MAXIMISING INCIDENT LEARNING OPPORTUNITIES

Felling Machine Rollover 2017
New Zealand

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1.0 PROJECT BACKGROUND

Simple cause and effect incident analyses do not address, understand or explain the dynamic interactions that persist in the complex systems our industry faces each day. An incident investigation intends to prevent reoccurrence and to protect our people from further injury. To effectively prevent future adverse events, we have to be able to learn from the context of each incident.

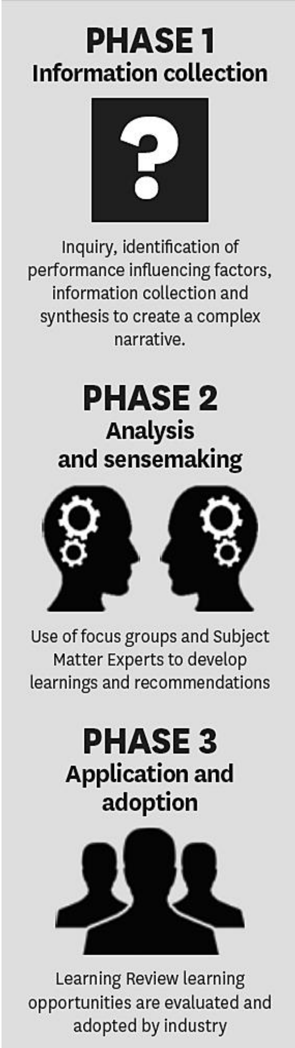
During 2016, FISC commissioned Scion to undertake a Pilot Project to demonstrate the applicability and practicality of a new approach to adverse event investigation in New Zealand forestry incidents. The Learning Review is a comprehensive, applicable methodology based on dynamic inquiry rather than categorical assessment. Phase II of the work began in January 2017 and includes the completion of five case study Learning Reviews of recent incidents in the forest industry, as well as building capacity within the industry to undertake the approach.

Error and uncertainty are unavoidable in the highly complex and dynamic environment in which the forest industry operates. Thus we must assume incidents will happen and direct our resources towards reducing the magnitude of adverse events. The Learning Review has been designed to maximise incident learning opportunities. We can use the process to learn ways to lessen the prevalence of contextual pressures, to allow error to exist without consequence, and to recover and adapt when the unexpected is bound to occur.

Maximising Incident Learning Opportunities Incident 3
Felling Machine Roll0ver 2017

During the selection process, a series of machine roll-over incidents were identified within a 12-month period. From the trend/series, one incident that encapsulated several common influencing conitions (maintenance, ground conditions and work pressures) was selected to extract potential insights and crucial learnings for the ultimate goal of prevention. The catalysing incident for the Learning Review occurred at the end of February 2017. It was determined that the incident aligned with the defined Selection Criteria, specifically:

i. The incident occurred well within the previous 12-month time period.
ii. The incident fits all ‘Access’, ‘Information’, ‘Severity’, ‘Geographic Range’, ‘Operational Scope’ requirements in terms of learning value capacity, legal risk issues and uniqueness.
iii. The incident is relevant to the FISC Critical Risk Area of Mechanised Harvesting.



2.0

Perspectives

This crew consists of family members, describing their working relationship as very productive and successful with 15 years working together.

This incident occurred on a remote site in the South Island. This ground based crew consists of 3 machines - a felling machine, Waratah processing head excavator and a skid digger. The machine involved in the incident was five years old (owned from new) 32t ZX290 digger with a specialised directional felling head. The Felling Machine Operator (FO) had 15 years of harvesting experience and five years of mechanised harvesting experience using this machine. The terrain was rolling hills with variable significantly soft soil. The harvesting was being conducted working across the terraced slope on an old working road which had dense sub canopy vegetation cover (e.g. Pungas and native scrubs). Moving out from the steep hill side and the old working road, the bottom terrace consisted of flat ground where poorly drained water pooled. The block being harvested comprised of large trees in their early 30's. On average, the piece size for the block was 3.14 tonne.

