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Harvesting and Logistics Theme

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Optimising Work Organisation for Maximum Performance

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Leadership in forest and environmental management, innovation and research

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EXECUTIVE SUMMARY

This research was a joint initiative co-funded by Future Forests Research (FFR) and by Accident Compensation Corporation (ACC). Problems with scheduling of logging operations had been identified in both FFR and ACC precursor research where similar findings identified that the logging industry has a culture of working undesirable hours, demonstrated by many instances of:

- undertaking overtime to meet production targets,
- early rising, long working hours (especially by operators of large machines), and
- taking only one break per day (especially crews in the North Island).

The early arrival of log trucks to site was found to be the trigger for early start to the work day in many cases; this may be influenced by barriers or bottlenecks to operational processes such as the size, layout and accessibility of the skid site, and the influence of sawmill or port operations.

The hazards associated with worker fatigue are generally well understood, yet interventions are largely directed at worker behaviour change through good hydration and nutrition. To complement this strategy this research has explored work organisational and scheduling factors that may contribute to the development of fatigue. Four cable logging crews using varied skid site layouts and organisational methods were studied. The research was undertaken through the adaptation of a methodology used in the manufacturing sector; the data collection techniques were developed specifically for the target group and to ensure that a range of known problems was explored. These methods included interviews with crews and contractors, process flow assessment and a more detailed analysis of the roles and tasks of activities deemed to experience time pressure.

Data indicated shortcomings in many areas of the work system, such as equipment and machinery design; layout, space and environment; work scheduling, pace and procurement; and job design. Some findings were relatively isolated and may have arisen as a result of the small sample size of the study. Nevertheless, the results enabled a number of recommendations to be made for intervention; these concern improvements at both a site and an organisational level:

- Equipment usability development – particularly the methods for rope movement, rope quality and configurations of the cable system to enhance efficiency; loader grapple design, storage and operational techniques for more efficient movement
- Layout – to establish buffer stock for time-pressured processes, and to ensure compatibility of skid site size with log storage, machinery 'population' and access needs
- Job design – to establish the physical and (especially) mental workload demands upon machinery operators; identify whether any loader driver tasks can be redesigned or reassigned; and explore how to address failed systems for job rotation within the industry
- Cost-benefit analyses – evaluate relative benefits of alternative layout and equipment choices and convey to industry
- Organisational – in the light of identified barriers to productivity, review the criteria to be considered when developing production targets (e.g., conditions, work practices and individual capability / variability); work in conjunction with the log truck industry to resolve scheduling problems.

In order to combat conditions that may contribute towards operator fatigue, the highest importance is placed on addressing these systems and cultural failures that have made these undesirable work conditions 'the norm' in the logging industry.

INTRODUCTION

This research was a joint initiative co-funded by Future Forests Research (FFR) and Accident Compensation Corporation (ACC). It explores areas that contribute to work scheduling problems in cable logging operations, and proposes recommendations for future intervention.

The research has been undertaken by ergonomists working in harvesting, and this is reflected in some of the perspectives and terminology adopted. Ergonomics concerns the understanding of interactions between humans and a range of factors which influence work performance and worker well-being. Ergonomics interventions have typically concentrated on the introduction of physical barriers or technical changes to prevent injury and define skill or behavioural requirements for loggers. The intention was to build upon these earlier initiatives to explore organisational aspects and how these can have latent impact upon ground level activities.

Problems with scheduling of logging operations have been identified in both FFR and ACC precursor research – "FFR Report: H002", (Hide *et al*. 2009) and in the ACC funded research "ACC Project no: A56820" (Hide *et al*. 2008). For the former the successes, or otherwise, in the implementation of human factors and ergonomics initiatives proposed since 1990 were explored; the latter enabled identification of underlying contributory causal factors in a sample of 15 logging incidents. Findings from both reports were similar. The logging industry has a culture of working undesirable hours, demonstrated by many instances of undertaking overtime to meet production targets, widespread early rising, long working hours (especially by operators of large machines), and taking only one break per day (especially North Island crews). The early arrival of log trucks to site is the trigger for early starts in many cases, yet this in turn may be influenced by barriers or bottlenecks to operational processes such as the size, layout and accessibility of the skid site and the demands of sawmills, ports, etc.

