

Parameter Estimates											
Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits	
Intercept	1	-41.30960	4.53753	-9.10	<.0001	0	.	.	0	-50.21583	-32.40336
In CRT Dist	1	18.59114	0.41996	44.27	<.0001	0.82721	0.75987	0.52090	1.31367	17.76685	19.41543
Inhaul Slope	1	-0.17722	0.03413	-5.19	<.0001	-0.09654	0.00975	0.00716	1.30070	-0.24422	-0.11022
Payload (kg)	1	-0.00465	0.00098069	-4.74	<.0001	-0.08251	0.00427	0.00597	1.14085	-0.00657	-0.00272
Logs	1	1.35894	0.52804	2.57	0.0102	0.04492	0.00155	0.00176	1.14616	0.32251	2.39536
Turn of Cycle	1	0.10061	0.06593	1.53	0.1274	0.02546	0.00047266	0.00061901	1.04750	-0.02879	0.23000
Turn of Day	1	-0.01790	0.01023	-1.75	0.0804	-0.02917	0.00081443	0.00081443	1.04470	-0.03797	0.00217

Dependent Variable: In Max Vel
Site 9

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	63267	12653	187.64	<.0001
Error	513	34594	67.43425		
Corrected Total	518	97861			

Root MSE	8.21184	R-Square	0.6465
Dependent Mean	120.03064	Adj R-Sq	0.6431
Coeff Var	6.84145		

Parameter Estimates											
Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits	
Intercept	1	44.46976	5.06769	8.78	<.0001	0	.	.	0	34.51377	54.42574
In CRT Dist	1	10.98797	0.49702	22.11	<.0001	0.63139	0.30930	0.33680	1.18368	10.01154	11.96441
Inhaul Slope	1	-0.59310	0.34483	-1.72	0.0860	-0.04870	0.02135	0.00204	1.16328	-1.27056	0.08435
Payload (kg)	1	-0.01166	0.00058053	-20.09	<.0001	-0.54723	0.25562	0.27811	1.07674	-0.01280	-0.01052
Turn of Cycle	1	0.16953	0.04589	3.69	0.0002	0.09857	0.01708	0.00940	1.03319	0.07938	0.25969
Turn of Day	1	0.05879	0.00743	7.91	<.0001	0.21256	0.04315	0.04315	1.04717	0.04419	0.07338

Appendix E

Dependent Variable: Outhaul Accel
Site 1

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	99.99715	49.99857	97.96	<.0001
Error	365	186.29752	0.51040		
Corrected Total	367	286.29467			

Root MSE	0.71443	R-Square	0.3493
Dependent Mean	1.92880	Adj R-Sq	0.3457
Coeff Var	37.03983		

Parameter Estimates											
Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits	
Intercept	1	-0.23153	0.19107	-1.21	0.2264	0	.	.	0	-0.60726	0.14420
Out CRT Dist	1	0.31755	0.02483	12.79	<.0001	0.54097	0.27566	0.29164	1.00345	0.26872	0.36637
Outhaul Slope	1	0.02023	0.00315	6.43	<.0001	0.27179	0.07362	0.07362	1.00345	0.01404	0.02641

Dependent Variable: Outhaul Accel
Site 2

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	144.73411	28.94682	23.31	<.0001
Error	495	614.76341	1.24195		
Corrected Total	500	759.49752			

Root MSE	1.11443	R-Square	0.1906
Dependent Mean	2.60499	Adj R-Sq	0.1824
Coeff Var	42.78045		

Parameter Estimates											
Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits	
Intercept	1	0.11556	0.24559	0.47	0.6382	0	.	.	0	-0.36697	0.59810
Out CRT Dist	1	0.21443	0.02525	8.49	<.0001	0.34906	0.11508	0.11790	1.03347	0.16481	0.26404
Outhaul Slope	1	0.01480	0.00606	2.44	0.0150	0.09998	0.01090	0.00975	1.02515	0.00289	0.02671
Grapple	1	-0.62288	0.20025	-3.11	0.0020	-0.13231	0.00732	0.01582	1.10646	-1.01633	-0.22943
Turn of Day	1	0.00199	0.00082368	2.42	0.0160	0.10516	0.02008	0.00956	1.15639	0.00037351	0.00361
Turn of Cycle	1	0.02356	0.00494	4.77	<.0001	0.19916	0.03718	0.03718	1.06672	0.01385	0.03326

Dependent Variable: Outhaul Accel
Site 3

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	104.87939	34.95980	69.48	<.0001
Error	412	207.31590	0.50319		
Corrected Total	415	312.19529			

Root MSE	0.70936	R-Square	0.3359
Dependent Mean	2.89663	Adj R-Sq	0.3311
Coeff Var	24.48917		

Parameter Estimates											
Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits	
Intercept	1	0.98033	0.24664	3.97	<.0001	0	.	.	0	0.49551	1.46516
Out CRT Dist	1	0.21526	0.02371	9.08	<.0001	0.47080	0.30792	0.13282	1.66879	0.16865	0.26187
Outhaul Slope	1	0.01252	0.00504	2.49	0.0133	0.13138	0.01644	0.00996	1.73233	0.00262	0.02243
Choker Drop	1	-0.32508	0.12129	-2.68	0.0077	-0.11063	0.01158	0.01158	1.05700	-0.56351	-0.08666

Dependent Variable: Outhaul Accel
Site 4

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	476.29600	238.14800	248.40	<.0001
Error	619	593.46246	0.95874		
Corrected Total	621	1069.75846			

Root MSE	0.97915	R-Square	0.4452
Dependent Mean	2.96109	Adj R-Sq	0.4434
Coeff Var	33.06734		

Parameter Estimates											
Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits	
Intercept	1	-0.10312	0.15618	-0.66	0.5094	0	.	.	0	-0.40983	0.20360
Out CRT Dist	1	0.27629	0.01240	22.29	<.0001	0.68726	0.41582	0.44510	1.06116	0.25195	0.30064
Turn of Cycle	1	0.02903	0.00507	5.73	<.0001	0.17667	0.02941	0.02941	1.06116	0.01908	0.03898

Dependent Variable: Outhaul Accel
Site 5

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	151.37896	30.27579	40.42	<.0001
Error	773	579.04425	0.74909		
Corrected Total	778	730.42321			

Root MSE	0.86550	R-Square	0.2072
Dependent Mean	3.25558	Adj R-Sq	0.2021
Coeff Var	26.58503		

Parameter Estimates											
Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits	
Intercept	1	3.29952	0.30045	10.98	<.0001	0	.	.	0	2.70972	3.88932
Out CRT Dist	1	0.13543	0.02324	5.83	<.0001	0.19694	0.05733	0.03484	1.11332	0.08981	0.18104
Outhaul Slope	1	-0.05950	0.00561	-10.61	<.0001	-0.34982	0.13362	0.11542	1.06025	-0.07051	-0.04849
Choker Drop	1	-0.09633	0.06279	-1.53	0.1254	-0.04923	0.00263	0.00241	1.00411	-0.21958	0.02692
Turn of Day	1	0.00163	0.00054481	2.99	0.0029	0.09654	0.00982	0.00918	1.01514	0.00056065	0.00270
Turn of Cycle	1	0.00767	0.00396	1.94	0.0530	0.06488	0.00385	0.00385	1.09317	-0.00010084	0.01544

Dependent Variable: Outhaul Accel
 Site 6

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	167.78273	83.89137	122.26	<.0001
Error	533	365.72934	0.68617		
Corrected Total	535	533.51207			

Root MSE	0.82835	R-Square	0.3145
Dependent Mean	3.01922	Adj R-Sq	0.3119
Coeff Var	27.43608		

Parameter Estimates											
Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits	
Intercept	1	3.49658	0.06189	56.49	<.0001	0	.	.	0	3.37500	3.61817
Outhaul Slope	1	-0.02004	0.00275	-7.29	<.0001	-0.33611	0.01167	0.06841	1.65140	-0.02544	-0.01464
Grapple	1	-3.22575	0.21023	-15.34	<.0001	-0.70716	0.30282	0.30282	1.65140	-3.63872	-2.81278

Dependent Variable: Outhaul Accel
 Site 7

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	2.53052	2.53052	3.88	0.0498
Error	269	175.28107	0.65160		
Corrected Total	270	177.81159			

Root MSE	0.80722	R-Square	0.0142
Dependent Mean	3.44022	Adj R-Sq	0.0106
Coeff Var	23.46416		

