UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha

DEPARTMENT OF

FOREST ENGINEERING

Cable Assisted Steep Slope Harvesting: Wire Rope Tension Analysis

Honours Project Report

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RUNNING HEADER: CABLE-ASSIST TENSION MONITORING

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1. Acknowledgements

I would like to express my great appreciation to my supervisor Dr Rien Visser for providing me with guidance and useful feedback throughout the course of my research. I am also deeply grateful to both Dr Dzhamal Amishev and Dr Hunter Harrill for providing me with the raw data sets on which the study is based. I would also like to extend my grateful thanks to; Dr Kris Brown for his time and consideration, and to Callum <lastname> for his explanations of EMS system functionality.

A special thanks to my forestry colleagues, and to my parents for their support and encouragement throughout my study.

2. Abstract

Cable-assisted forest harvesting has been relatively recently introduced as a method to improve safety and productivity of felling on steep terrain. In New Zealand there have been a number of cases of system failures resulting in machines overturning and workers sustaining permanently debilitating injuries. While there are regulations in place to govern the construction and application of these systems, there is a lack of understanding around their performance and limitations. Unsafe cable tension levels have been measured from operational systems which currently meet all of the design and operational regulations. In order to inform and improve future designs, this study analyses the cable tensions of two cable-assist systems; an EMS TractionLine system working in Washington USA, and a DC Forestry Equipment Falcon Winch Assist system working in Nelson, New Zealand.

Videos of the TractionLine harvester operator's display were taken by Dzhamal Amishev of FP Innovations. These videos were broken down to extract the tension profiles during start up and working periods, along with data on engine power settings and movement intervals. Further analysis on the tension series revealed relationships between irregular tension and movement, as well as the engine setting's effect on the tension magnitudes.

Tension data and time-studies were conducted by Hunter Harrill on the DC Falcon Winch Assist system. The tension data was taken from a direct data feed from the anchor machine. This data was synchronised and calibrated with the time-study data, showing the relationship between movement and tension peaks. Again, the base tension magnitude has been linked to the specific user-selected winch power settings, as shown in a power calibration data set.

The behaviours observed in this and previous studies were then discussed in order to make recommendations about any future calibrations and regulations required for safe operation of the systems in future.

3. Introduction

Forests in New Zealand are often planted on marginal land which tends to be steep with poor soils. Typically these blocks are harvested using motor-manual felling and cable yarder extraction. Increased emphasis on health and safety in the last decade has led to an increased degree of mechanisation in forestry operations in New Zealand, with similar trends seen previously overseas. Cable assisted steep terrain harvesting is becoming more prevalent as the degree of mechanisation in forest operations continues to increase. Cable assist operations have been shown in increase productivity (Visser & Stampfer, 1998) and certainly provide safety improvements over motor-manual felling on steep terrain (Visser, Raymond, & Harrill, 2014). However there have been a number of incidents involving machines overturning after the stabilising wire rope has failed, or after the anchor machine's stability has been compromised due to overloading. Despite the fact that many system manufacturers claim the cables are held at constant tensions during operation, in previous studies it has been observed that peak tension events which exceed safe working loads are still occurring regularly. In order to improve both the operational efficiency and safety of these systems we first need to build an understanding of their behaviour. Using video data taken by Dzhamal Amishev of FP Innovations, analyses will be performed on an EMS TractionLine system operating in south-west Washington USA to help understand the behaviour of this system during normal operation. The DC Falcon Winch Assist system will also be analysed, using tension and time-study data provided by Hunter Harrill of the University of Canterbury. The tension trends and magnitudes will be analysed, along with the engine power settings in order to find the determinants of the loading magnitudes.

4. Critical Review

There are a number of sets of guidelines for cable-assisted harvesting (Worksafe New Zealand, 2012; Visser & Stampfer, 2015; Theobald, 2016) which give generalised recommendations based on slope and stability requirements. The Approved Code of Practice (ACOP) from Worksafe New Zealand states that for winch-assisted harvesting on steep slopes "The tension on the wire rope shall be restricted to 33 percent of its breaking load at all times" (article 6.4.2) which equates to a factor of safety (FS) of 3.0. Compared to other recommended values from mining and civil engineering applications a FS of 3 is particularly low; factors of 7 – 12 are typically recommended in applications where a person's safety is directly dependant on the system (Bise, C. J., 2003; U.S. Department of the Interior Bureau of Reclamation, 2014).

In order to control the tension in the cables many systems use a hydraulic fluid pressure regulator on the winch drum. While this theoretically will produce a constant torque and therefore constant cable tension, previous studies have shown that shock loading still occurs (Schaare, 2015; Visser, 2013) which results in tension spikes during operations. These spikes were measured to exceed the safe working load of the cables up to 19 times per hour, often adding 70% of the base working load into the cable in spikes with around 0.2s durations (Schaare, 2015). Using a FS of 3, the base tension could be set up to 33% of the ultimate load; a subsequent tension spike could push the tension up to 57% of the ultimate load which is past the endurance limit of the steel. Here, despite there being no immediate permanent deformation, the life of the rope is significantly shortened (Wenger, 1984).

There have been a number of incidents in New Zealand of cable assisted harvesters overturning after the wire ropes have broken, and a recent case of an anchoring bulldozer being pulled out of position and falling down the hillside. There are no reports related to cable-assisted harvesting currently logged in the NZFOA Incident Recording Information System (IRIS) so the specific details of the failures are not readily available, however there is no doubt that serious system failures have occurred.

5. Study Objectives

A good first step in reducing the number of failures in cable assist harvesting systems is to first properly understand the behaviours of the limiting components. Tension regulation has clearly been an issue, with ropes breaking and anchoring machines being displaced. The objectives of this study are as follows:

- **a)** Characterise the cable tension behaviour of the TractionLine cable-assist system working in Washington, USA
- **b)** Characterise the cable tension behaviour of the DC Forestry Equipment *Falcon Winch Assist* cable-assist system working in Nelson, New Zealand
- **c)** Compare and contrast these results against previous studies' results. This will place the new findings in context to help build understanding

Understanding the general behaviour of these systems will be a useful tool in future system developments, providing a reference point for performance.

6. Data Gathering

6.1 EMS TractionLine System

The EMS TractionLine cable-assist harvesting system is a package which can be equipped to existing excavators provided they are suitable. The additional elements include: twin cable winches, 2 x 350m of 7/8" cable, excavator boom extension with 2 built-in sheaves, and a pivoting double sheave attachment at the bucket and of the boom. The installed equipment is pictured below

Figure 1: Operational Photos of TractionLine system components

6.1.1 Tension monitoring

The TractionLine cable-assist system monitors the following attributes in real-time:

- Rope tension
- Rope length remaining

- Winch motor power setting
- Winch machine movement
- Engine oil pressure, water temperature and hydraulic level
- System status and faults

This information is displayed on a small LCD screen in the harvester operator's cab. The tension values are back-calculated from the hydraulic fluid pressure on the winch. Of particular interest are the rope tensions and engine power setting. FP Innovations have provided video footage of the LCD readout during operation in south-west Washington, USA; below is an example of the LCD readout.

Figure 2: Example of the in-cab LCD readout

The screen refresh rate of the tension and displacement information is around 2Hz. This somewhat limits the resolution of the data that can be extracted in comparison to previous studies where the tension data was effectively continuous (Schaare, 2015; Evanson, 2013). In order to extract the maximum possible data resolution a sampling rate of 4Hz has been used to make sure no fluctuations are missed.

A number of different videos have been provided, with nearly four hours of footage in total. The videos have been broken down using the following methodology:

1. Take screenshots of the video at 0.25 second intervals
2. Step through the resulting still images and record the two tensions (T_1 and T_2)
3. Watch the video segment and note down the time periods of machine movement, as well as the movement direction (uphill/downhill), as well as the winch motor power setting
4. Produce graphs displaying the data for the different segments

Because of the labour intensive data conversion process not all of the video footage has been transposed. To best characterise the system, small segments across the range of video parts have been analysed; this ensures that segments from various work phases and positions will be taken into account.

The tension data sets for both wires will be plotted together to establish whether or not the two lines share load equally. Schaare (2015) and Evanson (2013) showed that tension peaks will often occur in conjunction with harvester movement up and down the hillside. In order to establish whether or not this is reciprocated in these results, the movement phases noted while re-watching the footage will also be shown on the plots. During preliminary analysis it became clear that using the change in cable length value from the LCD readout was a poor indicator of movement intervals, due to the lack of precision – the smallest distance increments were 1 yard. A more accurate method of gauging the movement periods was watching the video footage and noting the movement time intervals, hence this time-study approach has been adopted. The winch power setting - indicated by the tachometer-style gauge - throughout the work phases has also been noted and will be plotted in the tension time series graphs.

6.2 DC Forestry Equipment System

The DC Forestry Equipment *Falcon Winch Assist* system is similar to the EMS system, in that it runs a cable from a winch at the rear of an excavator up and over the boom and down through a pivoting sheave located close to the bucket. Images of the system are shown below:

Figure 3: DC Falcon Winch Assist CAT 330C anchor machine and Hitachi harvester

Notable differences between these two systems include that the Falcon system uses a single 1 1/8" wire rope, and the tensions are measured through a load pin in the sheave located at the top most point on the boom, rather than being back-calculated through hydraulic pressure on the winch.

Hunter Harrill gathered the tension data from this system operating in Nelson in late August 2016. Time-study notes were also taken, showing downhill movement, uphill movement and stationary felling phases. The harvester operator also provided feedback on the power settings he had been using during different phases of work. These notes have been matched against the downloaded tension data to produce tension time series graphs, indicating movement and work phases.

7. Results

7.1 EMS TractionLine Data

These tension values have been back-calculated from the hydraulic fluid pressure on the winch drum. As such they should only be treated as indicative values, as they are not direct measures of line tension.

7.1.1 Start-up phase

The initial phase of work involves the harvester moving off the top of the hill onto a steeper section. The peaky tensions correlate with periods of movement – in this case all movement is downhill. Included on the tension plots are the engine power settings, shown below:

Figure 4: Tensions and winch power setting during initial work phase #1

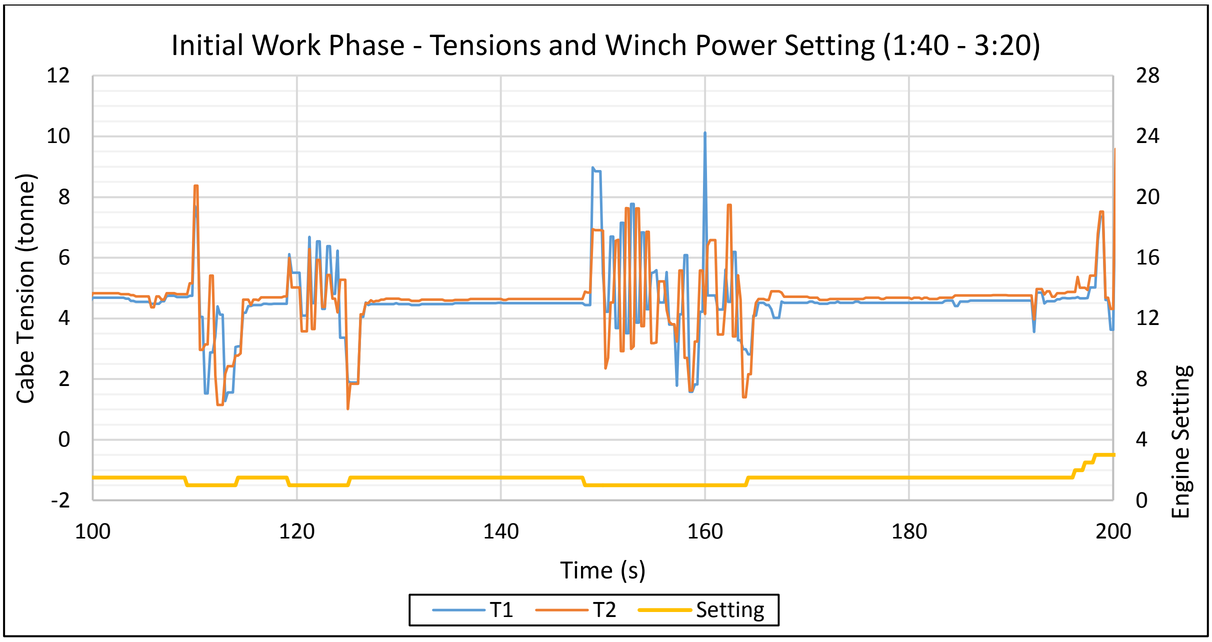

Figure 5: Tensions and winch power setting during initial work phase #2

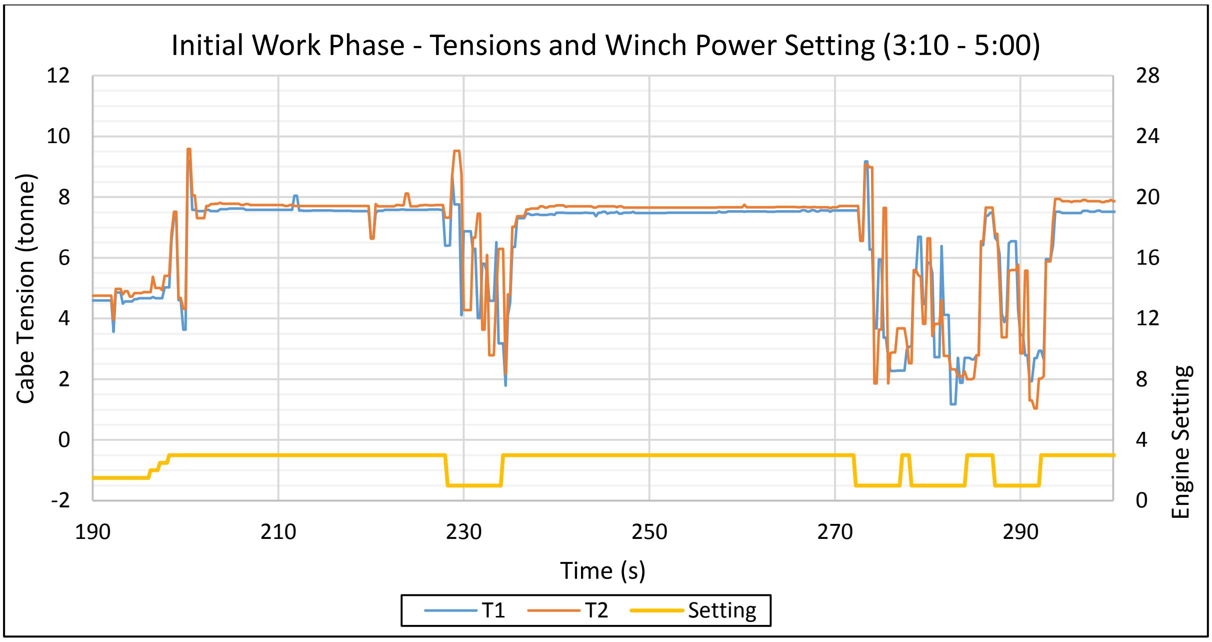

Figure 6: Tensions and winch power setting during initial work phase #3

The engine power is manually selected by the operator, and is set to 1 during periods of downhill movement. Higher power settings are selected during stationary phases which is reflected in a higher steady-state base tension, as seen by the contrast between *figure 4* and *figure 6*.

7.1.2 Movement intervals

Regular working behaviours show a base tension of close to 10T while stationary, with variable tensions occurring during movement periods. The tension always drops below 10 T during movement, regardless of the direction of travel. The figures below show examples of working tension time series with movement intervals included: a movement value of 0 = stationary, 1 = downhill, and 2 = uphill.

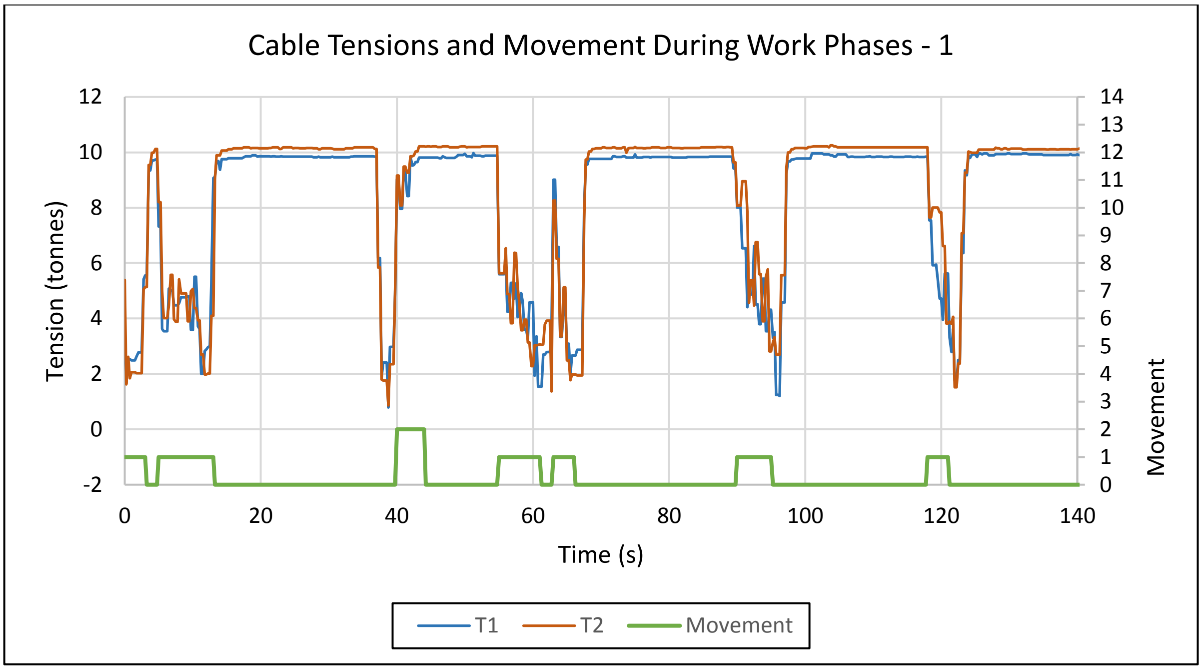

Figure 7: EMS tensions and movement periods #1

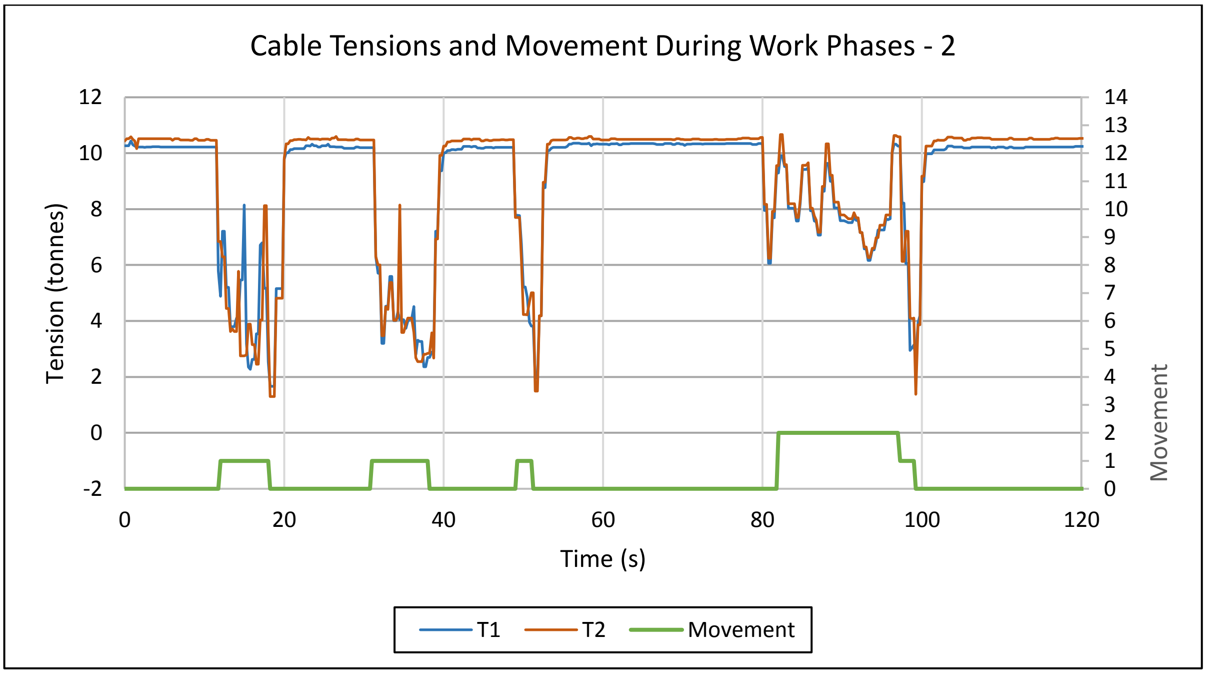

Figure 8: EMS tensions and movement periods #2

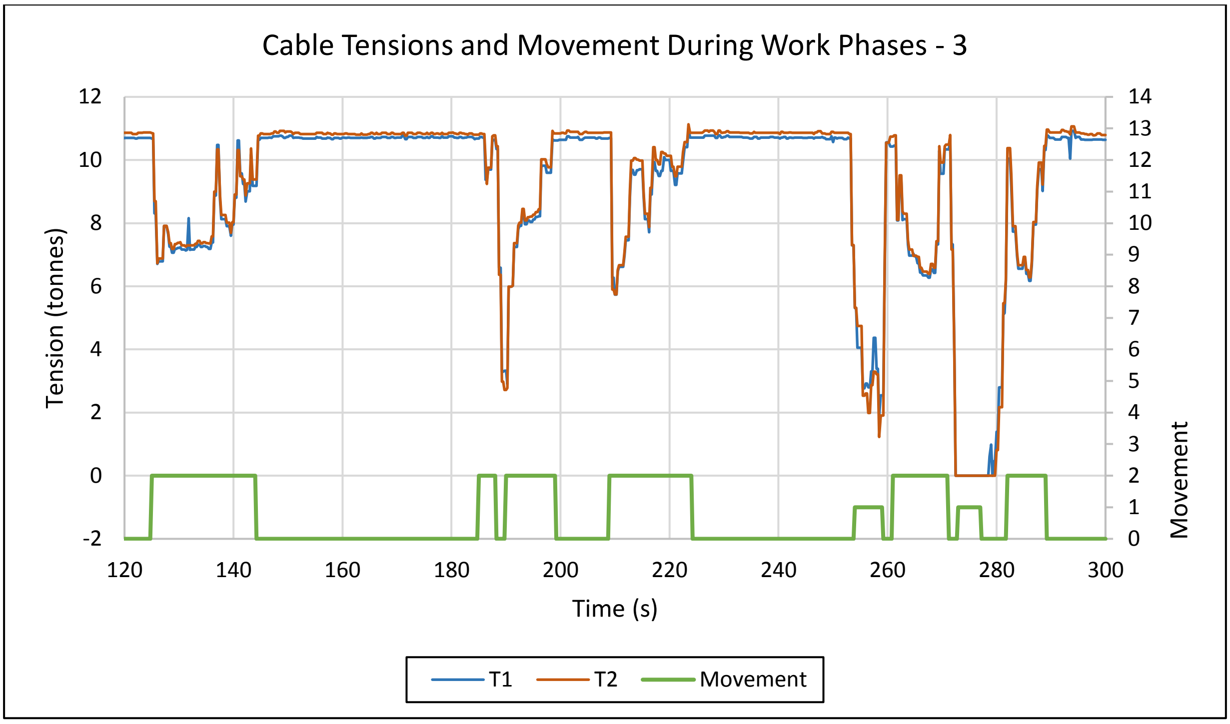

Figure 9: EMS tensions and movement periods #3

7.1.3 Winch engine settings

Closely related to the movement phases are the winch power settings. As mentioned previously, this is manually selected by the operator. Throughout regular work phases the setting is either at 1 or 4; during downhill movement the setting drops to 1, whereas for uphill movement and stationary phases setting 4 is used.