The hazards associated with worker fatigue are well understood, yet interventions are largely directed at worker behaviour change through good hydration and nutrition. To complement this, the project aims and objectives were:

Aim: To identify work organisational and scheduling factors that may contribute to fatigue, and explore remedial measures

Objectives:

- Undertake a literature search to:
    - Review available data concerning physical and psychological work loadings for key harvesting tasks;
    - Establish existing work scheduling guidance for these tasks and explore their adoption and barriers to their uptake;
    - Explore measures implemented outside the logging sector to improve and manage work scheduling;
    - Identify materials that have influenced the development of New Zealand forest workload operations and planning; and
    - Evaluate guidance for best practice in determining skid site layouts.
- Design study methods to identify barriers / bottlenecks affecting site and off-site based scheduling, and of skid site layouts, log storage and movement of equipment / people
- Undertake field studies with four cable operations using varied skid site layouts and organisational methods
- Identify appropriate remedial measures and intervention measures that might facilitate more desirable work scheduling

The following sections catalogue the literature findings, methods development and results from site data. These are collated and presented with relevant recommendations later in the report under the heading "Interpretation of findings".

LITERATURE SEARCH

Temporal Risk Factors, Work Hours and Scheduling

As a baseline to the study, a literature search was undertaken to establish:

(1) International data concerning the effect of temporal factors upon physical and psychological workload of logging workers;
(2) New Zealand guidance concerning optimal logging crew work hours and scheduling; and
(3) Varied measures implemented outside the logging sector to improve and manage work scheduling, as a means of establishing whether alternative and/or more successful measures have been adopted by NZ industries with similar work circumstances.

Additionally, to assist in the development of data collection methods, the literature search was broadened to establish:

(4) Materials that have influenced the development of New Zealand forest workload operations and planning; and
(5) Guidance for best practice in determining skid site layouts

International Data

Both New Zealand and international sources were explored to find empirical studies (or reviews) used to identify physical and psychological work loadings for key harvesting tasks (full details in Appendix One). Such data have been identified through (i) the exploration of research relating to adverse health effects arising through harvesting work, and (ii) research relating to the identification of factors that can impede performance (see New Zealand Guidance). Findings showed that the range of international research appears more directed at tree falling or machine-based tasks, whereas material from New Zealand also includes the breaking out and log making tasks.

Table 1: Health impairments and temporal risk factors for injury

Adverse health effect	Chainsaws	Heavy machinery	Other	Temporal risk factor
Noise	√	√		
Whole body vibration	√	√ Skidder operation		√
Hand-arm vibration	√	√ Anti-vibration saw		√
Upper extremity disorder / OOS		√ Feller-buncher op.		√
Musculoskeletal disorders (general)		Harvester op.		√
Heat stress			Environment	√
Heart & vascular disorders	Exhaust fume			√
Mental stress and strain		√ Harvester op.		√

√ **=** general rather than a specific tool type. Collated from the following resources: (Neitzel and Yost 2002), (Cation *et al*. 2008), (Bovenzi 2008), (Sutinen *et al*. 2006), (Ostensvik *et al*. 2008), (Ostensvik *et al*. 2009), (Byers 1997), (Cummins 1998, Cummins 1999; Kumm and Gellerstedt 2005), (Wästerlund 1998), (Bunger *et al*. 1997), (Inoue 1996), (Sullman and Kirk 1998).

The health impairments arising from adverse work loadings covered a range of disorders, summarised in Table 1. In each case a temporal risk factor was identified, yet, whilst many of the resources identified that duration of exposure would need control, it was only the resources directed at alleviating factors that affect performance, such as boredom and fatigue, that defined specific actions. Notably these were primarily resources of New Zealand origin and arose from previous work by researchers from the Logging Industry Research Organisation (LIRO) such as Byers, Cummins, Kirk, Parker and Sullman.

New Zealand Guidance

The type of guidance proposed for both task specific and general forestry / harvesting tasks is summarised in Table 2.

Table 2: Recommendations to relieve boredom and fatigue

	[1]Logmaking	[2]Feller buncher op	[3]All harvesting or forestry tasks	[4]Heavy vehicle drivers	[5]Motor-manual tree felling & delimbing	[6]Processor operators
Job rotation		√				
Job rotation at every break	√					√
Micro pauses / frequent short breaks		√	√			√
Rest breaks	√	√			√	√
At least 2 x 30 minute breaks per day			√			
40 minute break every 3- 4 hours						√
Get out of cab, walk around & stretch – preferably hourly		√	√			√
Limit shift length to < 4hours			√			√
Replace lost sleep			√	√		
2 operators / shift on an extended work day						√

Collated from the following resources:- [1](Parker *et al*. 1993), [2]Byers, 1997, [3](Kirk 1996), [4](Sullman *et al*. 1997), [5](Kirk *et al*. 1996), [6](Kirk 1998)

The findings in Table 2 give a clear indication of a range of guidance directed at harvesting workers to mitigate a wide range of factors that lead to fatigue. These findings indicate that the nature of breaks, job rotation, shift length, sleep duration, and scheduling of machinery driver tasks needs to be explored during data collection.