Parameter Estimates											
Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits	
Intercept	1	3.63145	0.10872	33.40	<.0001	0	.	.	0	3.41739	3.84551
Outhaul Slope	1	-0.00990	0.00502	-1.97	0.0498	-0.11930	0.01423	0.01423	1.00000	-0.01978	-0.00000927

Dependent Variable: Outhaul Accel
Site 8

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	271.79972	45.29995	66.40	<.0001
Error	844	575.80515	0.68223		
Corrected Total	850	847.60486			

Root MSE	0.82597	R-Square	0.3207
Dependent Mean	2.66757	Adj R-Sq	0.3158
Coeff Var	30.96358		

Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits	
Intercept	1	0.42729	0.15262	2.80	0.0052	0	.	.	0	0.12773	0.72684
Out CRT Dist	1	0.27457	0.01533	17.92	<.0001	0.53943	0.28612	0.25834	1.12635	0.24449	0.30465
Outhaul Slope	1	0.00609	0.00177	3.45	0.0006	0.10007	0.01260	0.00956	1.04732	0.00262	0.00956
Choker Drop	1	-0.20923	0.08936	-2.34	0.0194	-0.06751	0.00286	0.00441	1.03303	-0.38464	-0.03383
Grapple	1	-0.19251	0.07536	-2.55	0.0108	-0.07463	0.00457	0.00525	1.06063	-0.34043	-0.04459
Turn of Day	1	-0.00106	0.00054333	-1.96	0.0509	-0.05660	0.00212	0.00308	1.04095	-0.00213	0.00000399
Turn of Cycle	1	0.01384	0.00353	3.93	<.0001	0.11485	0.01241	0.01241	1.06300	0.00692	0.02077

Dependent Variable: Outhaul Accel
Site 9

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	11.58303	5.79152	14.32	<.0001
Error	520	210.35758	0.40453		
Corrected Total	522	221.94061			

Root MSE	0.63603	R-Square	0.0522
Dependent Mean	3.75717	Adj R-Sq	0.0485
Coeff Var	16.92842		

Parameter Estimates											
Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits	
Intercept	1	3.54533	0.04980	71.19	<.0001	0	.	.	0	3.44751	3.64316
Outhaul Slope	1	0.03792	0.01629	2.33	0.0203	0.09943	0.01128	0.00988	1.00112	0.00592	0.06993
Turn of Day	1	0.00267	0.00056260	4.74	<.0001	0.20237	0.04091	0.04091	1.00112	0.00156	0.00377

Dependent Variable: Out Decel
Site 1

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	44.93204	22.46602	98.60	<.0001
Error	365	83.16666	0.22785		
Corrected Total	367	128.09870			

Root MSE	0.47734	R-Square	0.3508
Dependent Mean	-1.10761	Adj R-Sq	0.3472
Coeff Var	-43.09648		

Parameter Estimates											
Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits	
Intercept	1	0.25818	0.12766	2.02	0.0439	0	.	.	0	0.00714	0.50922
Out CRT Dist	1	-0.20482	0.01659	-12.35	<.0001	-0.52163	0.25331	0.27116	1.00345	-0.23744	-0.17220
Outhaul Slope	1	-0.01557	0.00210	-7.40	<.0001	-0.31271	0.09745	0.09745	1.00345	-0.01970	-0.01143

Dependent Variable: Out Decel
Site 2

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	158.31515	31.66303	59.49	<.0001
Error	495	263.46724	0.53226		
Corrected Total	500	421.78240			

Root MSE	0.72956	R-Square	0.3753
Dependent Mean	-1.95449	Adj R-Sq	0.3690
Coeff Var	-37.32734		

Parameter Estimates											
Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits	
Intercept	1	0.62552	0.16078	3.89	0.0001	0	.	.	0	0.30963	0.94141
Out CRT Dist	1	-0.25281	0.01653	-15.29	<.0001	-0.55225	0.30410	0.29510	1.03347	-0.28529	-0.22033
Outhaul Slope	1	-0.01537	0.00397	-3.87	0.0001	-0.13931	0.01956	0.01893	1.02515	-0.02316	-0.00757
Grapple	1	0.53029	0.13110	4.05	<.0001	0.15115	0.01323	0.02065	1.10646	0.27272	0.78787
Turn of Cycle	1	-0.01484	0.00323	-4.59	<.0001	-0.16837	0.03326	0.02658	1.06672	-0.02120	-0.00849
Turn of Day	1	-0.00109	0.00053922	-2.03	0.0429	-0.07755	0.00520	0.00520	1.15639	-0.00215	-0.00003515

Dependent Variable: Out Decel
Site 3

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	63.19380	31.59690	73.70	<.0001
Error	413	177.07380	0.42875		
Corrected Total	415	240.26760			

Root MSE	0.65479	R-Square	0.2630
Dependent Mean	-2.03510	Adj R-Sq	0.2594
Coeff Var	-32.17490		

Parameter Estimates										
Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits
Intercept	1	-1.29267	0.22644	-5.71	<.0001	0	.	.	0	-1.73778 -0.84756
Out CRT Dist	1	-0.09754	0.02170	-4.50	<.0001	-0.24318	0.19878	0.03607	1.63947	-0.14019 -0.05489
Outhaul Slope	1	-0.02714	0.00452	-6.00	<.0001	-0.32451	0.06423	0.06423	1.63947	-0.03603 -0.01825

Dependent Variable: Out Decel

Site 4

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	312.69174	78.17294	70.13	<.0001
Error	617	687.72609	1.11463		
Corrected Total	621	1000.41783			

Root MSE	1.05576	R-Square	0.3126
Dependent Mean	-2.71077	Adj R-Sq	0.3081
Coeff Var	-38.94684		

Parameter Estimates											
Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits	
Intercept	1	-0.47263	0.18648	-2.53	0.0115	0	.	.	0	-0.83885	-0.10641
Out CRT Dist	1	-0.21371	0.01339	-15.96	<.0001	-0.54969	0.28035	0.28379	1.06473	-0.24000	-0.18741
Outhaul Slope	1	-0.01453	0.00479	-3.03	0.0025	-0.10255	0.01473	0.01026	1.02508	-0.02393	-0.00513
Turn of Cycle	1	-0.01793	0.00550	-3.26	0.0012	-0.11280	0.01026	0.01184	1.07499	-0.02873	-0.00713
Turn of Day	1	0.00235	0.00092407	2.55	0.0112	0.08643	0.00722	0.00722	1.03454	0.00053763	0.00417

Dependent Variable: Out Decel
Site 5

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	156.48470	52.16157	88.77	<.0001
Error	775	455.36793	0.58757		
Corrected Total	778	611.85263			

Root MSE	0.76653	R-Square	0.2558
Dependent Mean	-2.76316	Adj R-Sq	0.2529
Coeff Var	-27.74116		

Parameter Estimates											
Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits	
Intercept	1	-3.21531	0.23130	-13.90	<.0001	0	.	.	0	-3.66937	-2.76126
Out CRT Dist	1	-0.13489	0.01980	-6.81	<.0001	-0.21433	0.08221	0.04459	1.03026	-0.17376	-0.09603
Outhaul Slope	1	0.06360	0.00489	13.00	<.0001	0.40856	0.16434	0.16227	1.02866	0.05400	0.07321
Choker Drop	1	0.17211	0.05559	3.10	0.0020	0.09611	0.00921	0.00921	1.00332	0.06300	0.28123

Dependent Variable: Out Decel
Site 6

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	105.89944	26.47486	41.46	<.0001
Error	531	339.07517	0.63856		
Corrected Total	535	444.97461			

Root MSE	0.79910	R-Square	0.2380
Dependent Mean	-2.65317	Adj R-Sq	0.2322
Coeff Var	-30.11864		

Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits	
Intercept	1	-2.03322	0.22592	-9.00	<.0001	0	.	.	0	-2.47703	-1.58941
Out CRT Dist	1	-0.06969	0.01910	-3.65	0.0003	-0.16556	0.12433	0.01911	1.43446	-0.10721	-0.03218
Outhaul Slope	1	0.00589	0.00272	2.16	0.0310	0.10813	0.01844	0.00672	1.74124	0.00054107	0.01124
Grapple	1	1.80801	0.23757	7.61	<.0001	0.43400	0.08828	0.08311	2.26630	1.34131	2.27471
Turn of Cycle	1	-0.00938	0.00426	-2.20	0.0283	-0.08439	0.00694	0.00694	1.02664	-0.01775	-0.00099826