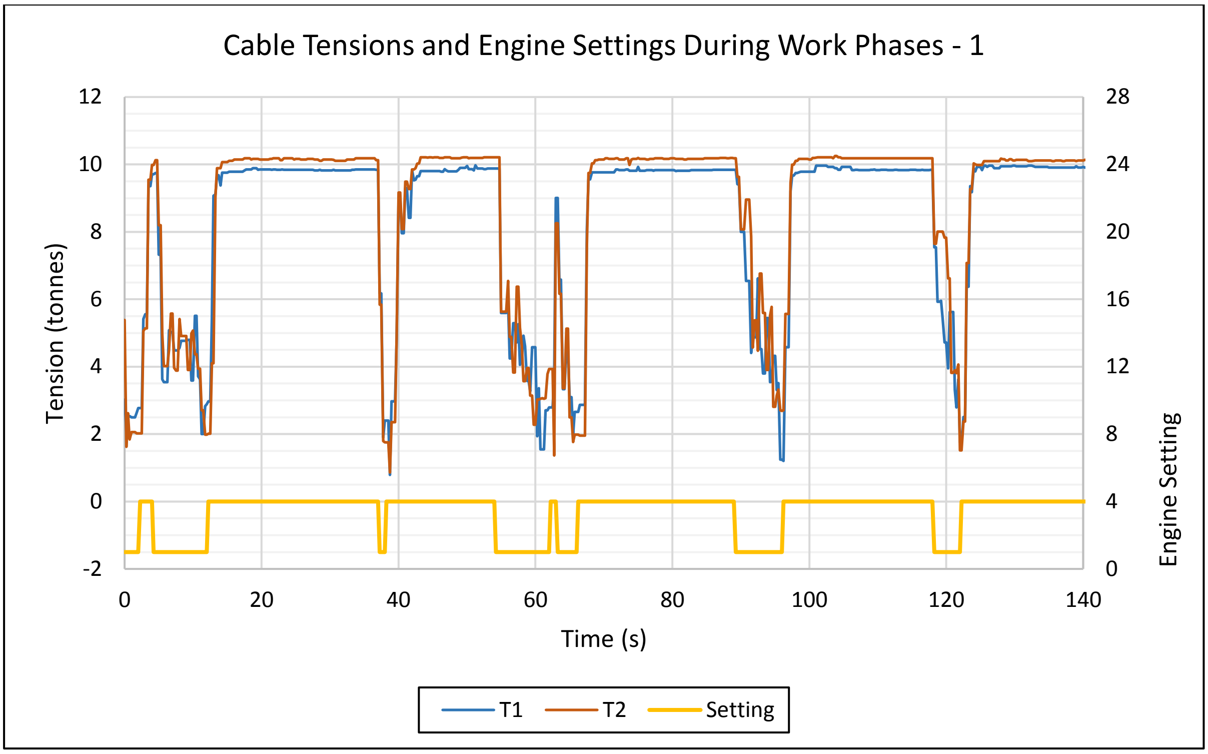

Figure 10: Tensions and winch power setting #1

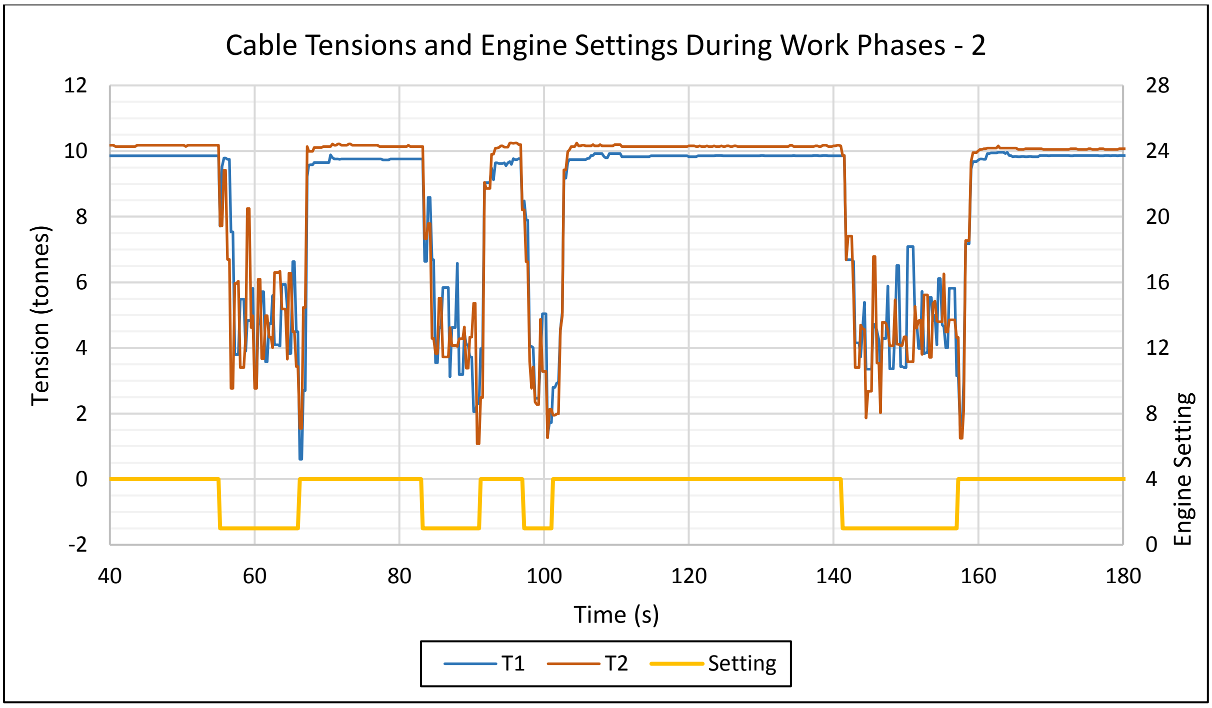

Figure 11: Tensions and winch power setting #2

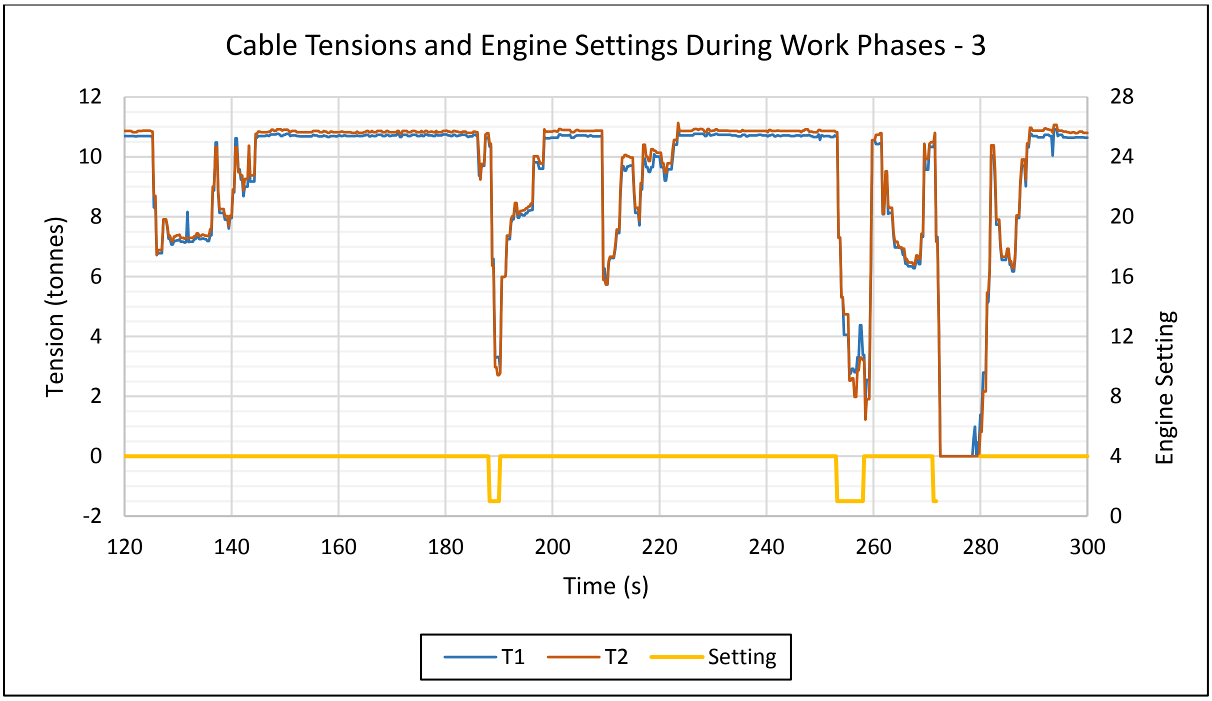

Figure 12: Tensions and winch power setting #3

Dropping the power setting dramatically drops the supporting tension in the cable, which is particularly evident during downhill movement phases. Uphill movement phases retain the high power setting and as such exhibit a higher average tension than downhill movement periods, however the drum tension does not spike up above the base tension value of around 10 - 11T.

Below is an example of a graph showing both the movement and winch power setting overlays. A full set of graphs displaying both movement and winch power settings similar to *figure 13* can be found in *Appendix 11.1*.

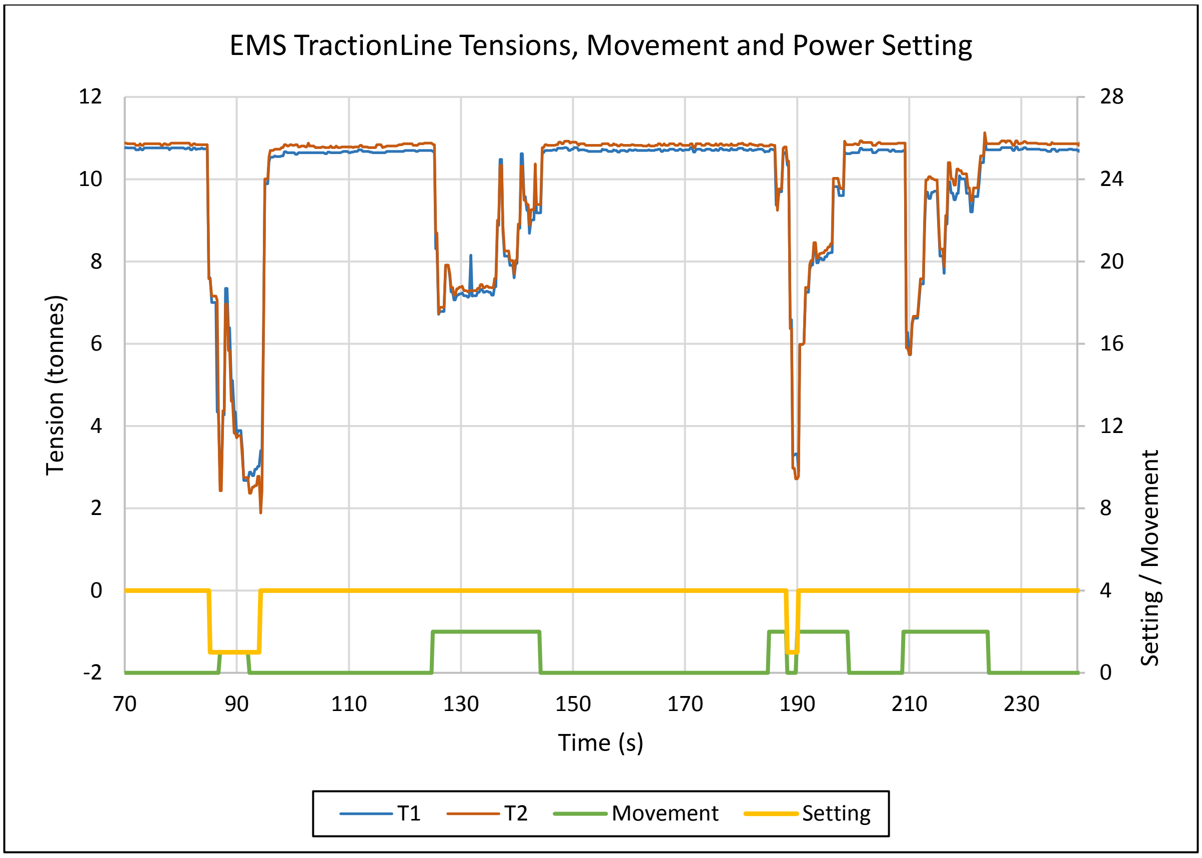

Figure 13: Tension data with power setting and movement data overlays

7.1.4 Key findings

The movement and winch power setting time series have shown a strong link with the tension behaviour of the TractionLine system operating in Washington. The operator also tends to use a standard protocol when setting the winch power:

- Setting 4 used during stationary work phases, i.e. felling and shovelling
- Setting 1 used during downhill movement
- Setting 4 used during uphill movement

The data sets relating to regular work phases were categorised to find the average cable tensions during typical movement intervals:

Movement Type	Usual Power Setting	T1 (Tonnes)	T2 (Tonnes)	T1 + T2 (Tonnes)
Stationary	4	9.63	9.83	19.46
Downhill	1	4.83	4.75	9.58
Uphill	4	8.38	8.54	16.92

Table 1: Summary of common work-phase tension averages

These tension averages are excluding the start-up phase data set in order to properly represent the higher working base tension averages.

7.2 DC Falcon Winch Assist Data

The Falcon Cable Assist system uses a load pin in one of the sheaves to measure the cable tension directly, as described in the method. Therefore the tension time series produced have high measurement frequencies which increases the precision of the data. It is also an accurate reflection of the real cable tension behaviour, as it is directly measured rather than being back-calculated.

7.2.1 Winch power calibration

A calibration data set was taken whereby the harvester operator gradually switched the power up through its eight settings while stationary, positioned part way down the slope with the rope wrapped around a rub tree. The tensions along with their respective settings annotated alongside are shown below:

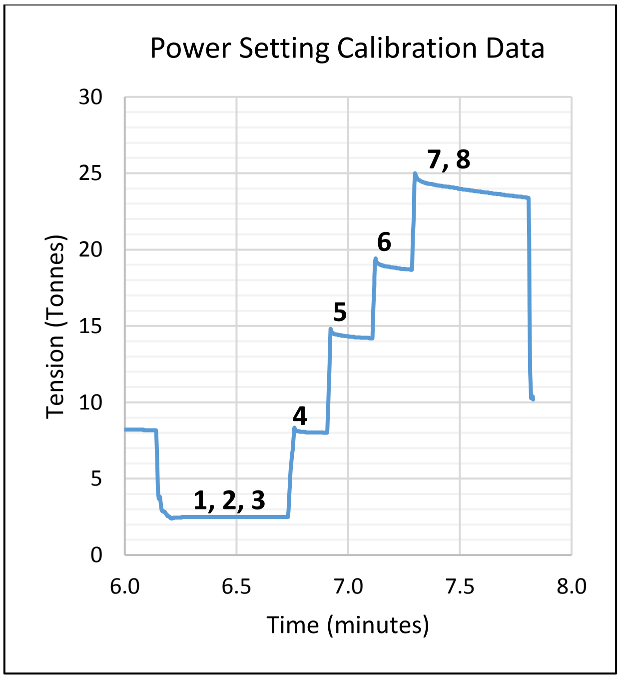

Figure 14: DC Falcon winch power setting calibration

Settings 1, 2 and 3 displayed the same tension levels, as did settings 7 and 8. Increments of around 5T were found between the other settings.