However, potential for confusion might be found in different rest break guidance for 'all harvesting or forestry tasks' compared to that specifically directed towards processor operators. For example, the former advises 2 x 30 minute breaks per day (Kirk 1996), whereas that for processor operators (a sample group of only 3 people) the recommendation is for a 40-minute break every 3 – 4 hours (Kirk 1998). In spite of these differences and the small sample group of processors, guidance appears comprehensive for the target groups in these studies. Nevertheless, it was not clear what rest break guidance should be adopted by those driving / operating the wider range of machinery not individually specified.

Varied Measures Implemented Outside the Logging Sector

As a baseline (for all New Zealand workers), minimum rest and meal breaks are specified within the Employment Relations (Breaks, Infant Feeding, and Other Matters) Amendment Act 2008, Part 6D. This specifies, within a work period between 6 and 8 hours, two 10-minute paid rest breaks and one unpaid 30-minute meal break (http://www.ers.dol.govt.nz/relationships/minimum.html).

Where work continues up to 12 hours duration, a further paid 10-minute rest break is specified; above this period of time (12 – 14 hours work) a further 30-minute break is also specified.

A search for alternative methods, adopted within New Zealand, to improve and manage scheduling of work with similar circumstances was undertaken. This included a web-based search of Trade Unions (e.g., New Zealand Council of Trade Unions, Service and Food Workers Union), industry bodies (e.g., Seafood Industry Council Ltd) and career guidance websites. Resources from two occupation types specifying minimum working hours and rest breaks were identified.

(i) Truck drivers - Part 4B "Work time and logbooks", inserted 1 October 2007 by section 19 of the Land Transport Amendment Act 2005 (2005 No 77) to the Land Transport Act 1998. http://www.legislation.govt.nz/act/public/1998/0110/latest/DLM433613.html?search=ts_all%40act_Land+Transport+Act+1998_resel&p=1&sr=1 , specifies that a driver may not exceed 13 hours of work time per day and must have at least 10 hours of continuous rest time. They may not exceed 70 hours of work time in any cumulative period, and this must be broken by rest time of at least 24 hours. Rest time must be at least 30 minutes duration, should not be work time and not be spent in a moving vehicle associated with work.

(ii) Flight crews – Pilot work hours vary according to aircraft type and presence of other pilots – for a single pilot crew the pilot should not be rostered for a duty period of more than 11 hours, fly more than 6 hours within a duty period. A 30 minute break should be taken with the first 5 hours and at intervals of not more than 4 hours thereafter (Civil Aviation Authority of New Zealand 2006).

Workload Scheduling and Planning

Using the National Forest Library key, reports concerning forest workload scheduling and planning (published since 1990) were sought (Appendix 2). This was undertaken in an attempt to establish whether there might be any conflicts of interest in measures adopted to manage scheduling and operational performance, compared with those necessary for human performance.

Precursor research to studies of work scheduling has typically entailed some form of work measurement to assess the time content of a task, establish relaxation allowances, optimise working methods and predict output. However, from an ergonomics perspective, work study has often been criticised for its lack of attention to the range of broader systems issues, and inadequate consideration of individual differences in performance and ability (Moores 1972).

A range of reports were found concerning planning and analysis of time studies (Bergstrand 1991); nomenclature to be used in forestry work study (Bjorheden *et al*. 1995); and observations concerning forestry time and performance studies (Samset 1990). Whilst the reports of Bergstrand (1991) and Bjorheden *et al*. (1995) both indicated that there should be measurement of user performance, it was not clear (nor appropriate necessarily in these particular documents) how allowances for human activities have been calculated. Samset (1990) noted differences in performance, both between operators and under varied conditions. However he suggested the creation of an average performance capacity score as a unit to be used in planning calculations; the drawbacks, where an 'average' value is adopted are that those whose capacity is outside the average value are not necessarily suitably accommodated and remain vulnerable to under- or over-demand.