Dependent Variable: Out Decel
Site 7

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	27.68612	13.84306	34.27	<.0001
Error	268	108.24776	0.40391		
Corrected Total	270	135.93387			

Root MSE	0.63554	R-Square	0.2037
Dependent Mean	-2.81439	Adj R-Sq	0.1977
Coeff Var	-22.58175		

Parameter Estimates											
Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits	
Intercept	1	-1.17053	0.67692	-1.73	0.0849	0	.	.	0	-2.50329	0.16223
Out CRT Dist	1	-0.22277	0.06727	-3.31	0.0011	-0.31760	0.19618	0.03258	3.09572	-0.35522	-0.09032
Outhaul Slope	1	0.01105	0.00696	1.59	0.1134	0.15232	0.00749	0.00749	3.09572	-0.00265	0.02474

Dependent Variable: Out Decel
Site 8

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	198.04231	33.00705	63.08	<.0001
Error	844	441.65468	0.52329		
Corrected Total	850	639.69699			

Root MSE	0.72339	R-Square	0.3096
Dependent Mean	-2.20623	Adj R-Sq	0.3047
Coeff Var	-32.78837		

Parameter Estimates											
Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits	
Intercept	1	-0.48719	0.13366	-3.64	0.0003	0	.	.	0	-0.74954	-0.22484
Out CRT Dist	1	-0.21363	0.01342	-15.92	<.0001	-0.48311	0.24476	0.20721	1.12635	-0.23997	-0.18728
Outhaul Slope	1	-0.01042	0.00155	-6.73	<.0001	-0.19705	0.04131	0.03707	1.04732	-0.01346	-0.00738
Choker Drop	1	0.21335	0.07827	2.73	0.0065	0.07924	0.00339	0.00608	1.03303	0.05973	0.36697
Grapple	1	0.26542	0.06600	4.02	<.0001	0.11845	0.01235	0.01323	1.06063	0.13587	0.39497
Turn of Cycle	1	-0.00843	0.00309	-2.73	0.0065	-0.08047	0.00551	0.00609	1.06300	-0.01449	-0.00237
Turn of Day	1	0.00079325	0.00047585	1.67	0.0959	0.04865	0.00227	0.00227	1.04095	-0.00014073	0.00173

Dependent Variable: Out Decel
Site 9

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	8.00775	2.66925	6.20	0.0004
Error	519	223.32353	0.43030		
Corrected Total	522	231.33128			

Root MSE	0.65597	R-Square	0.0346
Dependent Mean	-2.89140	Adj R-Sq	0.0290
Coeff Var	-22.68695		

Parameter Estimates										
Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits
Intercept	1	-2.25852	0.28550	-7.91	<.0001	0	.	.	0	-2.81941 -1.69764
Out CRT Dist	1	-0.04627	0.02788	-1.66	0.0977	-0.07231	0.00394	0.00512	1.02083	-0.10104 0.00851
Outhaul Slope	1	-0.02647	0.01698	-1.56	0.1195	-0.06799	0.00529	0.00452	1.02198	-0.05983 0.00688
Turn of Day	1	-0.00214	0.00058024	-3.69	0.0002	-0.15944	0.02539	0.02539	1.00116	-0.00328 -0.00100

Dependent Variable: Inhaul Accel
Site 1

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	34.58191	6.91638	53.84	<.0001
Error	366	47.01516	0.12846		
Corrected Total	371	81.59707			

Root MSE	0.35841	R-Square	0.4238
Dependent Mean	1.24059	Adj R-Sq	0.4159
Coeff Var	28.89014		

Parameter Estimates											
Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits	
Intercept	1	1.28019	0.17704	7.23	<.0001	0	.	.	0	0.93206	1.62833
In CRT Dist	1	0.18013	0.01800	10.01	<.0001	0.40288	0.18113	0.15767	1.02941	0.14473	0.21552
Inhaul Slope	1	-0.01219	0.00142	-8.57	<.0001	-0.36371	0.04705	0.11552	1.14514	-0.01499	-0.00939
Payload (kg)	1	-0.00043092	0.00003992	-10.79	<.0001	-0.45152	0.18180	0.18342	1.11149	-0.00050943	-0.00035242
Logs	1	-0.01687	0.01125	-1.50	0.1347	-0.05966	0.00354	0.00354	1.00601	-0.03900	0.00526
Turn of Cycle	1	0.00460	0.00180	2.56	0.0110	0.10264	0.01029	0.01029	1.02390	0.00106	0.00814

Dependent Variable: Inhaul Accel
Site 2

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	131.47657	26.29531	80.51	<.0001
Error	495	161.66834	0.32660		
Corrected Total	500	293.14491			

Root MSE	0.57149	R-Square	0.4485
Dependent Mean	1.94611	Adj R-Sq	0.4429
Coeff Var	29.36588		

Parameter Estimates											
Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits	
Intercept	1	-0.04713	0.19516	-0.24	0.8093	0	.	.	0	-0.43057	0.33631
In CRT Dist	1	0.28653	0.01572	18.23	<.0001	0.61417	0.38429	0.37015	1.01907	0.25565	0.31742
Payload (kg)	1	-0.00016560	0.00005179	-3.20	0.0015	-0.11123	0.01072	0.01139	1.08612	-0.00026736	-0.00006384
Logs	1	-0.02668	0.01582	-1.69	0.0924	-0.05831	0.00625	0.00317	1.07385	-0.05777	0.00441
Turn of Cycle	1	0.00734	0.00256	2.87	0.0043	0.10018	0.01867	0.00919	1.09242	0.00232	0.01237
Turn of Day	1	0.00204	0.00040358	5.07	<.0001	0.17392	0.02858	0.02858	1.05818	0.00125	0.00284

Dependent Variable: Inhaul Accel
Site 3

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	56.74789	14.18697	51.26	<.0001
Error	408	112.92732	0.27678		
Corrected Total	412	169.67521			

Root MSE	0.52610	R-Square	0.3345
Dependent Mean	1.93632	Adj R-Sq	0.3279
Coeff Var	27.17017		

Parameter Estimates											
Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits	
Intercept	1	1.04812	0.27273	3.84	0.0001	0	.	.	0	0.51200	1.58424
In CRT Dist	1	0.16533	0.02331	7.09	<.0001	0.41712	0.28424	0.08209	2.11958	0.11951	0.21114
Inhaul Slope	1	-0.01453	0.00391	-3.72	0.0002	-0.21505	0.02559	0.02255	2.05063	-0.02221	-0.00685
Payload (kg)	1	-0.00015763	0.00004418	-3.57	0.0004	-0.14811	0.02001	0.02077	1.05635	-0.00024448	-0.00007078
Turn of Day	1	0.00090280	0.00053657	1.68	0.0932	0.06842	0.00462	0.00462	1.01376	-0.00015200	0.00196

Dependent Variable: Inhaul Accel
Site 4

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	318.33386	79.58346	103.23	<.0001
Error	615	474.12292	0.77093		
Corrected Total	619	792.45677			

Root MSE	0.87803	R-Square	0.4017
Dependent Mean	2.58710	Adj R-Sq	0.3978
Coeff Var	33.93870		

Parameter Estimates											
Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Type I	Squared Semi-partial Type II	Variance Inflation	95% Confidence Limits	
Intercept	1	0.59568	0.22684	2.63	0.0089	0	.	.	0	0.15020	1.04116
In CRT Dist	1	0.24805	0.01239	20.02	<.0001	0.63235	0.37038	0.39004	1.02517	0.22372	0.27238
Payload	1	-0.00016885	0.00006054	-2.79	0.0055	-0.08829	0.00746	0.00757	1.02999	-0.00004996	0.0002877
Turn of Cycle	1	0.02134	0.00446	4.78	<.0001	0.15085	0.02097	0.02224	1.02339	0.01257	0.03011
Turn of Day	1	-0.00132	0.00076704	-1.72	0.0852	-0.05455	0.00289	0.00289	1.02923	-0.00283	0.00018401

Dependent Variable: Inhaul Accel
 Site 5

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	128.06203	42.68734	129.90	<.0001
Error	774	254.35176	0.32862		
Corrected Total	777	382.41379			

Root MSE	0.57325	R-Square	0.3349
Dependent Mean	2.59010	Adj R-Sq	0.3323
Coeff Var	22.13247		