7.2.2 Working phases

During operation the machine activity intervals were logged by Hunter Harrill and have been transposed onto the corresponding tension time series. As with numerous previous data sets, fluctuating tensions correspond with periods of machine movement, with relatively constant tensions during felling/shovelling phases.

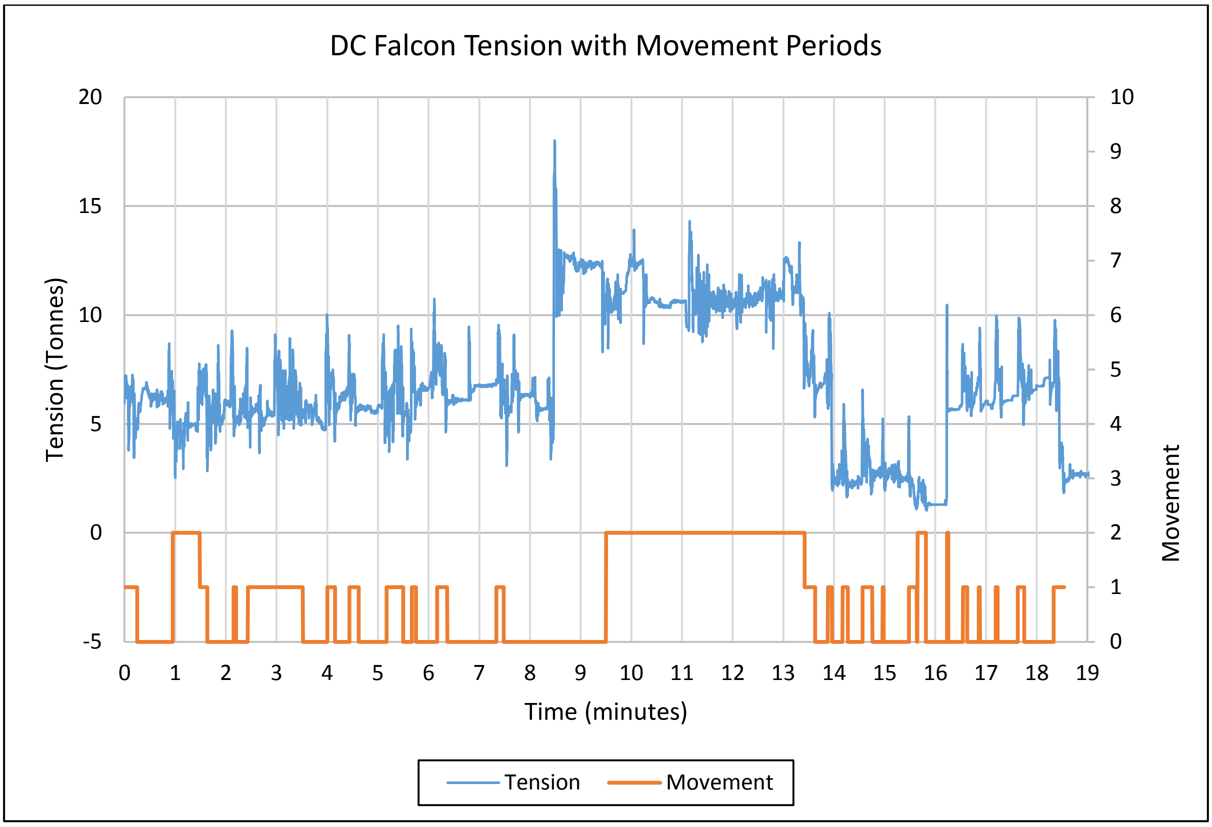

Figure 15: DC Falcon tension and movement time series - complete set 1

For this work period the operator said that he was using settings 3 and 4 on the way down the slope (0 – 8 minutes) and setting 5 on the way back uphill (9 – 14 minutes). The average tension levels throughout these phases align closely with the calibration data set.

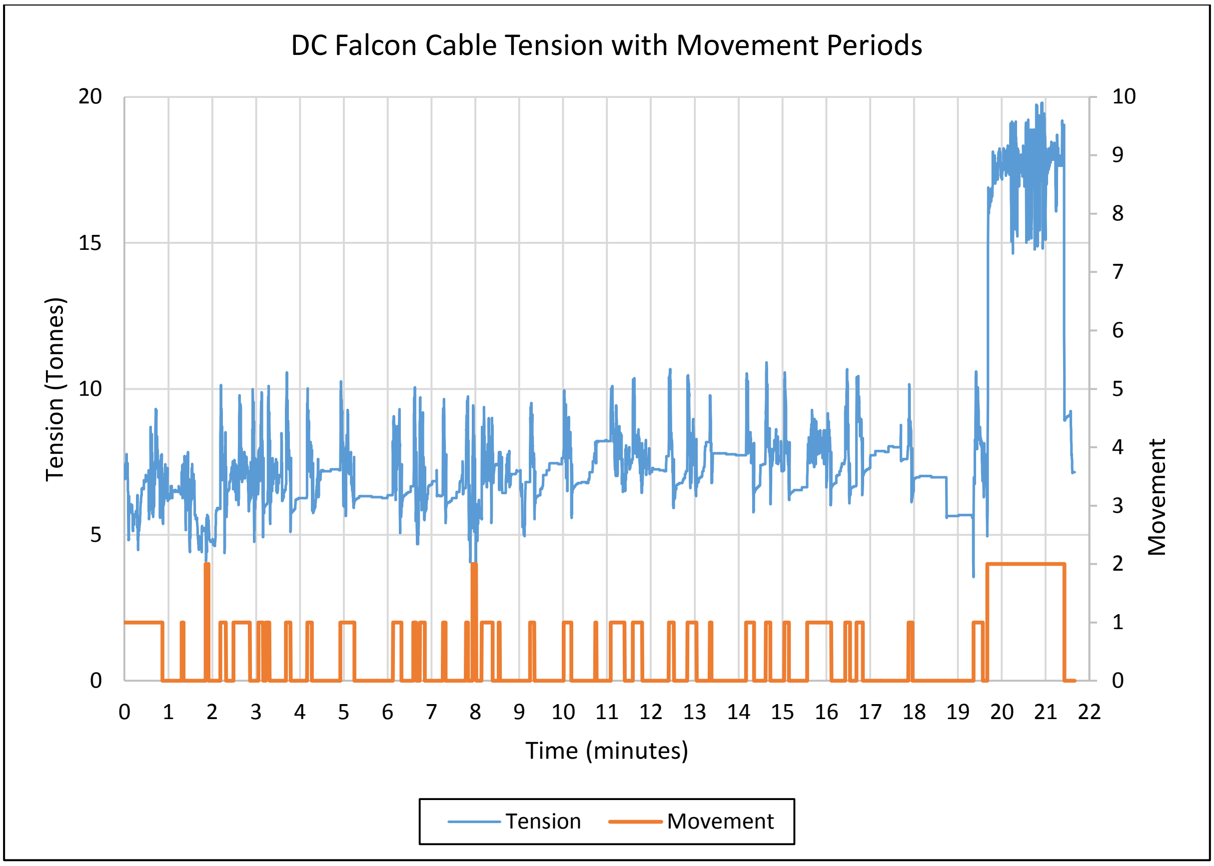

Figure 16: DC Falcon tension and movement time series - complete set 2

The operator stated that for this section he was walking the harvester downhill in setting 4 (0 – 19 minutes) and came back up using setting 5 and 6 (20 – 21 minutes). Once again, from visual inspection, the average tension levels displayed here align well with the calibration chart.

Some shorter examples of the tension plots are shown below in order to better display the peak behaviours and correlation with movement intervals:

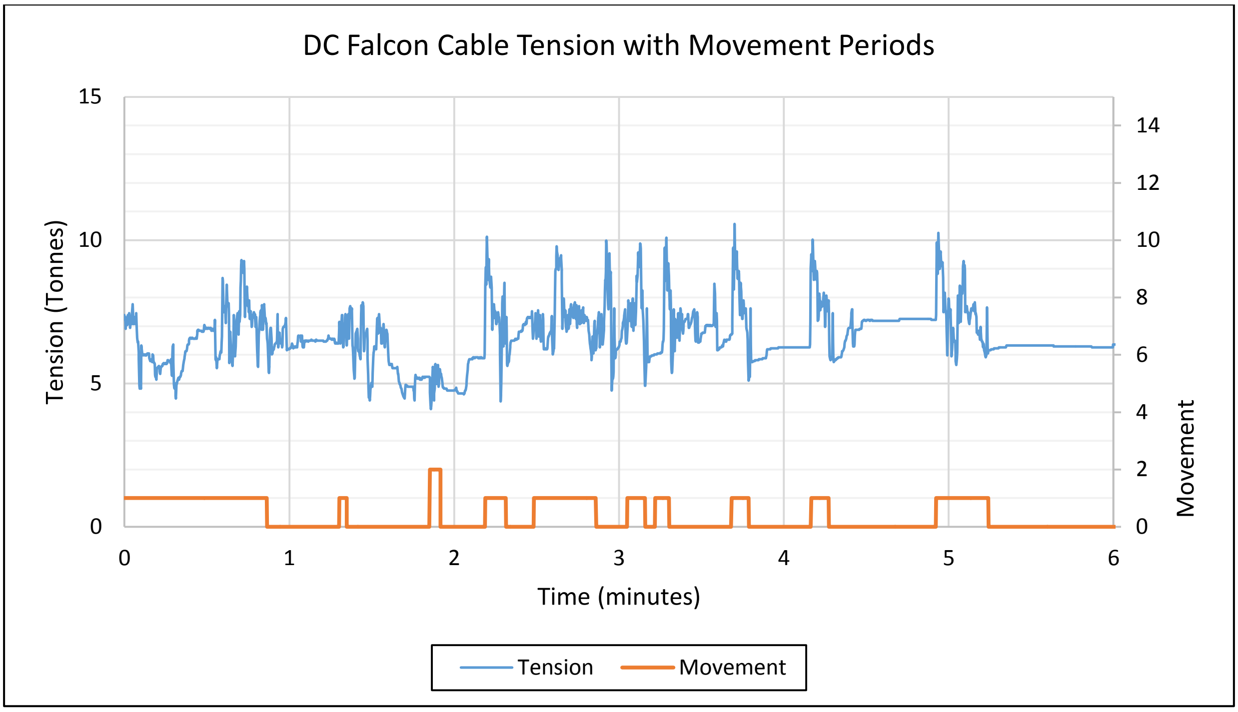

Figure 17: DC Falcon tensions and movement intervals #1

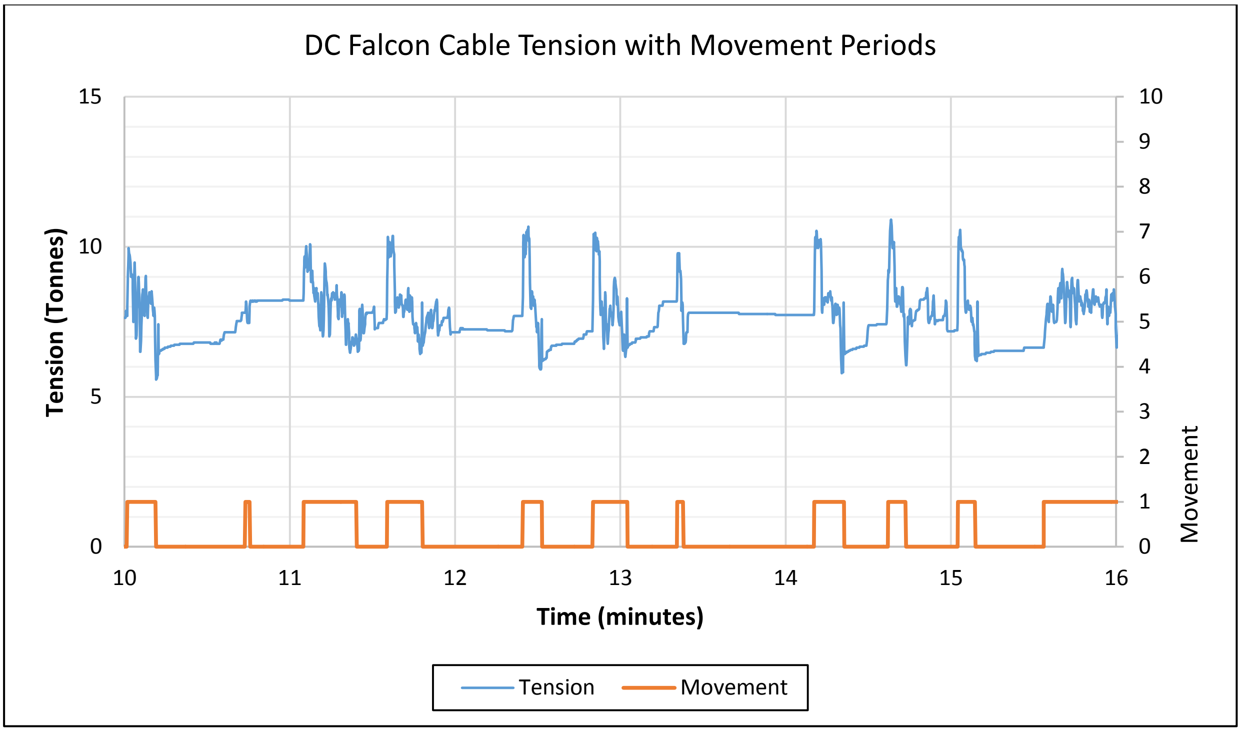

Figure 18: DC Falcon tensions and movement intervals #2

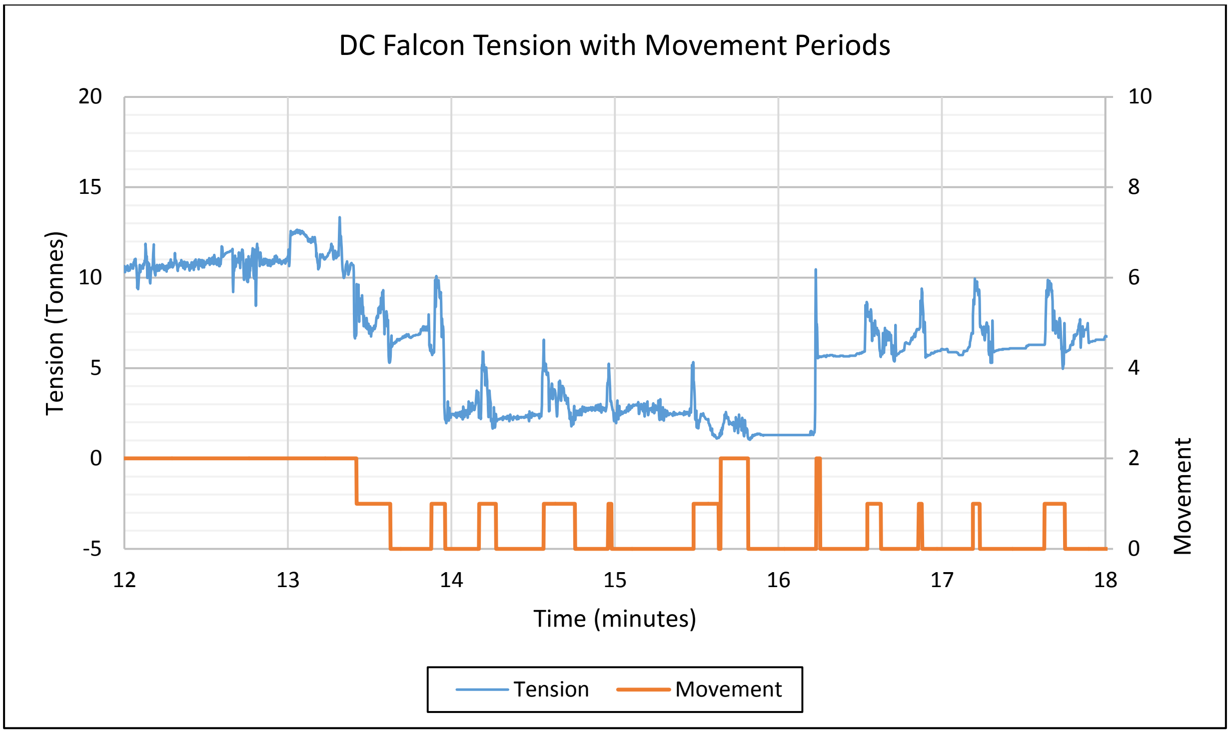

Figure 19: DC Falcon tensions and movement intervals #3

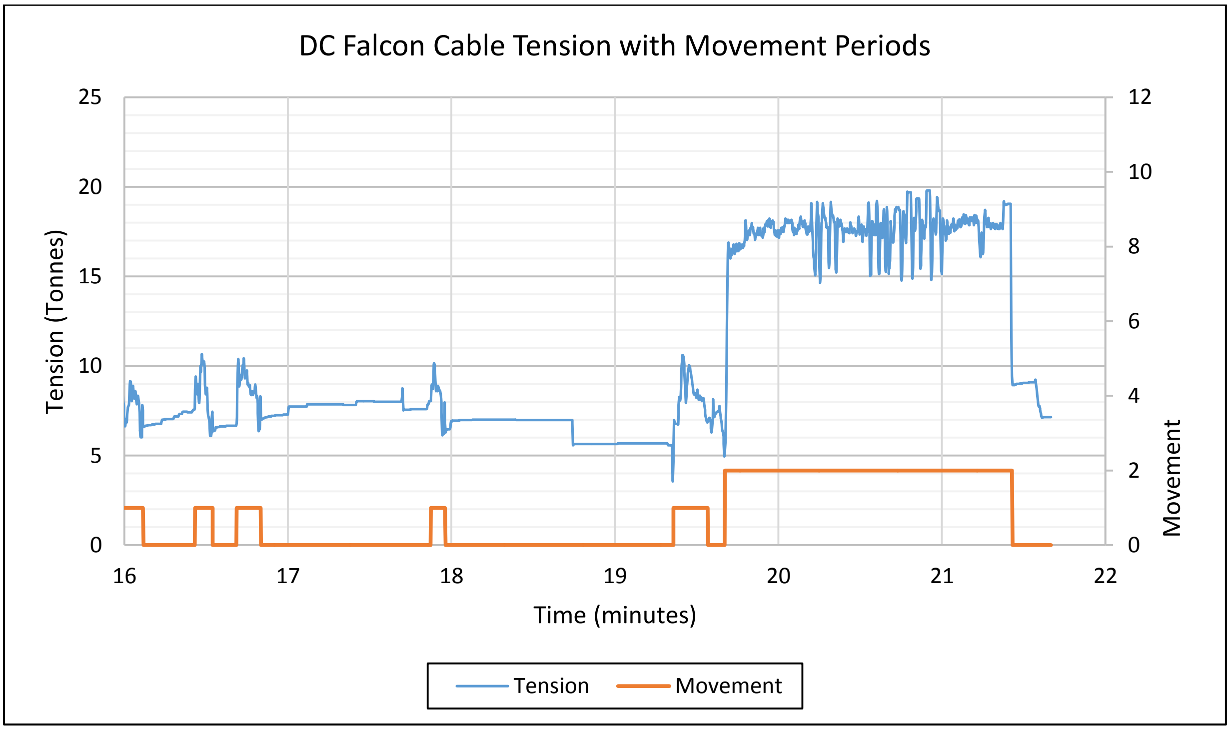

Figure 20: DC Falcon tensions and movement intervals #4

7.2.3 Key findings

Through visual inspection of the graphs, the maximum amount added to the base tension was around 4T. While tension spikes are certainly significant in assessing working demands, the winch power setting has a much greater effect on increasing the tension magnitude overall. The average tensions categorised by movement type are summarised in the table below:

Movement	Data Set 1		Data set 2	
	Tension (Tonnes)	Setting (Operator)	Tension (Tonnes)	Setting (Operator)
Stationary	6.17	3 and 4	6.86	4
Downhill	6.06	3 and 4	7.75	4
Uphill	9.86	5	16.64	5 and 6

Table 2: DC Falcon average tensions and power setting sorted by movement category

8. Discussion

8.1 EMS TractionLine System

An important consideration in assessing the tension data of the TractionLine system is that the values are back-calculated from the winch motor hydraulic fluid pressure. This measurement takes into account the amount of wire rope spooled onto the drum when considering the torque applied to the winch drum. Another easily calculated factor is the gearing ratio of the drum drive, however this introduces another degree of separation from the point of measurement, which will introduce an element of inaccuracy. Because of this indirect method of measurement, the tension values can only be taken as indicative, with no data to correlate the winch readings to real line tension. This consideration is particularly relevant in cable-assisted harvesting systems as the highest loadings are usually due to tension spike events (Schaare, 2015), which may not translate directly into winch drum torque due to a number of factors including: drum inertia, system response delays and localised stress concentrations at other locations - such as sheaves or rub trees - reducing winch loading.

In a discussion with Callum <lastname>, an EMS design engineer, it was confirmed that the on board software does in fact smooth the output tension values in order to make the outputs more meaningful for the harvester operators. This will slightly reduce the magnitude of sharp fluctuations over short durations. However Schaare (2015) found that for smoothing periods of less than 20% of the spike period the nature of the spike plot is mostly retained:

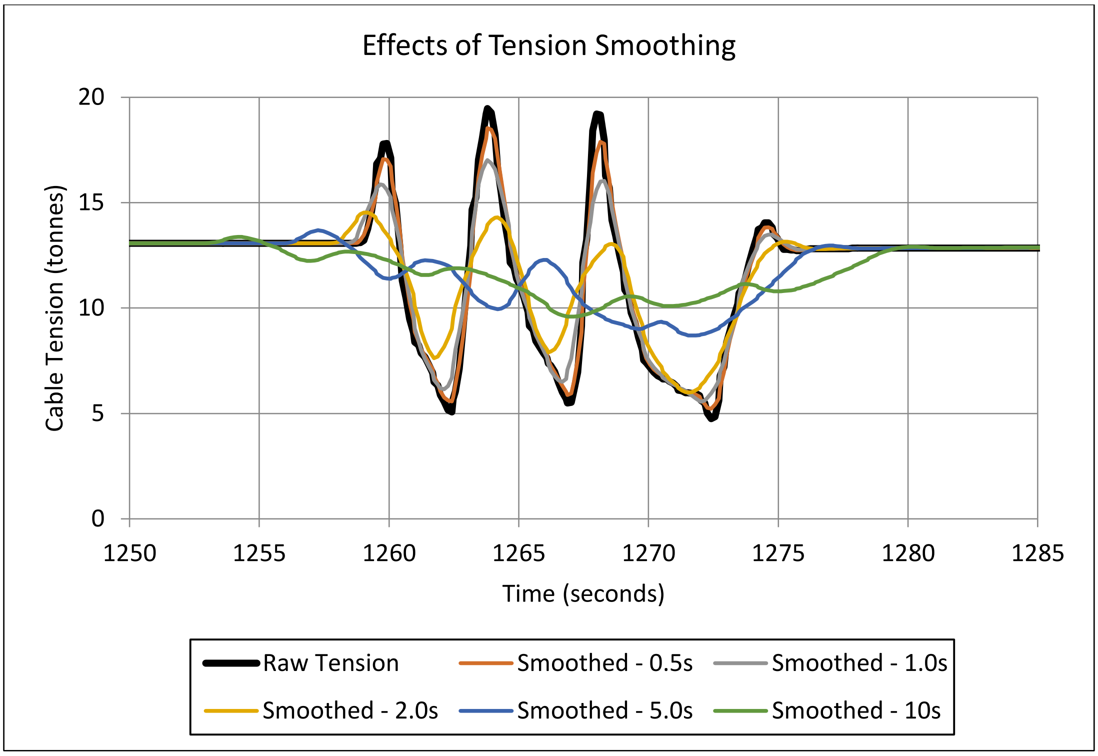

Figure 21: Schaare (2015) - effects of tension value smoothing on an arbitrary data set

In this example the tension oscillation has a period of roughly 5 seconds. The smoothing profile of 0.5 and 1 second intervals still retain most of the character of the tension profile, with longer smoothing intervals having a more pronounced effect.