Figure 1. Incident site
Picture: (Left) Old working road looking towards the incident site. (Right) looking towards incident site against the slope, red line indicates old working road; all pictures are post-harvest, taken four months following the incident.

In the previous week, a few days prior to the incident, the felling machine became non-operational due to the pin that attaches the modified arm to the felling head breaking. The felling head was removed and taken for repairs 30 minutes away. This left the crew without the felling machine until the following week and the FO working in the skid digger until its repair.

The FO remembers the day as "a bad day".

It was really dark while re-installing the felling head. The coloured markings are very obvious in the daylight.

The incident occurred on a Tuesday in late summer. The weather was calm and clear. The crew travelled individually to site with the FO arriving first. The FO left home to arrive on site at approximately 4:45am, living not very far away. Upon arrival, he jumped into the skid digger to load log trucks. The other two crew members arrived on site soon after with a trailer carrying the repaired felling head. The toolbox meeting was conducted at 5:15am. Following the meeting, the FO moved to the felling machine to reattach the felling head. This process took a couple of hours and was conducted in limited early morning light. During this process, unnoticed by the FO, a hose was installed incorrectly. The hose has coloured markings that matched correct connection ports, and upon reinstallation the hose was fitted inverted.

To fix the centre joint was a quick half an hour job, just changing all fittings and the bottom cap.

Easier to get the part out, opposed to putting it in

The FO manoeuvred the machine in to the stand and started felling around 8:00am. By 9:00am the machine had stopped functioning. Work ceased for the felling machine to investigate the issue. By 9:30am the issue is found to be a blown centre joint in the felling head as a result of the incorrect fitting of the hose earlier that morning. The FO leaves for town between 10:00 am and 10:30am to retrieve a replacement centre joint. Between 12:30pm - 1:30pm the FO was back on site to fit the centre joint into the felling machine. This procedure took approximately one and a half hours to replace the part and return the machine to working order.

I wanted to get wood on the ground to keep everything going for the next day. He stayed to release pressure for the next morning.

FO considered the flat terrace at the bottom near the road as too wet and had too much debris. FO felt like it was safer to work along the old working road than to work up and down the slope.

FO didn't notice or feel that one of the tracks had sunk in. One side of the working road (the downhill side) was slipping away. "It feels different in the machine to what it looks like on the outside".FO had a gut feeling that "it's on its way over", "started to rear up".

The FO said "It happens quick but in slow motion too. The movement to 10 o'clock created the roll over momentum.

The FO believed that the track sinking and the road giving way was the reason why the machine became destabilised. The movement to 10 o'clock create the roll over momentum.

The FO jumped back into the felling machine at 3:30pm with the intention of working late as he would usually leave at 4:00pm on a normal day. By this time, the Waratah operator had completed processing and stacking all wood available. Having finished all they could do on site, the other two members finished for the day leaving the FO working alone.

The FO was working on an old working road moving across the slope following the road. By 4:30pm, approximately 20 trees were felled and shovelled downhill towards the road. Moving towards the two remaining trees in the block which were standing in front of a depression in the slope.

With his tracks facing straight ahead (12 o'clock) along the road, the FO proceeded to reach for a tree to his left (10 o'clock). The FO fells the tree and shovels it downhill towards the road (9 o'clock).

The FO then slews to his right (2 o'clock) to drop the final tree in the block. As he reaches for the final tree, the FO felt an instability within the machine. The machine track closest to the hill side was more stable and secure, the other side less so possibly due to the removal of vegetation (Pungas) on the road side for safe slewing. Immediately he tries to correct this imbalance by moving back to facing straight ahead (10 o'clock - as per FO recollection), in an attempt to balance the weight out. The machine continued to roll-over.