Parameter Estimates											
Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits	
Intercept	1	1.26509	0.32066	3.95	<.0001	0	.	.	0	0.63562	1.89455
In CRT Dist	1	0.26104	0.02686	9.72	<.0001	0.36938	0.28589	0.08114	1.68157	0.20830	0.31377
Inhaul Slope	1	0.03431	0.00511	6.72	<.0001	0.25546	0.03938	0.03881	1.68170	0.02429	0.04433
Turn of Cycle	1	-0.00841	0.00251	-3.34	0.0009	-0.09808	0.00961	0.00961	1.00096	-0.01334	-0.00347

Dependent Variable: Inhaul Accel
Site 6

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	80.68794	20.17198	35.43	<.0001
Error	530	301.76018	0.56936		
Corrected Total	534	382.44811			

Root MSE	0.75456	R-Square	0.2110
Dependent Mean	2.61570	Adj R-Sq	0.2050
Coeff Var	28.84728		

Parameter Estimates											
Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits	
Intercept	1	2.12883	0.36922	5.77	<.0001	0	.	.	0	1.40352	2.85414
In CRT Dist	1	0.11990	0.03200	3.75	0.0002	0.18999	0.11371	0.02091	1.72644	0.05705	0.18276
Payload	1	-0.00021334	0.00005486	-3.89	0.0001	-0.15872	0.00527	0.02251	1.11917	-0.00032112	-0.00010556
Logs	1	0.04769	0.01333	3.58	0.0004	0.14607	0.04389	0.01907	1.11879	0.02152	0.07387
Grapple	1	-1.18604	0.20864	-5.68	<.0001	-0.30163	0.04811	0.04811	1.89118	-1.59589	-0.77618

Dependent Variable: Inhaul Accel
Site 7

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	13.68242	3.42061	11.18	<.0001
Error	349	106.74698	0.30587		
Corrected Total	353	120.42941			

Root MSE	0.55305	R-Square	0.1136
Dependent Mean	1.70763	Adj R-Sq	0.1035
Coeff Var	32.38710		

Parameter Estimates											
Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits	
Intercept	1	2.72707	0.20703	13.17	<.0001	0	.	.	0	2.31988	3.13426
Inhaul Slope	1	0.00973	0.00376	2.59	0.0100	0.13533	0.00363	0.01705	1.07410	0.00235	0.01712
Payload (kg)	1	-0.00041454	0.00008438	-4.91	<.0001	-0.25610	0.06558	0.06130	1.07005	-0.00058051	-0.00024858
Logs	1	-0.05026	0.02113	-2.38	0.0179	-0.12104	0.01454	0.01437	1.01944	-0.09182	-0.00871
Turn of Cycle	1	0.01060	0.00309	3.43	0.0007	0.17487	0.02987	0.02987	1.02392	0.00452	0.01668

Dependent Variable: Inhaul Accel
Site 8

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	246.21742	41.03624	111.88	<.0001
Error	840	308.11151	0.36680		
Corrected Total	846	554.32893			

Root MSE	0.60564	R-Square	0.4442
Dependent Mean	2.02149	Adj R-Sq	0.4402
Coeff Var	29.96010		

Parameter Estimates											
Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits	
Intercept	1	0.31212	0.17626	1.77	0.0770	0	.	.	0	-0.03383	0.65807
In CRT Dist	1	0.31910	0.01694	18.84	<.0001	0.57207	0.38463	0.23490	1.39321	0.28586	0.35234
Inhaul Slope	1	-0.00783	0.00132	-5.91	<.0001	-0.17174	0.02940	0.02311	1.27647	-0.01042	-0.00523
Payload (kg)	1	-0.00019085	0.00003847	-4.96	<.0001	-0.13654	0.00696	0.01629	1.14465	-0.00026635	-0.0001153
Grapple	1	-0.29537	0.05982	-4.94	<.0001	-0.14082	0.01520	0.01613	1.22942	-0.41279	-0.17795
Turn of Cycle	1	0.00710	0.00258	2.76	0.0059	0.07245	0.00414	0.00504	1.04223	0.00205	0.01216
Turn of Day	1	-0.00096480	0.00040053	-2.41	0.0162	-0.06334	0.00384	0.00384	1.04494	-0.00175	- 0.00017865

Dependent Variable: Inhaul Accel
Site 9

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	25.98246	8.66082	41.93	<.0001
Error	515	106.38656	0.20658		
Corrected Total	518	132.36902			

Root MSE	0.45451	R-Square	0.1963
Dependent Mean	2.09364	Adj R-Sq	0.1916
Coeff Var	21.70888		

Parameter Estimates											
Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits	
Intercept	1	3.21640	0.10898	29.51	<.0001	0	.	.	0	3.00230	3.43051
Inhaul Slope	1	-0.03001	0.01789	-1.68	0.0941	-0.06699	0.01174	0.00439	1.02258	-0.06516	0.00515
Payload (kg)	1	-0.00033863	0.00003118	-10.86	<.0001	-0.43202	0.18121	0.18410	1.01380	-0.00039988	- 0.00027738
Turn of Day	1	0.00059385	0.00040619	1.46	0.1444	0.05838	0.00334	0.00334	1.02186	-0.00020414	0.00139

Dependent Variable: Inhaul Decel
Site 1

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	58.58259	29.29129	267.95	<.0001
Error	369	40.33749	0.10932		
Corrected Total	371	98.92008			

Root MSE	0.33063	R-Square	0.5922
Dependent Mean	-0.81371	Adj R-Sq	0.5900
Coeff Var	-40.63234		

Parameter Estimates											
Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits	
Intercept	1	1.40170	0.14060	9.97	<.0001	0	.	.	0	1.12522	1.67817
In CRT Dist	1	-0.37635	0.01642	-22.93	<.0001	-0.76451	0.56435	0.58080	1.00633	-0.40863	-0.34407
Payload (kg)	1	0.00017600	0.00003504	5.02	<.0001	0.16749	0.02788	0.02788	1.00633	0.00010709	0.00024491

Dependent Variable: Inhaul Decel
Site 2

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	258.48116	64.62029	222.75	<.0001
Error	496	143.89106	0.29010		
Corrected Total	500	402.37222			

Root MSE	0.53861	R-Square	0.6424
Dependent Mean	-1.32635	Adj R-Sq	0.6395
Coeff Var	-40.60867		

Parameter Estimates											
Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits	
Intercept	1	1.77855	0.18759	9.48	<.0001	0	.	.	0	1.40999	2.14712
In CRT Dist	1	-0.40607	0.01471	-27.60	<.0001	-0.74292	0.54721	0.54925	1.00488	-0.43497	-0.37716
Payload	1	0.00013808	0.00005121	2.70	0.0073	0.07916	0.00093137	0.00524	1.19556	0.00003746	0.0002387
Grapple	1	0.92941	0.10663	8.72	<.0001	0.26782	0.02303	0.05477	1.30958	0.71990	1.13891
Turn of Day	1	-0.00392	0.00039391	-9.94	<.0001	-0.28430	0.07122	0.07122	1.13491	-0.00469	-0.00314

Dependent Variable: Inhaul Decel

Site 3

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	49.81490	16.60497	133.30	<.0001
Error	409	50.94742	0.12457		
Corrected Total	412	100.76232			

Root MSE	0.35294	R-Square	0.4944
Dependent Mean	-1.74504	Adj R-Sq	0.4907
Coeff Var	-20.22530		

Parameter Estimates											
Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits	
Intercept	1	-0.18200	0.12969	-1.40	0.1613	0	.	.	0	-0.43694	0.07294
In CRT Dist	1	-0.22081	0.01105	-19.99	<.0001	-0.72292	0.46139	0.49393	1.05807	-0.24252	-0.19909
Payload (kg)	1	0.00014666	0.00002963	4.95	<.0001	0.17882	0.02954	0.03028	1.05588	0.00008841	0.00020491
Turn of Day	1	-0.00059900	0.00035828	-1.67	0.0953	-0.05891	0.00346	0.00346	1.00429	-0.00130	0.00010530

Dependent Variable: Inhaul Decel
Site 4

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	179.68871	59.89624	90.37	<.0001
Error	616	408.27071	0.66278		
Corrected Total	619	587.95942			

Root MSE	0.81411	R-Square	0.3056
Dependent Mean	-1.94097	Adj R-Sq	0.3022
Coeff Var	-41.94357		

Parameter Estimates											
Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits	
Intercept	1	-0.71210	0.19986	-3.56	0.0004	0	.	.	0	-1.10459	-0.31961
In CRT Dist	1	-0.18470	0.01142	-16.17	<.0001	-0.54665	0.29516	0.29487	1.01342	-0.20713	-0.16228
Payload (kg)	1	0.00012195	0.00005611	2.17	0.0301	0.07403	0.00396	0.00532	1.02929	0.00001175	0.00023215
Turn of Day	1	0.00170	0.00070825	2.40	0.0167	0.08140	0.00649	0.00649	1.02070	0.00030873	0.00309