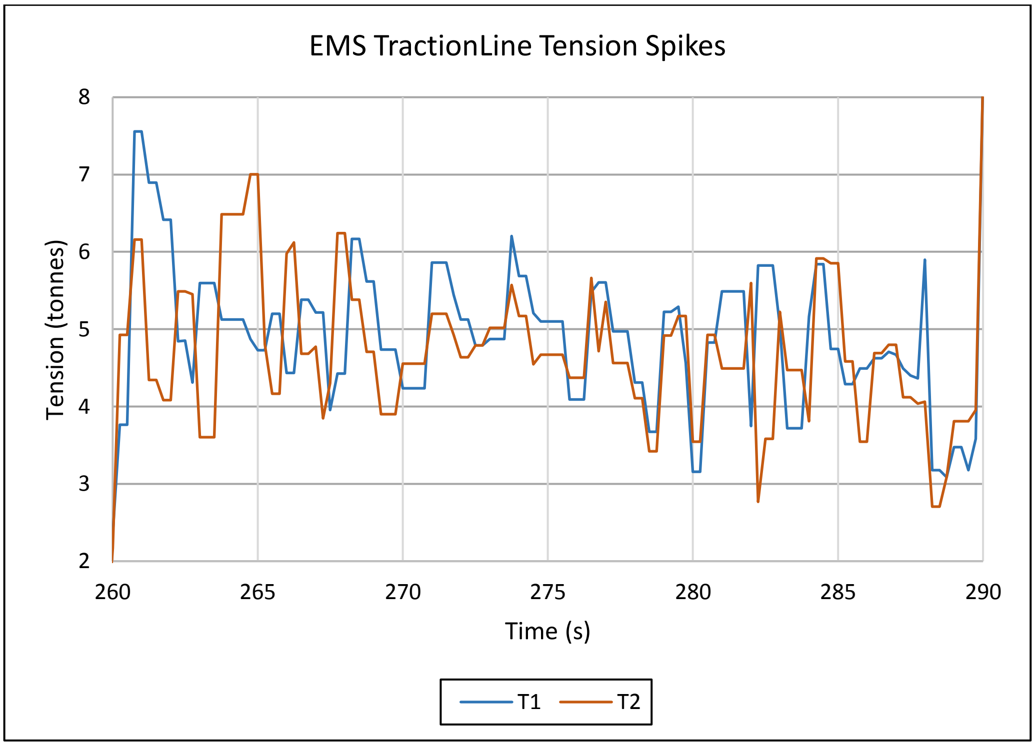

Figure 22: EMS TractionLine tension spike profiles

Figure 23 shows a tension profile during a period of downhill movement. There are distinct peaks in the values, indicating that the smoothing algorithm has not completely eliminated the tension fluctuations from the outputs, as we have seen happen at longer smoothing intervals in the previous example. As such, the tension values measured can be assumed to be relatively accurate indications of the forces applied to the winches.

The tensions measured during stationary work phases were relatively constant, with an average value of 9.73T, as seen in *table 1*. However the average tensions during movement periods were lower than this base value; 4.79T during downhill movement, and 8.46T during uphill movement. The harvester has an in-cab winch power setting dial, giving the operator manual control over the winch. As discussed in section *7.1.4 Key Findings*, the operator chose to use ‘setting 4’ for stationary and uphill movement phases, while they dropped into ‘setting 1’ for downhill movement phases. The difference in tensions resulting from the three predominant movement-setting combinations make logical sense; while the harvester is stationary the winch will be working at maximum capacity, when walking uphill it will reduce the load on the winch hence producing slightly reduced tensions despite being powered at the same setting, and during downhill movement the power is backed off which results in a lower average tension despite the winch working against the direction of movement. An important issue this raises is: when does the harvester require the most stabilisation? During movement periods inconsistent terrain can lead to the harvester rocking around on the slope, whereas while stationary the harvester tends to remain more stable, as seen in supplementary video footage of this system in operation provided by Dzhamal Amishev. Perhaps this is an indication that the stabilising tension provided to the harvester should in fact be highest during movement phases in order to reduce the risk of overturning.

The EMS TractionLine system displayed consistent tensions between the two cables, with a relatively steady difference of around 0.2T as seen in *table 1*. It has been argued that one cable should remain at a significantly lower tension due to the danger of both cables breaking in close succession if they are both loaded up close to their limits. It should be noted that this system’s maximum load applied by the winches was only 21% of the ultimate wire rope capacity, so catastrophic failure is extremely unlikely. Regardless of the specific loading figures that have been measured here, if the design of the dual-cable system is based on the premise of engineering redundancy, then there is little point in running both cables at the same high tension level. Leaving one cable at a lower tension would ensure that should the high tension cable break the other cable would have some capacity to take up the load. Since the time of recording this data, EMS have incorporated such a system into their designs.

8.2 DC Falcon Winch Assist System

A curious outcome of the calibration data set is that there was no discernible difference in the tension being applied at settings 1, 2 and 3; settings 7 and 8 were also found to be equal. Hunter Harrill postulated that this may have been partially due to the fact that during the test the harvester was halfway down the slope and the cable was wrapped around a rub-tree further up the hillside, which may have interfered with the tension graduations. However I believe this is unlikely to be the case, due to the sharp tension increments clearly present for the other settings.

In general the tension levels during working phases aligned closely with the calibrated tension level of the power setting indicated by the operator. Tension peaks during work phases typically add 3T to the base tension, which is largely dictated by the winch power setting. Peaks occurring during high tension ‘setting 6’ uphill movement phases tended to have a lower magnitude than those at lower base tensions, as well as showing stronger negative troughs immediately following peaks due to oscillating behaviour; the peaks typically added 2T to the base tension and the troughs subtracted 3T.

Although there were no instances of breaches of SWL during the working periods monitored here, the calibration data set indicates that the winches are capable of reaching the SWL of 1 1/8” swaged cable (23.7T). As mentioned previously, the calibration data was taken as a stationary test. As the working data shows, the tensions tend to spike during movement. If the system is capable of pulling up to SWL while stationary, then it will almost certainly peak up over SWL during movement while using this power setting. Hunter Harrill also noted that during his site visit he read the operator’s manual for the Falcon Winch Assist system, in which he found the predicted tensions for each of the winch power settings. The tensions measured in the field calibration were significantly higher than those put forward in the manual.

8.3 Comparison to previous studies

The data gathered from the Washington-based EMS system is significantly different to anything seen in previous studies (Schaare, 2015; Evanson, 2013). The differences include: tension data taken from hydraulic winch motors, tension drops during movement due to operator controls, and it is a dual-rope system. The tension data gathered from the majority of other systems indicates that the tensions tend to peak upwards during movement. Assuming that the drum tensions are an accurate reflection of the real rope tension, this EMS system has performed well in mitigating these tension spikes in comparison to other systems. However the question still remains about whether or not the level of tension application is appropriate for the work phase, as the line tensions drop during movement when instability is usually highest.

The Nelson-based DC Falcon Winch Assist system has behaved in a much more similar manner to results seen previously (Schaare, 2015). The tensions peaks from the DC system are fairly uniform at each power setting and add a maximum of 4T into the cable. The base tension levels are well regulated with effectively 5 power settings, making tension prediction fairly reliable. In previous studies, systems without regulated power settings have had the potential to pull well over the SWL, sometimes reaching the endurance limit of the ropes. The tension peaks of the non-regulated systems were also larger in magnitude, sometimes adding 10T to the rope tension (Schaare, 2015).

8.4 Recommendations

Both systems have displayed effective tension regulation systems which give the harvester operator precise control over the line tension provided by the winches. In comparison to systems without pre-programmed tension settings, both have shown more precise tension application, as well as reduced magnitudes of shock loads caused by movement.

Pre-programmed tension settings provide clear benefits in precision of control, however it is important to consider dynamic loading and field effects in the calibration of these systems. I suggest that it would be appropriate to incorporate a factor of safety against shock loading and field effects, such as using rub trees, in programming the winch power settings. This would be a force reduction factor which would be applied to static tension test results to determine the maximum tension to be applied by the winch. By way of example, the Nelson DC Falcon system the calibration data set shows a maximum static tension of close to 25T, a conservative estimate of the maximum tension spike magnitude is 5T, and the SWL of the rope is 23.7T (assuming 1 1/8” 6x25 IWRC swaged rope). The following procedure can be used to find an appropriate reduction factor:

$$F = \frac{SWL - peak}{max}$$

$$F = \frac{23.7 - 5.0}{25.0}$$

$$F = 0.748$$

Note that the peak magnitude must first be measured for the system, as well as the static maximum tension calibration value. This factor should then be applied to the maximum tension value, and any other lower tension increments:

$$T = 0.748 \times 25.0$$

$T = 18.7$ Tonnes maximum applied load

This maximum applied load can then be re-programmed into the winch as the max setting to avoid overloading. Lower power settings can also be adjusted by the same factor.

9. Conclusion

The EMS TractionLine system working out of Washington holds steady tension at around 10T during stationary periods, 5T during downhill movement, and 9T during uphill movement. The average tension values are closely related to the operator-selected winch power setting, which is dependent on the harvester's direction of travel. The indicated cable tensions never peaked up past the base level of stationary phases, which are held constant at roughly 70% of the SWL of the cables.

The DC Forestry Equipment Falcon Winch Assist system working in Nelson effectively has 5 winch power settings which step the tension up from 3T at the lowest setting, up to 24T at its highest. The highest setting reaches the SWL of the cable during static calibration tests; with harvester-movement-induced tension peaks the SWL will almost certainly be broken when running its highest power setting. Tension peaks during movement tend to be of a predictable size of around 4T.

Both systems show a high degree of control over the cable tension, with peaks being relatively small and the average tensions correlating closely with pre-programmed winch power settings. This is in stark contrast to non-regulated systems involved in previous studies which have displayed extreme tension peaks during movement, with few adjustments being made during different work / movement phases.

In order to ensure that the calibrated power settings on the winch unit do not exceed the tension limits of the cable during movement phases, I suggest that a tension reduction factor be incorporated based on: the maximum setting's stationary tension, an operational tension peak magnitude, and the safe working load of the rope(s) used.