The FO managed to turn the machine off during the rolling action, saving it from further damage. The FO could see what he thought caused the rollover upon exiting the machine. Felling the previous tree caused a weight change which destabilised the road causing the road side track to sink. The felling machine track was floating when the FO slewed to cut the remaining tree. The Track would have sunk by only two - three inches until the FO slewed to grab the next tree which the track then dropped one metre. The felling machine was out of commission for a week sustaining damage in the few thousands of dollars. The FO required no medical assistance.

Figure 2. Incident site

Picture: Old working road looking towards the incident site overlaid with a clock depiction. Red squares with stumps indicate the two remaining trees and the red line in the background indicates the slope depression.

3.0 ANALYSIS AND SENSEMAKING

Sensemaking focus groups were conducted to map/understand the connections between pieces of information gathered in Phase 1 Data Collection and Synthesis. Collectively, the focus group members have 81 years of experience between them. The following analysis will illustrate the conditions identified during the focus group dialogues that may have influenced the mechanical felling machine and associated work practices. Meaningful recommendations are generated predicated on the multifaceted consideration of those conditions.

From a human factors perspective, workload optimisation is essential for safe and efficient task performance. It is a balancing act between stress or pressure and work demands. Elevated pressure levels can improve performance but only up to a certain point. Beyond that point, performance/production decreases and error likelihood increases.

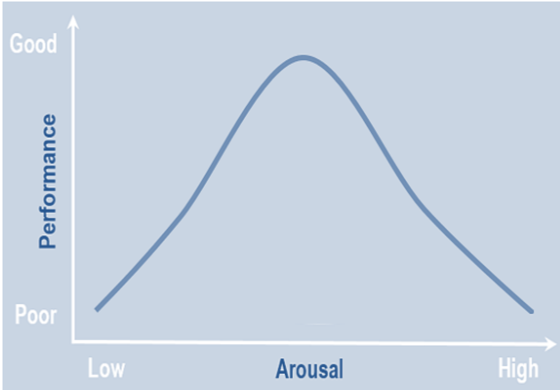


Figure 3. The curvilinear relationship between arousal (pressure) and performance (Yerkes & Dodson, 1908).

As described, the incident crew was highly productive. However, the crew faced a unique set of challenges and pressures internally. The crew in question comprises of a small number of members (3), and they are all direct family members. Not an uncommon situation in forestry but it does create additional pressure to perform, setting higher targets and expectations which can affect actions and decisions made during normal operations and under stress.

On a standard day, the FO positions the machine for harvesting, selects and reaches for the tree, cuts and shovels or moves it to the side to a chosen location. This tree is moved again to the processing area and processed (delimbed and cut to length) and put into log piles to be sorted by the skid digger and loaded on to trucks. The primary goal of the FO is to get wood cut and delivered to the processing machine. A delivery line such as this can easily be derailed if issues occur- like one component in the line being non-operational, which is what happened in this incident. Mechanical harvesting is described as 'joystick-intense', mentally demanding work in which visual information and supervision of the machine are crucial for safety and efficiency. The FO's tasks include, controlling the machine, boom and arm, ensuring proper positioning and movement of the felling head, evaluating ground conditions, determining tree selection and quality, assessing issues (such as hang-ups), and awareness of maintenance needs. Environmental conditions define and limit a machines boundaries within a stand. Moreover, difficult terrain, slippery ground and steep slopes hinder work. The forest setting creates variability and requirements from the operator to adapt, in some cases suddenly, like in the reviewed incident.

A common thread mentioned throughout the focus groups was the variability of soil characteristics present across different regions of New Zealand. All experts agreed that each region of NZ has its own set of challenges. Several areas in New Zealand (including the incident site) are known for their 'treacherous logging' and 'hard to work on' ground. Other factors such as machine size, log grades, log sizes, and mechanised processing can also influence felling and processing time. Given the harvested block comprised of large mid 30s trees with a 3.14t average piece size, the extraction process was slow-paced for both the FO and the processing machine operator. Focus group members agreed that harvesting large piece sizes can create delays. A focus group member currently working in the incident region provided vital insights on the swampy conditions and more clarity of the influence this aspect had on the incident day, the ground can be unpredictable and slippery.