Dependent Variable: Inhaul Decel
Site 5

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	97.63731	32.54577	97.17	<.0001
Error	774	259.25124	0.33495		
Corrected Total	777	356.88855			

Root MSE	0.57875	R-Square	0.2736
Dependent Mean	-1.72686	Adj R-Sq	0.2708
Coeff Var	-33.51443		

Parameter Estimates											
Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits	
Intercept	1	0.90985	0.23942	3.80	0.0002	0	.	.	0	0.43985	1.37984
In CRT Dist	1	-0.31222	0.02234	-13.98	<.0001	-0.45734	0.23897	0.18340	1.14045	-0.35607	-0.26838
Logs	1	0.01935	0.00728	2.66	0.0080	0.08701	0.00704	0.00664	1.14070	0.00507	0.03363
Turn of Day	1	-0.00196	0.00036198	-5.42	<.0001	-0.16606	0.02757	0.02757	1.00025	-0.00267	-0.00125

Dependent Variable: Inhaul Decel

Site 6

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	64.65165	12.93033	18.37	<.0001
Error	529	372.35235	0.70388		
Corrected Total	534	437.00400			

Root MSE	0.83898	R-Square	0.1479
Dependent Mean	-2.04000	Adj R-Sq	0.1399
Coeff Var	-41.12624		

Parameter Estimates											
Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits	
Intercept	1	0.01299	0.31823	0.04	0.9674	0	.	.	0	-0.61215	0.63813
In CRT Dist	1	-0.24851	0.03033	-8.19	<.0001	-0.36837	0.09823	0.10813	1.25490	-0.30809	-0.18893
Inhaul Slope	1	-0.00403	0.00241	-1.68	0.0944	-0.07568	0.00965	0.00452	1.26681	-0.00877	0.00069592
Payload (kg)	1	0.00008655	0.00005988	1.45	0.1489	0.06024	0.00095920	0.00337	1.07833	-0.00003108	0.00020418
Logs	1	-0.06560	0.01435	-4.57	<.0001	-0.18796	0.03314	0.03368	1.04896	-0.09378	-0.03742
Turn of Cycle	1	0.00852	0.00443	1.92	0.0549	0.07729	0.00596	0.00596	1.00211	-0.00018002	0.01722

Dependent Variable: Inhaul Decel
Site 7

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	24.81177	8.27059	17.45	<.0001
Error	350	165.92328	0.47407		
Corrected Total	353	190.73506			

Root MSE	0.68852	R-Square	0.1301
Dependent Mean	-1.59350	Adj R-Sq	0.1226
Coeff Var	-43.20826		

Parameter Estimates											
Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits	
Intercept	1	-2.15320	0.12185	-17.67	<.0001	0	.	.	0	-2.39286	-1.91354
Inhaul Slope	1	-0.02901	0.00456	-6.36	<.0001	-0.32047	0.09776	0.10060	1.02084	-0.03798	-0.02004
Logs	1	0.08253	0.02606	3.17	0.0017	0.15794	0.02481	0.02493	1.00082	0.03128	0.13379
Turn of Cycle	1	-0.00668	0.00384	-1.74	0.0830	-0.08755	0.00751	0.00751	1.02009	-0.01424	0.00087592

Dependent Variable: Inhaul Decel
Site 8

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	237.90781	59.47695	133.93	<.0001
Error	842	373.92235	0.44409		
Corrected Total	846	611.83015			

Root MSE	0.66640	R-Square	0.3888
Dependent Mean	-1.79516	Adj R-Sq	0.3859
Coeff Var	-37.12202		

Parameter Estimates											
Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits	
Intercept	1	0.85219	0.17861	4.77	<.0001	0	.	.	0	0.50161	1.20278
In CRT Dist	1	-0.36523	0.01589	-22.99	<.0001	-0.62324	0.37951	0.38357	1.01267	-0.39641	-0.33404
Payload (kg)	1	0.00009003	0.00004200	2.14	0.0324	0.06131	0.00096642	0.00333	1.12725	0.00000758	0.00017248
Logs	1	-0.05538	0.02251	-2.46	0.0141	-0.07020	0.00393	0.00439	1.12174	-0.09956	-0.01120
Turn of Cycle	1	-0.00693	0.00280	-2.47	0.0136	-0.06730	0.00444	0.00444	1.02024	-0.01244	-0.00143

Dependent Variable: Inhaul Decel
Site 9

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	28.45759	9.48586	15.83	<.0001
Error	515	308.61964	0.59926		
Corrected Total	518	337.07723			

Root MSE	0.77412	R-Square	0.0844
Dependent Mean	-2.39769	Adj R-Sq	0.0791
Coeff Var	-32.28609		

Parameter Estimates											
Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits	
Intercept	1	-1.22877	0.43612	-2.82	0.0050	0	.	.	0	-2.08557	-0.37198
In CRT Dist	1	-0.20752	0.04398	-4.72	<.0001	-0.20318	0.02654	0.03958	1.04299	-0.29392	-0.12112
Payload (kg)	1	0.00029548	0.00005388	5.48	<.0001	0.23623	0.05136	0.05347	1.04361	0.00018963	0.00040133
Turn of Day	1	-0.00132	0.00068747	-1.92	0.0559	-0.08117	0.00653	0.00653	1.00904	-0.00267	0.00003303

Appendix F

Dependent Variable: Turn
Site 1

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	8	97357	12170	23.88	<.0001
Error	359	182981	509.69545		
Corrected Total	367	280337			

Root MSE	22.57644	R-Square	0.3473
Dependent Mean	123.73641	Adj R-Sq	0.3327
Coeff Var	18.24559		

Parameter Estimates											
Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits	
Intercept	1	85.96419	8.85144	9.71	<.0001	0	.	.	0	68.55699	103.37138
Out Decel	1	5.24394	2.75782	1.90	0.0580	0.11210	0.05623	0.00657	1.91146	-0.17957	10.66745
Out Max Vel	1	0.42650	0.05362	7.95	<.0001	0.45996	0.10556	0.11504	1.83906	0.32105	0.53195
In Accel	1	-7.62326	2.86919	-2.66	0.0082	-0.12955	0.04833	0.01283	1.30759	-	-1.98073
										13.26580	
Choker Drop	1	19.78453	3.04396	6.50	<.0001	0.28731	0.06320	0.07681	1.07473	13.79829	25.77077
Choker Pickup	1	11.98048	3.08096	3.89	0.0001	0.17398	0.02744	0.02749	1.10102	5.92148	18.03949
Payload (kg)	1	0.00904	0.00271	3.33	0.0009	0.16110	0.01839	0.02020	1.28508	0.00371	0.01438
Turn of Cycle	1	-0.36155	0.12462	-2.90	0.0039	-0.13645	0.02374	0.01530	1.21655	-0.60661	-0.11648
Turn of Day	1	-0.05001	0.03217	-1.55	0.1209	-0.07116	0.00439	0.00439	1.15236	-0.11328	0.01326

Dependent Variable: Turn
Site 2

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	184125	20458	50.37	<.0001
Error	490	199015	406.15362		
Corrected Total	499	383140			

Root MSE	20.15325	R-Square	0.4806
Dependent Mean	116.95400	Adj R-Sq	0.4710
Coeff Var	17.23178		

Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits	
Intercept	1	69.66400	5.86854	11.87	<.0001	0	.	.	0	58.13338	81.19461
Out Accel	1	-6.43930	1.06354	-6.05	<.0001	-0.28498	0.03466	0.03886	2.08997	-8.52897	-4.34963
Out Decel	1	6.20665	1.85822	3.34	0.0009	0.20534	0.10336	0.01183	3.56526	2.55559	9.85771
Out Max Vel	1	0.51741	0.03733	13.86	<.0001	0.81594	0.25901	0.20367	3.26873	0.44407	0.59076
In Decel	1	-6.26220	1.25182	-5.00	<.0001	-0.20292	0.01946	0.02653	1.55218	-8.72180	-3.80260
Choker Drop	1	7.56010	2.82444	2.68	0.0077	0.08875	0.00863	0.00759	1.03707	2.01060	13.10961
Choker Pickup	1	11.65768	2.82458	4.13	<.0001	0.13685	0.02481	0.01806	1.03717	6.10790	17.20745
Payload (kg)	1	0.00595	0.00180	3.31	0.0010	0.11050	0.00905	0.01164	1.04922	0.00242	0.00948
Turn of Cycle	1	-0.28225	0.09346	-3.02	0.0027	-0.10622	0.01297	0.00967	1.16704	-0.46588	-0.09861
Turn of Day	1	-0.04189	0.01469	-2.85	0.0045	-0.09838	0.00863	0.00863	1.12197	-0.07075	-0.01304