These reports are also fairly dated, and it was not clear whether these work study measures are applied here in New Zealand. Alone they do not address the wide range of systems (as opposed to process) issues and individual variability that needed to be accommodated in a comprehensive approach to workload planning. Nevertheless the work study methods did incorporate some useful methods to record work tasks. A simplified form of these techniques was previously applied in an assessment of landing workers' activities (Mythen, 1987). Although this formed a useful resource for methods development, the enquiry did not explore the human performance aspects considered influential in work scheduling.

However, whilst lacking comprehensive precursor work of this nature in the forestry sector, materials successively developed to explore human factors of planning and scheduling practice in the manufacturing industry served as a foundation resource for this research.

Undertaking successive studies in the late 1990s, a Nottingham University research team devised an investigatory framework to capture generic areas of interest in the assessment of planning and scheduling (MacCarthy *et al*. 2001). Through refining techniques adopted by the team in earlier studies (Crawford *et al*. 1999) it was proposed that a range of factors to be considered in scheduling systems concern task, role and monitoring activities, and the business environment. In turn these were heavily influenced by factors such as the environment, other personnel, performance measures, events occurring elsewhere in the system, time pressure etc. These concepts underpinned later development of methods for data collection.

Best Practice for Skid Layout

Finally, and in response to issues concerning skid site layout, guidelines for design and layout were evaluated in order to identify any shortcomings and to direct future intervention.

The Forest Roading Manual addresses the planning, design, construction and maintenance of forest roads and landings (Larcombe, 1999). This advised that a wide variety of factors influence landing design, and suggested 12 aspects (such as terrain, type of machinery to be used, number and length of log stacks, etc.) be considered.

Additionally, two formulae were suggested as a rough guide for determining either hauler or skidder landing size. Against given coefficients, the number of log sorts and either the average log length or production rate (m^3/day) permit calculation of the required landing area in hectares. The data source and studies underpinning creation and validation of these formulae is based on previous LIRO research (Raymond, 1987) – advised by personal communication, Raymond, 2010. It is not clear whether any impediments in timely log uplift from site were accommodated in these formulae.

The manual also proposed generic landing layouts:

- (i) Drive-through (the truck drives through the middle of the landing and can be loaded from either side;
- (ii) Road side – trucks drive through but the landing is to one side, permitting loading only from one side; and
- (iii) Spur road end hauling – access and egress is via a single route into the skid site.

The descriptions of each of these layout styles suggested that the drive-through style is more advantageous due to loading access on either side of the truck. However there was no comment on the impact of the truck presence on other skid site operations, or safety implications of shared traffic/pedestrian routes. Split-level landings and 2-stage operations were also proposed for steep or difficult country.

General rules to maximise the area of utilisation were also proposed, such as stacking logs around the perimeter, keeping fastest moving logs in the most accessible location and keeping log butt ends in the same direction for easy loading.

The Best Practice Guidelines for Loading (FITEC 2000) identified typical loader operator responsibilities (e.g., layout planning, stock management, transport and scheduling) and criteria for planning loading. However, whilst recommended layout criteria was clearly described, there was no pictorial guidance on optimum layouts. For example, these might offer a range of design alternatives that allow easy truck access, minimise human / machinery paths crossing, and problem management such as optimum layout of small sites with a high number of cuts, etc. Landing layout is also addressed in the Best Practice Guidelines for Manual Log Making and Processing (FITEC 2001); again descriptive advice was clearly presented, but there was no pictorial guidance on layout design alternatives.

METHODS

Three core elements of the toolkit of data collection techniques used in the human factors of planning and scheduling manufacturing studies (Jackson *et al*. 2004) were adopted for use in this study – observation, interview and task analysis. The generic areas of interest, already proposed by the Nottingham University team, were used as a baseline from which to build in enquiry that specifically applied to cable logging crews. The techniques (a – d below) were adopted to reveal barriers / bottlenecks in process flow, such as those affecting site and off-site based scheduling, or arising from demands upon skid site access, and the practices adopted for log storage and movement of equipment / people / logs on the skid site.