Realistically, all mobile machinery is at risk of rolling over. These particular harvesting machines are fitted with guarding and a frame around the operator's workspace, which can alter the centre of gravity and tipping point, creating instability and the possibility of rollover. The tipping point is the angle at which a line straight down from the centre of gravity (where the weight is concentrated) falls outside the felling machine's tracks (or the space between the outside of one track and the outside of the opposite track). The machine tips over at this point because there's nothing beyond the lower track to keep it from rolling. Operating these machines is trickier on sites with variable terrain and therefore requires a considerable amount of assessing and decision making from the operator. Typically, no machine operator is an expert in physics. However, operators are actively predicting variables and making decisions on complex equations and forces on the fly. Unfortunately, despite all required training and experience, these incidents continue to occur. A particular saying which reoccurred throughout the focus groups was the repetition of the actions taken compared to the chance of a negative result occurring, "They may have done the same thing 100 or even 1000 times, but this time it just didn't work". It was maintained by the focus group members, that during harvesting operations, they tended to make decisions as they went, thinking and decision-making based on previous positive outcomes (experience). Reflecting on any wrong choices makes for powerful learning opportunities. With more positive outcomes we lose awareness of the risks associated with that behaviour. The loss of awareness is merely the seductive power of risk normalisation at work.

A contentious issue throughout the focus groups was whether the FO was aware of the deteriorating track. The majority agreed that the FO would have been unaware of the track deterioration. Most believed he had no concerns or he simply wouldn't have moved to cut the final tree. It was mentioned that pushing the machine was natural, but no-one wishes to damage their machine. Focus group experts mentioned that the tracks sinking a little bit was not a big deal and they would have continued if they were in his shoes. When harvesting trees, it is preferred to harvest moving up the slope to clear a place for shovelling trees downhill.

3.1 Preventative techniques suggested

Some recommendations regarding methods and techniques for avoiding potential roll-over were collected from the focus group members:

- If such a scenario is recognised, the Corduroy Method is recommended by the subject matter experts. Corduroy acts as a separator and a re-enforcer. Slash or logs (logs are preferred as it creates a more rigid platform) separates a weak subgrade from the aggregate. Using the Corduroy technique spreads the load and minimises exposed erodible earth. Corduroy is relatively quick to setup. However, in this incident, the focus group members mentioned that the key is knowing how far to push the machine and whether/when to put corduroy down. If the FO would have noticed the ground changing and was aware of his track 'floating' he could then have reacted accordingly and used Corduroy. Typically Corduroy is placed to improve the stability for the next user.
- When an operator starts to feel the machine rolling, it is best practice to get the felling head on the ground to maintain/restore balance. However, this was attempted by the FO in this reviewed incident, with an unsuccessful outcome.
- Other suggestions included backing out and utilising the felling head to test how strong the ground is. This method is used by the more experienced machine operators in the focus groups when conditions involve soft soil; this is a proactive way to test the grounds condition consistently.
- All focus group members were resolved in the method of Stop-Backup-Check be applied when on unstable ground. However, this would only be successfully applied in cases where the operator is aware of instability or ground deterioration.

Experienced operators revealed two methods of performing efficiently and safely that would be beneficial to adopt by all other operators. Simply put, experience gains insights to allow higher performance and delivery at a sustainable level to which novices are yet to learn. The importance of constant maintenance throughout the day was stressed by many. Maintenance is the key, to keep a smooth flowing operation with fewer surprises and delays and ultimately less stress to keep within the optimal performance range (seen in Fig.3.). The more experienced operators tend to check the machines to keep it running smoothly constantly through the day. Constant checks take far less time than if the machine were to become non-operational. Rushing through work creates breakdowns and ignoring obvious signs. During checking the machine the operator can mentally break from the joystick-intense environment. Operators require regular breaks, and maintenance checks can provide this. Furthermore, successful operators tend to set themselves personal targets throughout the day, typically they do not normally achieve these, but it buys time for when breakdowns do occur.