Dependent Variable: Turn
Site 3

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	8	358716	44839	29.86	<.0001
Error	403	605244	1501.84615		
Corrected Total	411	963960			

Root MSE	38.75366	R-Square	0.3721
Dependent Mean	162.94903	Adj R-Sq	0.3597
Coeff Var	23.78269		

Parameter Estimates											
Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits	
Intercept	1	93.16669	13.67135	6.81	<.0001	0	.	.	0	66.29062	120.04276
Out Accel	1	-14.32953	3.22575	-4.44	<.0001	-0.25703	0.02558	0.03074	2.14888	-20.67092	-7.98813
Out Decel	1	7.72505	3.22392	2.40	0.0170	0.12128	0.01421	0.00895	1.64418	1.38725	14.06285
Out Max Vel	1	0.91387	0.07800	11.72	<.0001	0.75990	0.23997	0.21387	2.70002	0.76054	1.06721
In Accel	1	-7.95355	3.46639	-2.29	0.0223	-0.10171	0.00862	0.00820	1.26130	-14.76801	-1.13909
Choker Drop	1	32.61108	6.59192	4.95	<.0001	0.19961	0.03840	0.03813	1.04497	19.65223	45.56993
Choker Pickup	1	18.18971	6.65357	2.73	0.0065	0.10881	0.01202	0.01164	1.01682	5.10967	31.26976
Payload (kg)	1	0.01020	0.00328	3.10	0.0020	0.12694	0.01071	0.01502	1.07298	0.00374	0.01666
Turn of Cycle	1	-1.00509	0.26380	-3.81	0.0002	-0.15230	0.02262	0.02262	1.02560	-1.52369	-0.48649

Dependent Variable: Turn
Site 4

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	10	1188634	118863	68.72	<.0001
Error	599	1036063	1729.65452		
Corrected Total	609	2224698			

Root MSE	41.58912	R-Square	0.5343
Dependent Mean	186.64590	Adj R-Sq	0.5265
Coeff Var	22.28236		

Parameter Estimates											
Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits	
Intercept	1	87.72761	10.56719	8.30	<.0001	0	.	.	0	66.97436	108.48085
Out Accel	1	-7.21303	2.06768	-3.49	0.0005	-0.15524	0.12854	0.00946	2.54725	-11.27382	-3.15224
Out Accel	1	7.62258	1.99003	3.83	0.0001	0.15546	0.01922	0.01141	2.11876	3.71430	11.53085
Out Max Vel	1	0.63181	0.05880	10.75	<.0001	0.67053	0.24391	0.08976	5.00883	0.51633	0.74728
In Accel	1	-5.89305	2.08875	-2.82	0.0049	-0.11095	0.00623	0.00619	1.98913	-9.99521	-1.79090
In Max Vel	1	0.24781	0.07209	3.44	0.0006	0.20942	0.01078	0.00919	4.77317	0.10623	0.38938
Choker Drop	1	40.96999	4.87470	8.40	<.0001	0.23723	0.05093	0.05492	1.02477	31.39640	50.54357
Choker Pickup	1	18.62354	4.98103	3.74	0.0002	0.10627	0.01319	0.01087	1.03900	8.84113	28.40595
Payload (kg)	1	0.01291	0.00289	4.46	<.0001	0.12661	0.01280	0.01547	1.03627	0.00722	0.01859
Turn of Cycle	1	-1.42322	0.21854	-6.51	<.0001	-0.18907	0.02894	0.03297	1.08418	-1.85243	-0.99402
Turn of Day	1	0.18732	0.03716	5.04	<.0001	0.14400	0.01976	0.01976	1.04948	0.11434	0.26029

Dependent Variable: Turn
Site 5

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	8	191088	23886	24.10	<.0001
Error	766	759068	990.94976		
Corrected Total	774	950156			

Root MSE	31.47935	R-Square	0.2011
Dependent Mean	152.35742	Adj R-Sq	0.1928
Coeff Var	20.66152		

Parameter Estimates											
Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits	
Intercept	1	108.47173	5.87633	18.46	<.0001	0	.	.	0	96.93610	120.00736
Out Accel	1	-6.69743	1.63042	-4.11	<.0001	-0.18546	0.00612	0.01760	1.95453	-9.89805	-3.49681
Out Decel	1	8.64403	1.86061	4.65	<.0001	0.21911	0.00286	0.02251	2.13282	4.99153	12.29653
Out Max Vel	1	0.69503	0.07163	9.70	<.0001	0.62912	0.15476	0.09818	4.03138	0.55441	0.83565
In Decel	1	-6.72108	2.21560	-3.03	0.0025	-0.12374	0.00490	0.00960	1.59530	-11.07045	-2.37171
In Max Vel	1	-0.14355	0.06885	-2.08	0.0374	-0.11273	0.00409	0.00453	2.80278	-0.27871	-0.00839
Choker Drop	1	9.28865	2.53887	3.66	0.0003	0.13127	0.00666	0.01396	1.23444	4.30468	14.27262
Choker Pickup	1	8.00059	2.53810	3.15	0.0017	0.11265	0.01164	0.01036	1.22463	3.01813	12.98304
Turn of Cycle	1	-0.43560	0.14000	-3.11	0.0019	-0.10175	0.01010	0.01010	1.02531	-0.71043	-0.16077

Dependent Variable: Turn
Site 6

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	10	233884	23388	19.55	<.0001
Error	521	623282	1196.31813		
Corrected Total	531	857166			

Root MSE	34.58783	R-Square	0.2729
Dependent Mean	160.54511	Adj R-Sq	0.2589
Coeff Var	21.54400		

Parameter Estimates											
Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Sqr Semi-partial Corr Type I	Sqr Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits	
Intercept	1	85.49173	11.20762	7.63	<.0001	0	.	.	0	63.47406	107.50940
Out Accel	1	-3.67631	1.74101	-2.11	0.0352	-0.09063	0.01818	0.00622	1.31977	-7.09656	-0.25605
Out Decel	1	4.71207	1.96751	2.39	0.0170	0.10593	0.01861	0.00801	1.40174	0.84684	8.57730
Out Max Vel	1	0.50078	0.05454	9.18	<.0001	0.47073	0.17588	0.11765	1.88345	0.39363	0.60793
In Accel	1	-5.01559	2.16263	-2.32	0.0208	-0.10594	0.00216	0.00751	1.49511	-9.26413	-0.76704
In Decel	1	3.39233	1.99552	1.70	0.0897	0.07553	0.00000920	0.00403	1.41440	-0.52792	7.31258
In Max Vel	1	0.23515	0.07214	3.26	0.0012	0.17836	0.01990	0.01483	2.14554	0.09342	0.37688
Choker Drop	1	12.12167	3.53420	3.43	0.0007	0.13475	0.01697	0.01642	1.10602	5.17864	19.06471
Choker Pickup	1	7.26134	3.52095	2.06	0.0397	0.08002	0.00739	0.00594	1.07873	0.34434	14.17834
Payload (kg)	1	0.00674	0.00248	2.72	0.0068	0.10507	0.01049	0.01030	1.07205	0.00187	0.01162
Turn of Day	1	-0.04963	0.03237	-1.53	0.1258	-0.05973	0.00328	0.00328	1.08747	-0.11323	0.01396

Dependent Variable: Turn
Site 7

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	42186	7030.93188	10.44	<.0001
Error	228	153582	673.60743		
Corrected Total	234	195768			

Root MSE	25.95395	R-Square	0.2155
Dependent Mean	139.55319	Adj R-Sq	0.1948
Coeff Var	18.59789		

Parameter Estimates											
Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits	
Intercept	1	119.24291	11.86420	10.05	<.0001	0	.	.	0	95.86542	142.62040
Out Accel	1	-5.29463	2.28620	-2.32	0.0215	-0.14101	0.00398	0.01845	1.07749	-9.79941	-0.78986
Out Max Vel	1	0.48643	0.07326	6.64	<.0001	0.40650	0.13335	0.15167	1.08946	0.34206	0.63079
In Accel	1	-7.99681	3.18768	-2.51	0.0128	-0.15033	0.02662	0.02165	1.04362	-14.27789	-1.71574
Choker Drop	1	18.51174	5.80547	3.19	0.0016	0.19058	0.02689	0.03499	1.03816	7.07252	29.95097
Choker Pickup	1	9.65741	5.85983	1.65	0.1007	0.09942	0.00724	0.00935	1.05769	-1.88893	21.20375
Turn of Cycle	1	-0.38961	0.17322	-2.25	0.0254	-0.13491	0.01741	0.01741	1.04553	-0.73092	-0.04830