10. References

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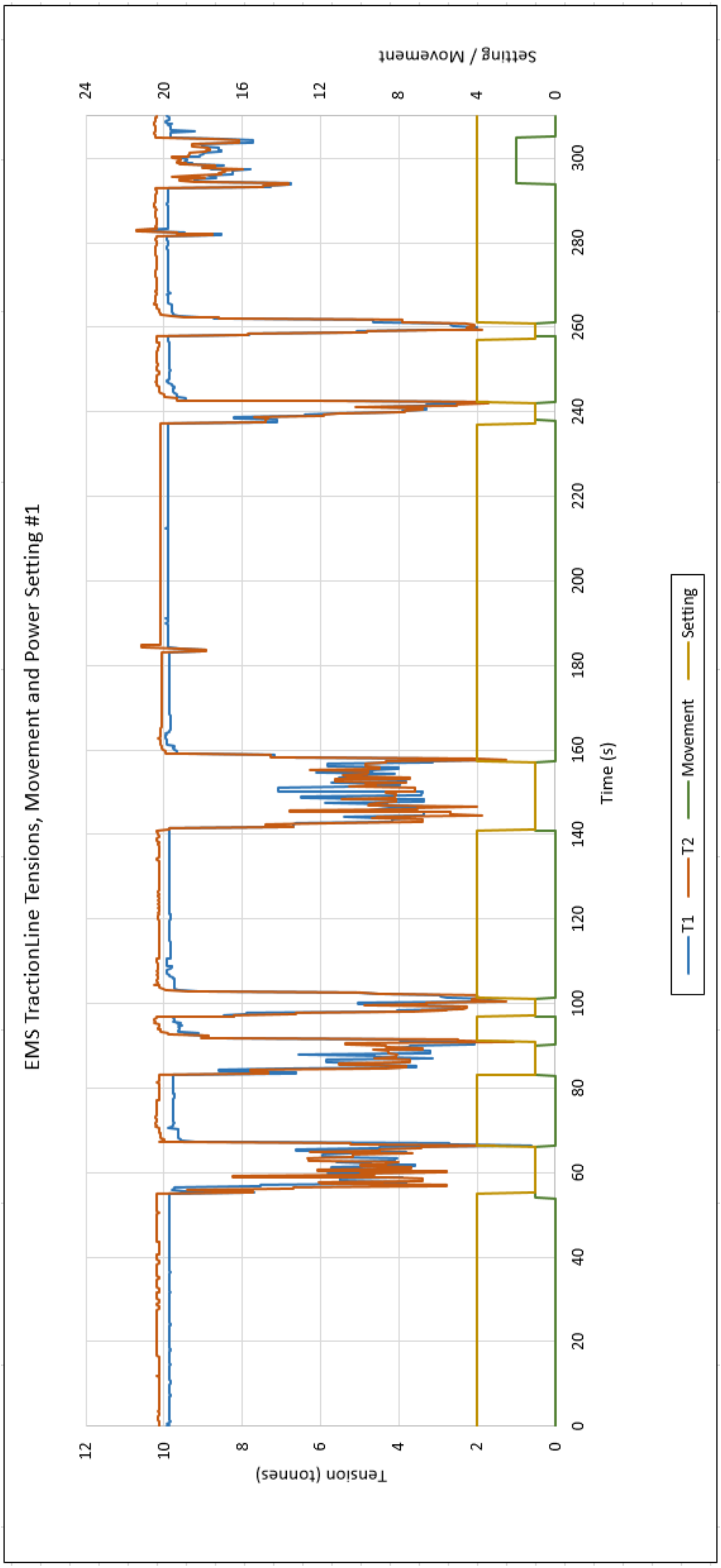
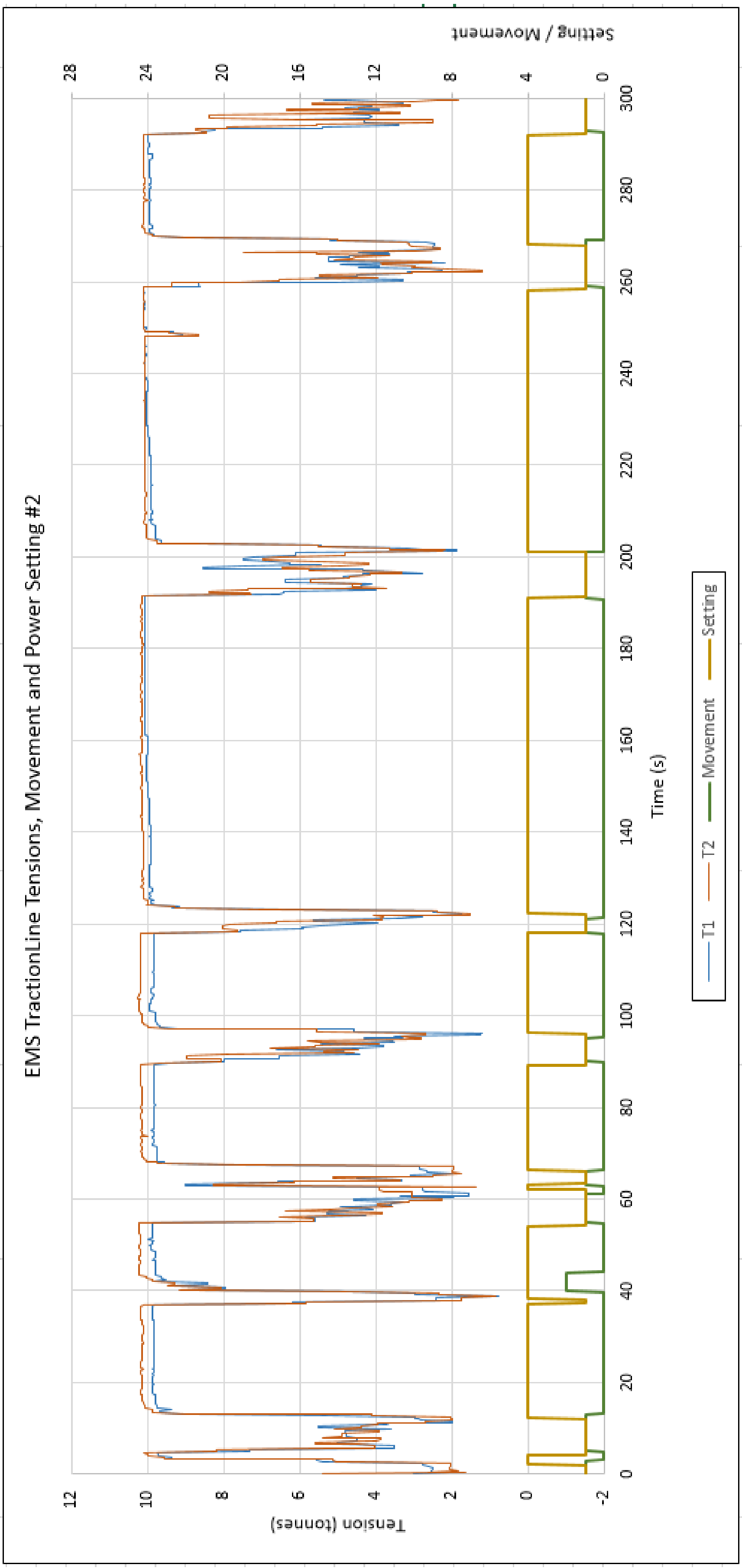
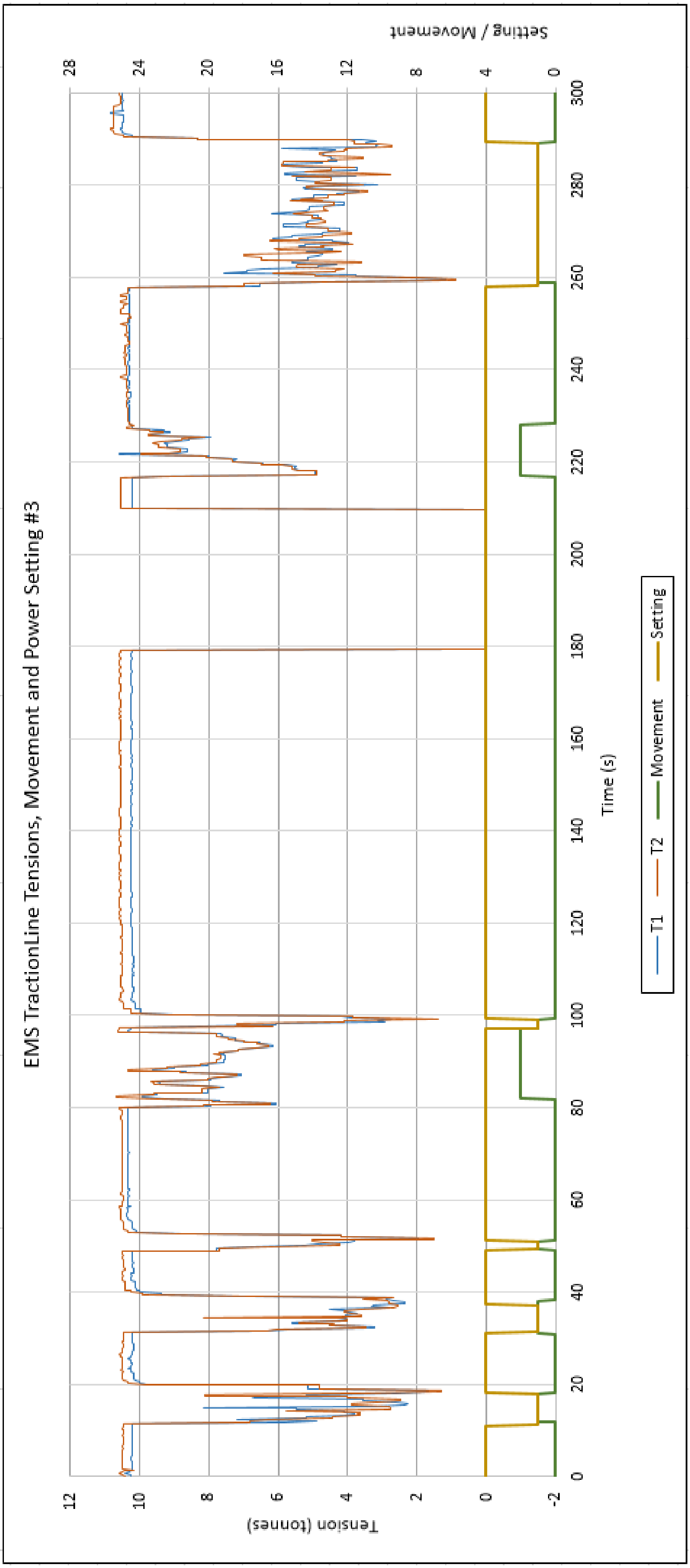
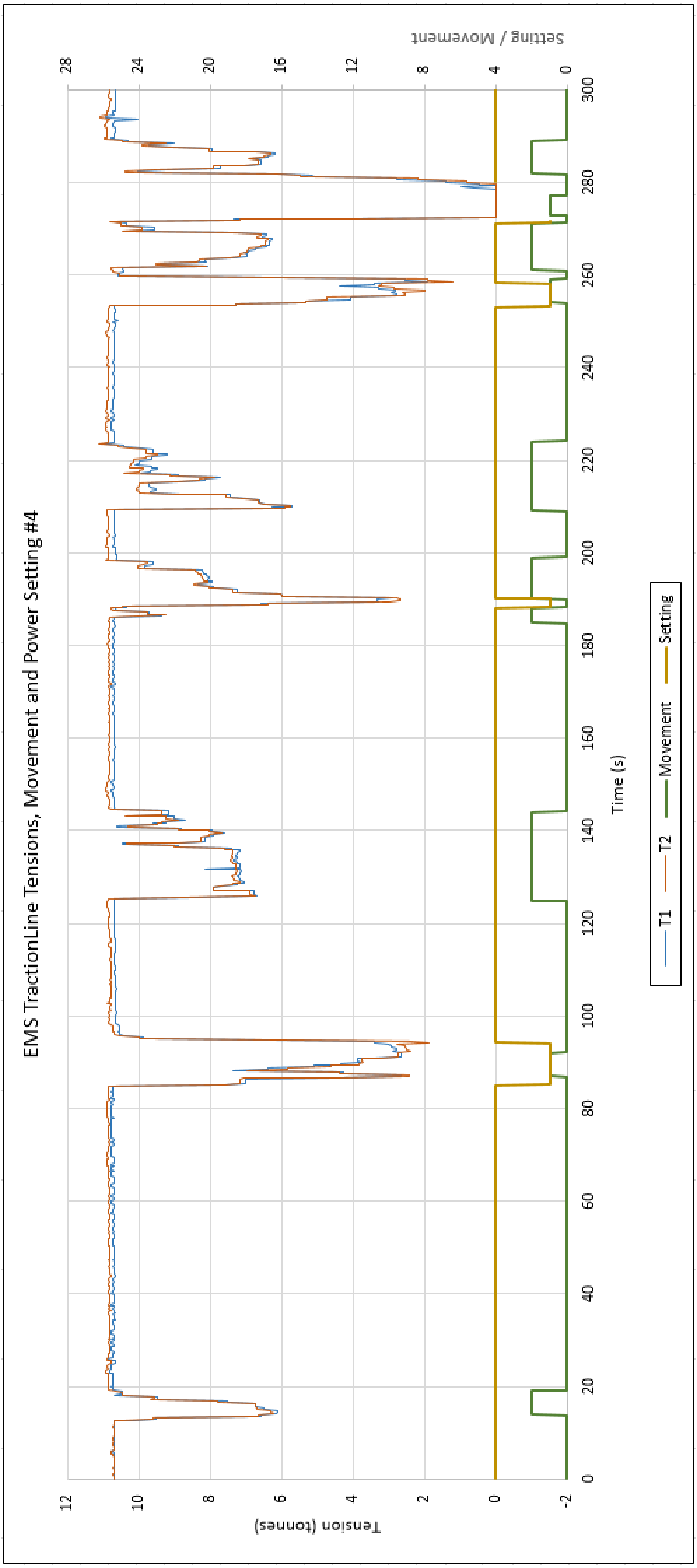
11. Appendix