These analysis techniques were used to evaluate operations of four sample cable logging crews using varied skid site layouts and organisational methods.

a) **Process flow observation and identification of bottlenecks and impediments to free flow.** Each operation (where possible) was observed to identify where process flow was being impeded during any of the usual sequence of activities and tasks (from tree falling through to the varied skid site activities). Each activity was observed to identify whether time pressure occurred. Time pressure was judged through either a glut of work waiting and/or by the next in line waiting for services. Under these conditions either a barrier to efficient work flow and/or potentially stressful demands upon the relevant operator were considered possible.

b) **Analyse tasks and roles of bottleneck activities identified in (a) above.** Having identified bottleneck activities, these were observed in order to establish the content and demands of work activities and impediments to process flow. Observation included cataloguing the activity types undertaken, when and why work flow impediments occurred and the amount of time spent on the different activities. This process varied between 1 and 3 hours per site.

c) **Interview data from crew members and the contractor / crew manager concerning factors that impact upon work hours and which might impede process flow.** Interview proforma were developed for crew members and the contractor / manager. Crew members were asked directly about working time related issues, and organisational factors that might impact workload; interviews lasted 10 minutes approximately. Contractors / managers were asked a range of questions concerning factors that might affect organisation and scheduling, such as production demands, equipment, location, truck liaison and contractual issues. These interview questions are reproduced in Appendix 3.

d) **Collection of GPS trace data from three different activities within each site studied.** Four hours of trace data were collected at each study site. At each site two of the GPS units were placed in the cab of vehicles operating on the skid site; the final GPS unit was strapped to the helmet of a log maker (although data are not reported here). Vehicle data were used to identify frequency of operations, travel speeds and, when viewed through 'Google Earth', travel distances.

A pilot study was undertaken, during which methods were trialled. As a result some minor changes were made to the contractor interview proforma, in order to improve clarity. The question intention remained unchanged and all data are reported.

FINDINGS – SITE DATA

Four site studies were undertaken between December 2009 and April 2010 at central and east coast North Island cable logging operations. Crews varied in size from 7 to 12 members, with the contractor either adopting an operational role or acting as an advisor (Appendix 4 provides more details of crew roles and numbers). Study One was to a cable logging operation with a single skid site, and the remaining sites were all 2-staging sites.

- Study One had a single skid site and used a mobile hauler to pull ~100 stems per day of 8 grades and varied lengths; there were two loaders that moved stems around for static delimbing, log making, stacking and truck loading. Two skid workers undertook log making and quality control (QC) work

- Study Two was of an operation involving first bunching the stems awaiting breaking out, hauling 150 – 200 stems/day of 10 different grades and 11 lengths with a swing yarder, delimbing with a Waratah processor, removal of logs to the second skid by a forwarder, and then final management of the second skid site (QC, stacking and truck loading) by a log maker and use of a loader

- Study Three used a mobile hauler placed on one skid site and pulled 180 – 200 stems/day of up to 14 grades. A skidder collected these stems and stacked them to the side of the route half way between this and the second skid site. A Waratah processor operated from the second skid site; where two loaders and two log makers managed movement of logs on site, delimbing / QC, tidying debris and truck loading

- Study Four was of an operation which pulled ~ 80 logs/day of up to 12 grades and used a mobile hauler to transport logs down from a step hillside on the opposite side of the valley – the hauler was placed on a much lower ridge at the base of this hillside. On arrival, stems were dropped short of the hauler position at the gully between the hillside and lower ridge. From there stems were transported by skidder to a skid site (on flat ground) at the other side of the lower ridge. At the skid site stems were manoeuvred and stacked by a Bell Logger (with necessary log making / QC in between). A loader was used also, but only for truck loading.

Establishing Time Pressure During Process Flow

Each study commenced with observation of the process flow and the identification of incidences where bottlenecks occurred (Table 3). Bottlenecks were deemed to have occurred where process flow was impeded in some way – typically through time pressure on any one operation (through a glut of work awaiting action, those next in line with insufficient 'product' to work upon and unable to proceed efficiently, or as a result of activity ceasing due to breakdown or movement of lines etc.). Although it was not possible to view all operations on each study a number of observations in common were noted.