Dependent Variable: Turn
Site 8

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	8	341321	42665	37.00	<.0001
Error	837	965032	1152.96538		
Corrected Total	845	1306353			

Root MSE	33.95534	R-Square	0.2613
Dependent Mean	137.98936	Adj R-Sq	0.2542
Coeff Var	24.60722		

Parameter Estimates											
Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits	
										Lower	Upper
Intercept	1	93.30860	7.85834	11.87	<.0001	0	.	.	0	77.88424	108.73296
Out Accel	1	-2.81250	1.60920	-1.75	0.0809	-0.07134	0.02885	0.00270	1.88800	-5.97104	0.34603
Out Decel	1	7.09771	1.90024	3.74	0.0002	0.15663	0.00355	0.01231	1.99246	3.36792	10.82750
Out Max Vel	1	0.52253	0.04546	11.49	<.0001	0.53660	0.12705	0.11660	2.46943	0.43330	0.61176
Choker Drop	1	32.66233	3.66774	8.91	<.0001	0.26835	0.07656	0.06999	1.02884	25.46329	39.86138
Choker Pickup	1	6.86881	3.69903	1.86	0.0637	0.05569	0.00374	0.00304	1.01916	-0.39165	14.12927
Payload (kg)	1	0.00449	0.00206	2.18	0.0294	0.06610	0.00252	0.00420	1.03987	0.00045029	0.00852
Turn of Cycle	1	-0.65373	0.14516	-4.50	<.0001	-0.13728	0.01696	0.01790	1.05286	-0.93866	-0.36881
Turn of Day	1	0.03421	0.02248	1.52	0.1285	0.04625	0.00204	0.00204	1.04707	-0.00993	0.07834

Dependent Variable: Turn
Site 9

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	98198	16366	25.70	<.0001
Error	512	326115	636.94282		
Corrected Total	518	424313			

Root MSE	25.23773	R-Square	0.2314
Dependent Mean	141.79961	Adj R-Sq	0.2224
Coeff Var	17.79816		

Parameter Estimates											
Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits	
Intercept	1	56.88939	11.11909	5.12	<.0001	0	.	.	0	35.04474	78.73404
Out Accel	1	-6.23558	1.80241	-3.46	0.0006	-0.14225	0.00459	0.01797	1.12630	-9.77662	-2.69454
Out Max Vel	1	0.48243	0.05674	8.50	<.0001	0.34837	0.13390	0.10851	1.11840	0.37095	0.59390
Choker Drop	1	7.08924	2.88294	2.46	0.0143	0.09548	0.01085	0.00908	1.00443	1.42540	12.75309
Payload (kg)	1	0.01164	0.00174	6.68	<.0001	0.26228	0.05937	0.06708	1.02544	0.00822	0.01506
Turn of Cycle	1	-0.39719	0.14200	-2.80	0.0053	-0.11091	0.01523	0.01174	1.04729	-0.67616	-0.11822
Turn of Day	1	-0.05179	0.02319	-2.23	0.0260	-0.08992	0.00749	0.00749	1.08018	-0.09734	-0.00623

Dependent Variable: Prod
Site 1

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	8	31455	3931.89714	15.04	<.0001
Error	359	93874	261.48866		
Corrected Total	367	125330			

Root MSE	16.17061	R-Square	0.2510
Dependent Mean	75.23252	Adj R-Sq	0.2343
Coeff Var	21.49418		

Parameter Estimates											
Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits	
Intercept	1	89.56639	3.69858	24.22	<.0001	0	.	.	0	82.29279	96.83999
Out Accel	1	3.21045	1.36359	2.35	0.0191	0.15344	0.00568	0.01157	2.03577	0.52882	5.89208
Out Decel	1	-9.72154	1.90536	-5.10	<.0001	-0.31080	0.00255	0.05431	1.77847	-13.46861	-5.97447
Out Max Vel	1	-0.25232	0.04873	-5.18	<.0001	-0.40698	0.10681	0.05593	2.96128	-0.34816	-0.15648
In Accel	1	-4.30140	2.54945	-1.69	0.0924	-0.10932	0.02029	0.00594	2.01235	-9.31514	0.71234
In Max Vel	1	-0.11481	0.06610	-1.74	0.0833	-0.12197	0.00622	0.00629	2.36366	-0.24481	0.01518
Choker Drop	1	-11.60411	2.18941	-5.30	<.0001	-0.25203	0.04384	0.05861	1.08376	-15.90980	-7.29842
Choker Pickup	1	-8.76797	2.20321	-3.98	<.0001	-0.19043	0.03497	0.03304	1.09746	-13.10079	-4.43515
Turn of Cycle	1	0.32273	0.08423	3.83	0.0002	0.18216	0.03063	0.03063	1.08341	0.15708	0.48837

Dependent Variable: Prod
Site 2

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	102724	14675	33.33	<.0001
Error	492	216597	440.23782		
Corrected Total	499	319321			

Root MSE	20.98185	R-Square	0.3217
Dependent Mean	95.87112	Adj R-Sq	0.3120
Coeff Var	21.88547		

Parameter Estimates											
Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits	
Intercept	1	121.11745	3.44424	35.17	<.0001	0	.	.	0	114.35022	127.88468
Out Accel	1	4.20646	1.07462	3.91	0.0001	0.20392	0.03074	0.02112	1.96855	2.09504	6.31787
Out Max Vel	1	-0.22381	0.03429	-6.53	<.0001	-0.38660	0.20794	0.05874	2.54458	-0.29118	-0.15644
In Accel	1	-2.83937	1.82643	-1.55	0.1207	-0.08601	0.01770	0.00333	2.22032	-6.42794	0.74920
In Max Vel	1	-0.18578	0.05059	-3.67	0.0003	-0.23956	0.01295	0.01859	3.08663	-0.28518	-0.08638
Choker Pickup	1	-5.32382	2.92045	-1.82	0.0689	-0.06846	0.00851	0.00458	1.02293	-11.06191	0.41428
Turn of Cycle	1	0.41982	0.09686	4.33	<.0001	0.17307	0.03218	0.02590	1.15649	0.22951	0.61013
Turn of Day	1	0.04426	0.01521	2.91	0.0038	0.11384	0.01167	0.01167	1.11032	0.01437	0.07415

Dependent Variable: Prod
Site 3

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	41811	8362.17331	31.47	<.0001
Error	406	107869	265.68641		
Corrected Total	411	149680			

Root MSE	16.29989	R-Square	0.2793
Dependent Mean	78.60722	Adj R-Sq	0.2705
Coeff Var	20.73587		

Parameter Estimates											
Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits	
Intercept	1	102.50019	3.28456	31.21	<.0001	0	.	.	0	96.04332	108.95706
Out Max Vel	1	-0.15352	0.02977	-5.16	<.0001	-0.32395	0.17631	0.04721	2.22294	-0.21204	-0.09500
In Max Vel	1	-0.09738	0.04134	-2.36	0.0190	-0.14786	0.00857	0.00985	2.21927	-0.17864	-0.01612
Choker Drop	1	-11.54694	2.74476	-4.21	<.0001	-0.17937	0.02717	0.03141	1.02411	-16.94266	-6.15122
Choker Pickup	1	-9.22764	2.79262	-3.30	0.0010	-0.14008	0.02007	0.01938	1.01254	-14.71744	-3.73783
Turn of Cycle	1	0.57274	0.11105	5.16	<.0001	0.22024	0.04722	0.04722	1.02735	0.35444	0.79105

Dependent Variable: Prod
Site 4

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	8	126011	15751	52.75	<.0001
Error	601	179468	298.61643		
Corrected Total	609	305480			

Root MSE	17.28052	R-Square	0.4125
Dependent Mean	60.22009	Adj R-Sq	0.4047
Coeff Var	28.69561		