11.1 EMS TractionLine movement and power setting plots

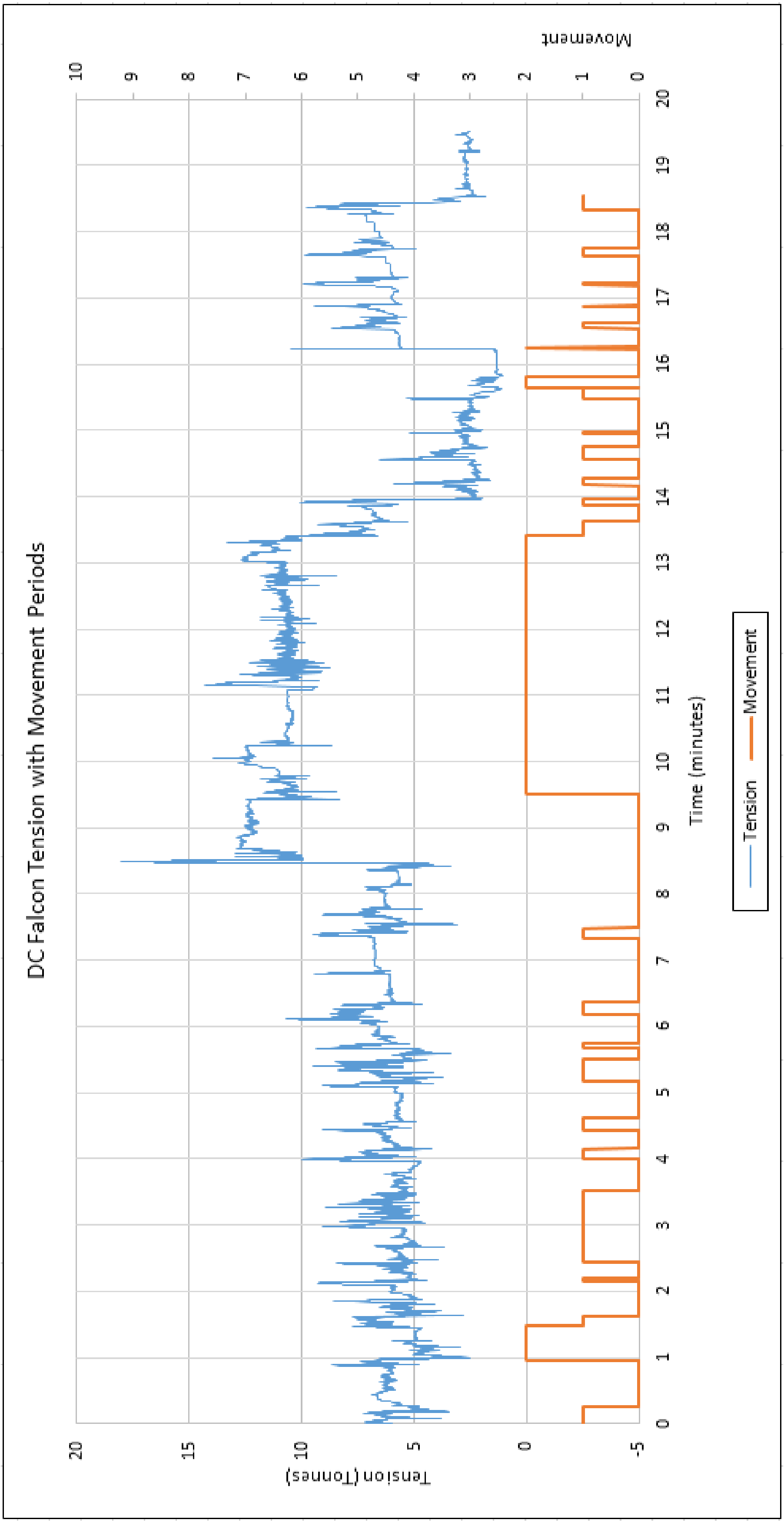


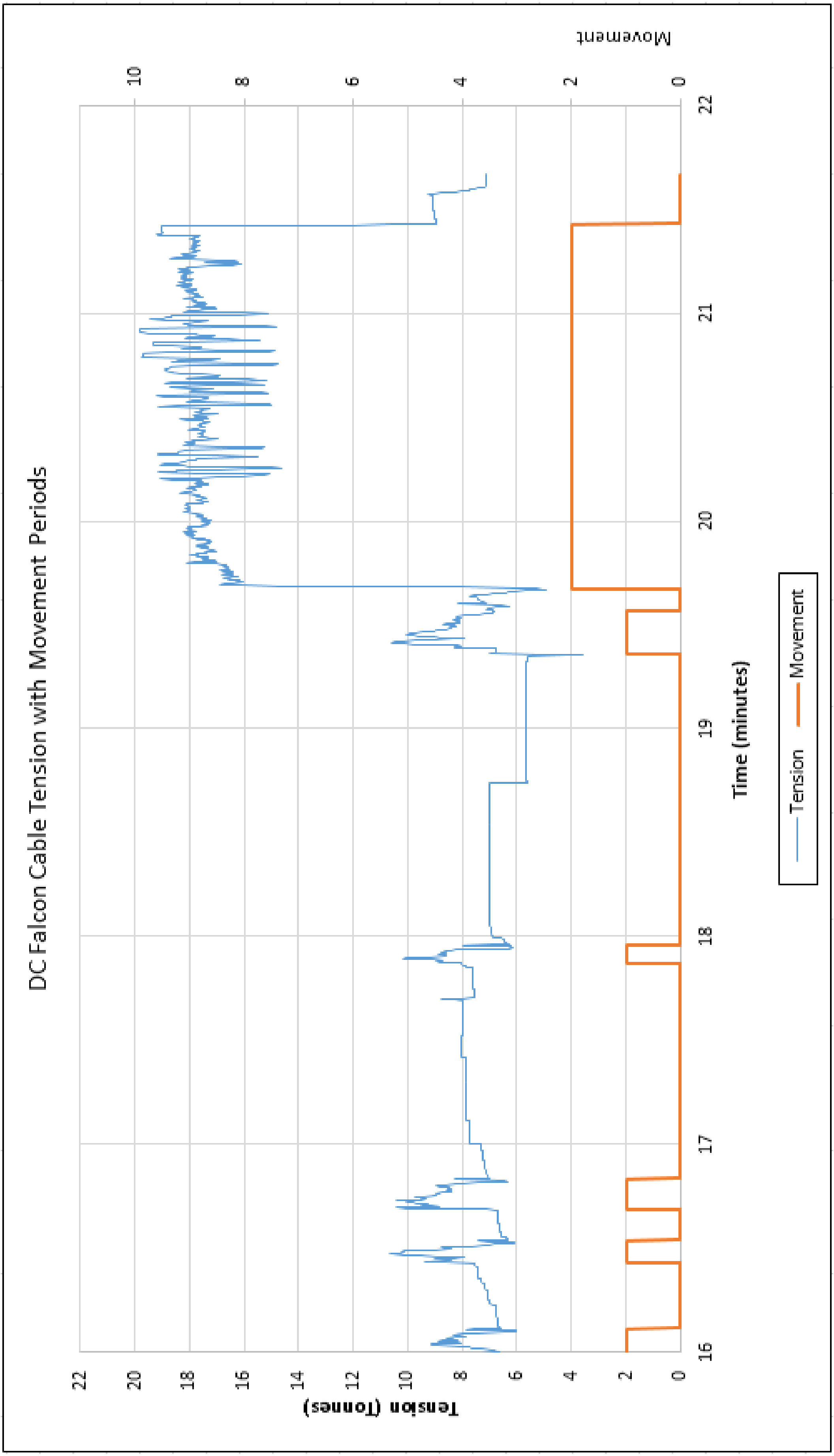

EMS TractionLine Tensions, Movement and Power Setting #2
Tension (tonnes)
Setting / Movement
Time (s)
T1
T2
Movement
Setting

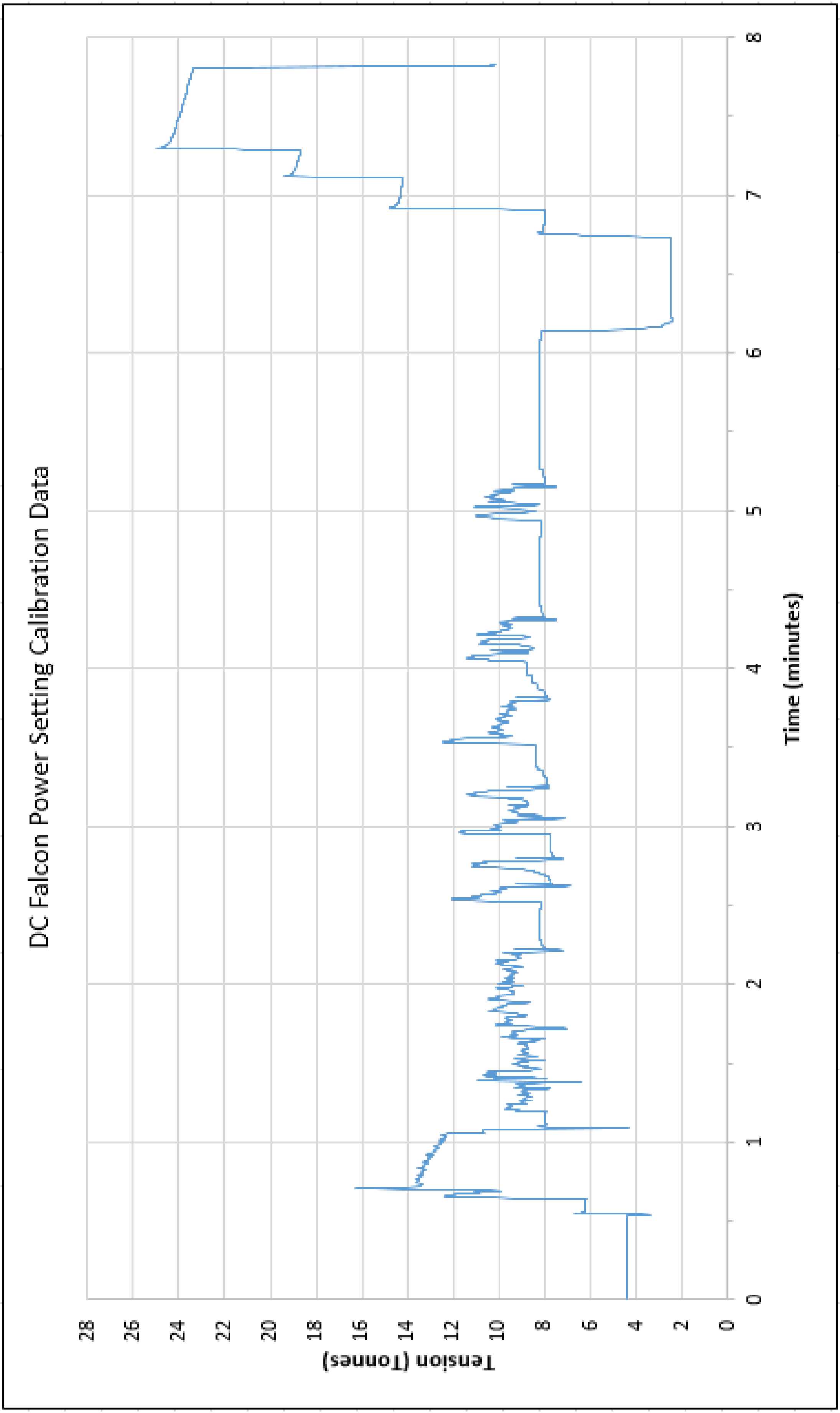

EMS TractionLine Tensions, Movement and Power Setting #3
Tension (tonnes)
Setting / Movement
Time (s)
T1
T2
Movement
Setting


EMS TractionLine Tensions, Movement and Power Setting #4
Tension (tonnes)
Setting / Movement
Time (s)
T1
T2
Movement
Setting

11.2 DC Falcon Winch Assist system data series

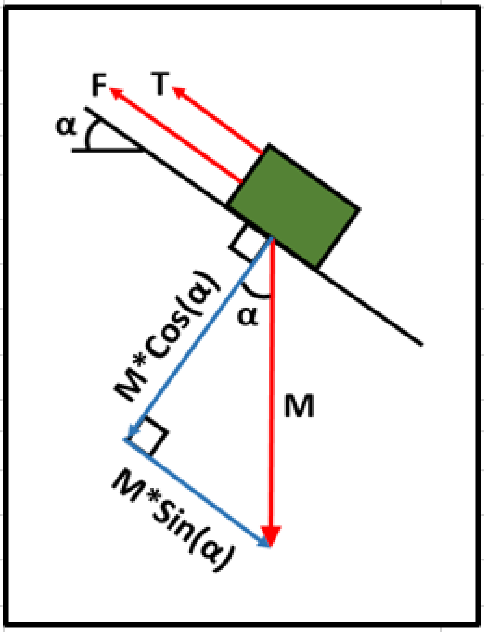



DC Falcon Cable Tension with Movement Periods
Tension (Tonnes)
0
2
4
6
8
10
12
14
16
18
20
22
Movement
0
2
4
6
8
10
Time (minutes)
16
17
18
19
20
21
22
Tension
Movement


DC Falcon Power Setting Calibration Data
Tension (Tonnes)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
Time (minutes)
0
1
2
3
4
5
6
7
8

11.3 Slope calculation spreadsheet

11.3.1 Assumptions and equations used



$$F = E_t\ M\ Cos(\alpha)$$

- F = friction force uphill
- E_t = traction efficiency
- M = machine mass
- α = slope angle

$$F_T = F + T - W - M\ Sin(\alpha)$$

- F_T = sum of all forces
- F = friction force uphill
- T = cable assist tension
- W = piece size / working loads
- M = machine mass
- α = slope angle

Common Cable Capacities (Tonnes) - Shaw's (2016)				
Rope Size and Construction	**Ultimate Capacity**	**SWL**	**80% SWL**	**2 x 80% SWL**
1 1/8" (28.6mm) 6x25 IWRC swaged	71.2	23.7	19.0	
7/8" (22.2mm) 6x25 IWRC swaged	43.3	14.4	11.5	23.1
1 1/8" 6x25 IWRC power swaged	84.7	28.2	22.6	
7/8" 6x25 IWRC power swaged	51.4	17.1	13.7	27.4

11.3.2 EMS stationary tension average input

Enter the input information then press CTRL+A to calculate the maximum allowable slope

INPUTS			FACTORS	
Machine Weight	40	T		
Traction Efficiency	50	%		
Cable Assist Tension	19.5	T		
Working Force	2	T		

OUTPUTS			FACTORS	
Net Force	0.0	T	M*Sin(α)	30.4
MAX slope - degrees	50	°	M*Cos(α)	26.0
MAX slope - percent	117	%	Radians	0.0175

Created by Russell Schaare, 2016

11.3.3 EMS downhill tension average input

Enter the input information then press CTRL+A to calculate the maximum allowable slope

INPUTS			FACTORS	
Machine Weight	40	T		
Traction Efficiency	50	%		
Cable Assist Tension	9.58	T		
Working Force	2	T		

OUTPUTS			FACTORS	
Net Force	0.0	T	M*Sin(α)	23.7
MAX slope - degrees	36	°	M*Cos(α)	32.2
MAX slope - percent	74	%	Radians	0.0175

Created by Russell Schaare, 2016

11.3.4 EMS uphill tension average input

Enter the input information then press CTRL+A
to calculate the maximum allowable slope

INPUTS

Machine Weight	40	T
Traction Efficiency	50	%
Cable Assist Tension	16.9	T
Working Force	2	T

OUTPUTS

Net Force	0.0	T
MAX slope - degrees	46	°
MAX slope - percent	104	%

FACTORS

M*Sin(α)	28.8
M*Cos(α)	27.8
Radians	0.0175

Created by Russell Schaare, 2016