3.2 Technical solutions

It is critical to remember that a management strategy or defence that is 100% reliant on humans are vulnerable to inevitable and unavoidable human conditions such as fatigue and overload. Where possible, technical solutions have been sought.

- Incorrect installation of the hydraulic hoses was recorded to be a common issue which can cause a tremendous amount of damage to machines. A technical suggestion gained from the focus groups included the suggestion to the machine manufacturers that during re-installation that each hose end has a unique port to avoid incorrect installation altogether.
- A technical solution worth exploring is the installation of a retrofitted track pressure sensor which alerts the operator if the track is beginning to float, weight shifting warning. This technology already exists and was being explored by the Log Transport Safety Council in an edition of the FFR Harvesting Technology watch April 2011 (HTW-007). Additionally a patented device exists from http://www.stabilitydynamics.com/lgalert.html. The LG Alert™ system can be individually calibrated and benefits vehicles with a high centre of gravity, dynamic loads, and operate on uneven terrain. Additionally, the installation time is predicted to take just one hour. Adapting this technology to harvesting machines alerting operators when moving across slopes could allow for advanced warning to prevent future incidents, allowing for remedying actions such as corduroying or reassessment.
- Recently, at a steep slope workshop it was stated that the tipping point for an excavator with its tracks in line is 47deg, but when it came to the tracks across the slope, it was only 12 degrees. This information needs to be supplied to a wider audience as 12deg is negligible and was around the same degrees as that in this incident. Operators may find it difficult to assess a 12deg slope in these machines. Additionally, it may be relatively straightforward to retrofit a level gauge (this already exists in automobiles) to warn an operator when within a dangerous range. Awareness of slope conditions would complement the track sensor to increase the safety of the operator on ground where it is safer to move across the slope.

- In this incident, the track size (60cm wide) was called into question, with the recommendation that wider set tracks could've added more stability to the machine in this incident. A machine with a long and wide set undercarriage would be better suited to these forestry conditions.

3.3 Issues raised

It is the purpose of this Learning Review process to uncover such inconsistencies between work as actually performed and work as imagined/dictated. To learn from vulnerabilities and issues raised by experienced frontline staff can be a powerful tool in any organisations arsenal. What follows are additional concerns and possible improvements which can be implemented to create a safer workplace for all.

Moving across slope

Throughout the incident and subsequent focus groups, it was discovered that moving across a gradient in these machines was common practice. Experience affords operators the ability to make decisions and push the limits during operations, especially, in certain situations where it was considered safer to move across the slope. This is yet another normalised risk in operations. With little margin for error, this standard practice needs more evaluation.

If ground conditions change the operator is suggested to utilise the Corduroy method, an 'old logging skill' also called a 'Bastard Bridge'. Corduroy acts as a separator and a re-enforcer. Laying Slash or logs (Logs preferred as it creates a more rigid platform) at a 90 degree to the road which separates a weak subgrade from the aggregate. Using the corduroy technique spreads the load and minimises exposed erodible earth. Corduroy is relatively quick to setup. However, the focus group members mentioned that the key is knowing how far to push the machine and whether/when to put corduroy down. An information resource could be created to remind operators when to use this technique, especially in situations when they feel it is safer to move across a slope (with a sharper tolerance of only 12 Degrees before risking roll-over) and is at more risk of tipping. This information resource accepts the fact that operators are moving across slope only when they feel it is safer to do so, heightening the awareness of the increased risk they should expect but providing an advised tool to keep them safe.

4.0 RECOMMENDATIONS

The following recommendations, developed by the project team in conjunction with the expert felling machine operators who participated in the focus groups and vetted by the New Zealand forest industry representatives, are intended to generate sensemaking, learning and understanding without the over-incorporation of normative procedures.