Parameter Estimates											
Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits	
Intercept	1	86.95245	2.59526	33.50	<.0001	0	.	.	0	81.85557	92.04933
Out Accel	1	1.25388	0.84813	1.48	0.1398	0.07283	0.13713	0.00214	2.48243	-0.41178	2.91955
Out Decel	1	-2.77242	0.82334	-3.37	0.0008	-0.15259	0.00882	0.01108	2.10071	-4.38938	-1.15545
Out Max Vel	1	-0.16520	0.02413	-6.85	<.0001	-0.47313	0.15843	0.04582	4.88552	-0.21258	-0.11781
In Max Vel	1	-0.10937	0.02683	-4.08	<.0001	-0.24942	0.01388	0.01624	3.83129	-0.16207	-0.05667
Choker	1	-10.65116	2.02309	-5.26	<.0001	-0.16644	0.02331	0.02710	1.02237	-14.62434	-6.67797

Parameter Estimates											
Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits	
Drop											
Choker Pickup	1	-4.64873	2.06558	-2.25	0.0248	-0.07158	0.00521	0.00495	1.03492	-8.70537	-0.59209
Turn of Cycle	1	0.51458	0.09000	5.72	<.0001	0.18448	0.02616	0.03195	1.06505	0.33782	0.69133
Turn of Day	1	-0.09759	0.01534	-6.36	<.0001	-0.20245	0.03957	0.03957	1.03593	-0.12771	-0.06746

Dependent Variable: Prod
Site 5

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	65250	7249.99409	25.00	<.0001
Error	765	221807	289.94395		
Corrected Total	774	287057			

Root MSE	17.02774	R-Square	0.2273
Dependent Mean	73.87128	Adj R-Sq	0.2182
Coeff Var	23.05056		

Parameter Estimates											
Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits	
Intercept	1	100.05250	3.41985	29.26	<.0001	0	.	.	0	93.33909	106.76591
Out Accel	1	3.15195	0.88539	3.56	0.0004	0.15880	0.01228	0.01280	1.96995	1.41386	4.89004
Out Decel	1	-3.38605	1.01074	-3.35	0.0008	-0.15616	0.00810	0.01134	2.15112	-5.37022	-1.40189
In Max Vel	1	-0.26192	0.03896	-6.72	<.0001	-0.43133	0.16495	0.04564	4.07637	-0.33841	-0.18543
Out Accel	1	3.17224	1.19606	2.65	0.0082	0.11268	0.00002617	0.00711	1.78700	0.82429	5.52019
Out Decel	1	1.96346	1.20513	1.63	0.1037	0.06576	0.00541	0.00268	1.61312	-0.40230	4.32921
Out Max Vel	1	-0.15994	0.04136	-3.87	0.0001	-0.22850	0.01415	0.01510	3.45668	-0.24113	-0.07875
Choker Drop	1	-3.85139	1.37371	-2.80	0.0052	-0.09903	0.00240	0.00794	1.23513	-6.54807	-1.15471
Choker Pickup	1	-4.43496	1.37324	-3.23	0.0013	-0.11361	0.01175	0.01053	1.22523	-7.13072	-1.73920
Turn of Cycle	1	0.21846	0.07649	2.86	0.0044	0.09284	0.00824	0.00824	1.04611	0.06830	0.36863

Dependent Variable: Prod
Site 6

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	37986	7597.21810	18.87	<.0001
Error	526	211786	402.63544		
Corrected Total	531	249772			

Root MSE	20.06578	R-Square	0.1521
Dependent Mean	83.32261	Adj R-Sq	0.1440
Coeff Var	24.08203		

Parameter Estimates											
Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits	
Intercept	1	107.31613	4.32254	24.83	<.0001	0	.	.	0	98.82456	115.80770
Out Accel	1	2.68640	0.99400	2.70	0.0071	0.12268	0.00242	0.01177	1.27823	0.73370	4.63911
Out Decel	1	-1.73097	1.14423	-1.51	0.1309	-0.07209	0.01332	0.00369	1.40862	-3.97880	0.51686
Out Max Vel	1	-0.20713	0.03131	-6.61	<.0001	-0.36069	0.11762	0.07053	1.84453	-0.26865	-0.14562
In Max Vel	1	-0.10098	0.03328	-3.03	0.0025	-0.14189	0.01527	0.01484	1.35673	-0.16636	-0.03560
Turn of Cycle	1	0.15676	0.10701	1.46	0.1436	0.05941	0.00346	0.00346	1.02043	-0.05347	0.36698

Dependent Variable: Prod
Site 7

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	7102.34201	1420.46840	7.34	<.0001
Error	229	44319	193.53273		
Corrected Total	234	51421			

Root MSE	13.91160	R-Square	0.1381
Dependent Mean	58.70269	Adj R-Sq	0.1193
Coeff Var	23.69841		

Parameter Estimates											
Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits	
Intercept	1	66.26473	5.54194	11.96	<.0001	0	.	.	0	55.34500	77.18445
Out Accel	1	1.89346	1.19473	1.58	0.1144	0.09840	0.00863	0.00945	1.02418	-0.46061	4.24753
In Max Vel	1	-0.18164	0.03686	-4.93	<.0001	-0.30639	0.08762	0.09140	1.02708	-0.25426	-0.10901
Choker Drop	1	-7.99363	3.10941	-2.57	0.0108	-0.16057	0.01786	0.02487	1.03657	-14.12034	-1.86691
Choker Pickup	1	-5.29568	3.13074	-1.69	0.0921	-0.10638	0.00894	0.01077	1.05084	-11.46442	0.87306
Turn of Cycle	1	0.18486	0.09238	2.00	0.0466	0.12489	0.01507	0.01507	1.03505	0.00283	0.36688

Dependent Variable: Prod
Site 8

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	119756	19959	42.90	<.0001
Error	839	390366	465.27535		
Corrected Total	845	510122			

Root MSE	21.57024	R-Square	0.2348
Dependent Mean	88.53500	Adj R-Sq	0.2293
Coeff Var	24.36352		

Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Parameter Estimates					95% Confidence Limits	
						Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation			
Intercept	1	103.67407	2.83620	36.55	<.0001	0	.	.	0	98.10718	109.24095	
Out Accel	1	3.17644	1.04735	3.03	0.0025	0.12894	0.02295	0.00839	1.98188	1.12070	5.23218	
Out Decel	1	-5.05319	1.22011	-4.14	<.0001	-0.17845	0.00387	0.01564	2.03554	-7.44803	-2.65836	
Out Max Vel	1	-0.28306	0.02943	-9.62	<.0001	-0.46518	0.12882	0.08436	2.56499	-0.34083	-0.22529	
In Max Vel	1	-0.12619	0.02905	-4.34	<.0001	-0.16759	0.01754	0.01721	1.63157	-0.18320	-0.06918	
Choker Drop	1	-13.80477	2.31187	-5.97	<.0001	-0.18150	0.03239	0.03252	1.01294	-18.34250	-9.26704	
Turn of Cycle	1	0.51665	0.09135	5.66	<.0001	0.17362	0.02918	0.02918	1.03311	0.33736	0.69595	

Dependent Variable: Prod
Site 9

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	50398	7199.76815	26.87	<.0001
Error	511	136925	267.95482		
Corrected Total	518	187323			

Root MSE	16.36933	R-Square	0.2690
Dependent Mean	85.66999	Adj R-Sq	0.2590
Coeff Var	19.10742		

Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate	Squared Semi-partial Corr Type I	Squared Semi-partial Corr Type II	Variance Inflation	95% Confidence Limits	
Intercept	1	149.78880	8.10786	18.47	<.0001	0	.	.	0	133.85996	165.71763
Out Accel	1	2.42633	1.16985	2.07	0.0386	0.08331	0.00243	0.00615	1.12783	0.12802	4.72464
Out Decel	1	-1.99663	1.14768	-1.74	0.0825	-0.06942	0.00249	0.00433	1.11315	-4.25137	0.25812
Out Max Vel	1	-0.09491	0.04373	-2.17	0.0304	-0.10315	0.06830	0.00674	1.57905	-0.18082	-0.00899
In Accel	1	-5.85184	1.54885	-3.78	0.0002	-0.15556	0.07659	0.02042	1.18507	-8.89475	-2.80894
In Max Vel	1	-0.51539	0.06588	-7.82	<.0001	-0.37252	0.05822	0.08755	1.58499	-0.64481	-0.38597
Turn of Cycle	1	0.42071	0.09269	4.54	<.0001	0.17680	0.03694	0.02947	1.06085	0.23860	0.60282
Turn of Day	1	0.06343	0.01546	4.10	<.0001	0.16577	0.02408	0.02408	1.14110	0.03306	0.09380