4.1 Operational Recommendations

Recommendation 1	*Propose to felling-head manufacturers to consider the design of their hydraulic hose system and introduce unique connectors which are 'one-way' installed.*	
	Expected Responsible Party	FISC in cooperation with industry stakeholders.

The current incident allowed for the identification of a potential improvement to the manufacture and design of felling heads. The inverted hose installation caused further delays and influenced the participant's behaviour by compressing delivery time in an intense setting. It was advised that this issue is common when repairing these machines and can be disastrous and yet so easily preventable. The suggestion to introduce unique ports for the hose ends was proposed.

Recommendation 2	*Explore options and applicability of track weight sensors and levelling (inclinometer) gauges to alert operators of slope degree and weight changes (floating) in machine tracks, as a precursory warning system to avoid rollovers.*	
	Expected Responsible Party	FISC in cooperation with industry stakeholders.

In this incident, after testing the track by felling and shovelling the tree downhill, the operator had no awareness of the degraded path. If the operator had known his outer track was 'floating' he could then stop, investigate, reverse, restore balance and proactively isolate and minimise the hazards. A technical solution worth exploring is the installation of retrofitted track pressure sensors these can alert the operator if the track is beginning to float, with an in-cab warning light which indicates a dramatic weight shift. This technology already exists and was being explored by the Log Transport Safety Council in an edition of the FFR Harvesting Technology watch April 2011 (HTW-007). Additionally, a patented device exists from http://www.stabilitydynamics.com/lgalert.html. The LG Alert™ system can be individually calibrated and benefits vehicles with a high centre of gravity, dynamic loads, and operate on uneven terrain. Adapting this technology to harvesting machines will allow for advanced warning to the operators and potentially prevent future incidents, allowing for actions such as corduroying. As already mentioned, operators may find it difficult to assess a 12-degree slope while moving across a gradient in these machines. Fairly straightforward to install, is an inclinometer gauge, to warn the operator when within a critical/dangerous range (12 degrees). This system would require a warning system to alert the operator. Optimally, this could be an app on an operator's phone which can be set with a tolerance of say 10 degrees and turned on when moving across a slope; this then can caution the operator. Relying on an operator's own equipment may introduce issues like forgetting to take it, charge it and turning the app ON. An operator's awareness of slope characteristics would complement the track sensor and increase the safety of the operator on ground where it is safer to move across the slope.

4.2 Organisational Recommendations

Recommendation 3	*Explore methods of minimising risks while working alone and share with industry.*	
	Expected Responsible Party	FISC in cooperation with industry stakeholders.

Working alone is a practice that is currently undertaken across the industry despite the risks as it is clearly operationally necessary. A workshop or focus group with experienced personnel, technology developers and management would be beneficial for an organisation to identify strategies to manage this practice to make it safer. Investigate existing technology and successful management practices employed by others to share with the industry.
e.g. "Guardian angel" https://www.jwtintelligence.com/2014/04/wearable-tech-the-guardian-angel/

Recommendation 4	*Conduct industry-wide research to investigate the machine fit-for-purpose concept.*	
	Expected Responsible Party	FISC in cooperation with industry stakeholders.

How machines are traversing the forestry environment is becoming an ever pressing issue due to nature of the forces at work and the balancing of such large machines. There is an evolving issue of whether these excavator machines are appropriate to use in forestry in New Zealand. Specifically, are they as safe as fit for purpose machines in such complex and variable environments? Are operators being put at risk? Today, many machines are designed specifically for forestry tasks in the forest environment with tracks manufactured wider, longer and wide set heavy duty undercarriages (designed to have a lower centre of gravity), extra hydraulic horsepower for better performance and premium operator cabs. The utilisation and rollout of machines 'fit for purpose' were discussed throughout the focus groups with members divided due to the potential associated costs involved. More research and discussion is required to assess retrofitted machines in forestry as opposed to specifically designed fit for purpose forestry machines. Perhaps, cost/benefit analysis on machines used in forestry could be developed to inform decision-making in the future.

APPENDIX A

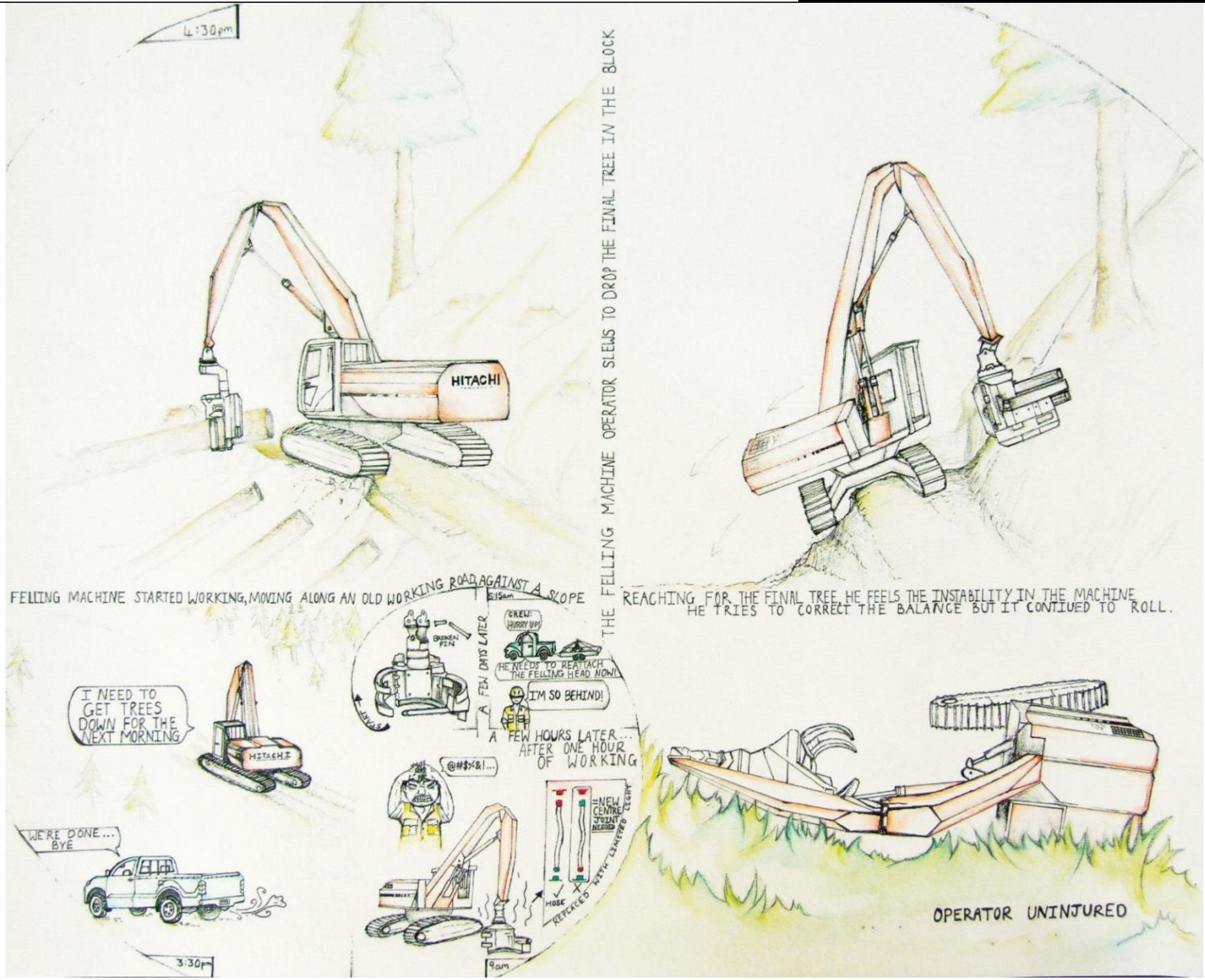


Figure 3. Visual Depiction of the Machine Rollover Incident (available in A2 poster).