Table 3: Summary of impressions of time pressure during each study

Operations	Impression of time pressure (shaded boxes indicate areas of concern)			
	Study One	Study Two	Study Three	Study Four
Tree falling	None on day of study	Not evident –- plenty of stems waiting for breaking out	Not evident - plenty of stems waiting for breaking out	Not evident - plenty of stems waiting for breaking out
Buncher operator	N/A	Unknown – falling and breaking out ran smoothly but reported that the buncher operator did not take breaks	N/A	N/A
Breaking out	Not evident – short breaks taken between hooking up	Not evident – short breaks taken between hooking up	Unable to see operation	Considered possible due to slower speed during training & poor terrain – otherwise short breaks taken between hooking up
Pole man	Not evident – short breaks taken between unhooking	Not evident – short breaks taken between unhooking	Unable to see operation	Not evident – short breaks taken between unhooking
Hauler operating	Considered unlikely where pace largely dictated by speed of cable operation; Considered likely during breakdown and cable moving	Considered unlikely where pace largely dictated by speed of cable operation Considered possible while moving cable	Unable to see operation	Considered unlikely where pace largely dictated by speed of cable operation Considerable - when cable moving problems
Waratah operating	N/A	Considered likely - limited space on skid for stem and waste placement & demand in need to serve forwarder	Considered possible given loader / truck demands	N/A
Forwarder / skidder operating	N/A	Not evident – no obvious build up of stems awaiting transfer (forwarder)	Not evident – no obvious build up of stems awaiting transfer (skidder)	Not evident - extensive periods of hauler breakdown & long drag distances (skidder)
Loader operating	Considerable – to clear Hauler work area, delimb, move & position stems / logs onto bearers or onto or between stacks, & load trucks. Periods of immobility due to space / access restrictions	Considered likely - to unload forwarder, move & position stems onto or between stacks / for QC, & load trucks	Considered likely – to collect stems, service Waratah & associated waste, move & position stems onto or between stacks / for QC, load trucks. Periods of immobility due to space / access restrictions	Not evident –breaks taken between stem deliveries / truck arrivals (NB: Also includes bell loader operation)
Log making /QC	Not evident – short breaks waiting for bearers to be loaded / unloaded	Not evident – short breaks regularly taken	Not evident – short breaks regularly taken	Not evident – short breaks regularly taken

No Obvious Time Pressure

- Falling – Whether or not falling was taking place there were always plenty of stems on the slopes, which indicated that the faller would not be pressured to increase their work pace to serve the breaker out / buncher operator.
- Log making/QC – Operators had the opportunity to take short breaks either waiting for stems/ logs to be delivered for them to work on or, once they had completed their work, for them to be removed. There was no build-up either before or after their activities.
- Pole man – There was no backlog plus there were opportunities to rest between the unhooking activities.
- Forwarder / skidder operation – Given the speed and carrying capacity of these vehicles, neither experienced a build up of stems / logs waiting to be removed, or of the loader / truck awaiting more stems for the following stage of the process.

Insufficient Information / Isolated Incidences of Time Pressure

- Breaking out - Little time pressure was observed during breaking out, except with Study Four where training of a new crew member and difficult terrain appeared to extend the time normally taken to hook up; although it was not possible to interview these workers this may have created time pressure for them. For the remaining studies, although known to be physically demanding, the operation was relatively quick and short breaks were possible while the hauler was operating.
- Buncher operator – Whilst the operation ran smoothly (plenty of available logs and bunches created in readiness for the breaker-outs), it was reported that the taking of breaks was avoided and, although underlying reasons for this were unknown, this suggests that further information is needed.

Likely Time Pressure

- Hauler operation – There were significant problems with the hauler during two of the studies; on Study One and Study Four there were problems whilst moving the ropes to another area of the hillside (in one case having to rewind a drum and, for the other, the procedure entailed ‘re-threading’ the straw line onto the tower) and mending broken ropes. In both cases there was a considerable period of down time, which impeded process flow for breaker outs and skid site workers. Ropes were also moved during Study Two and, although this caused some delay, it was not as protracted as with the other two sites.
- Waratah operation – These were used on two of the sites studied.
    - For Study Two it was positioned at the point of drop off from the swing yarder, and while the work rate appeared roughly compatible with that of delivery rate, the work area (especially space for waste placement) appeared cramped and may have contributed towards demands upon the operator. Given the rate of log removal by the forwarder, yet rare build up of any stock level, there appeared to be likely pressure upon the work pace.
    - For Study Three the Waratah was placed on the second skid site (away from the hauler) and was working on stems already placed there. This role appeared less pressured, given that the workload came from a stockpile rather than continuous flow. NB: there was regular arrival of log trucks and this could have lead to perceptions of work pressure (e.g., if there was a high demand for logs of a certain specification); excepting “smoko”, the Waratah operator did not stop for breaks
- Loader operation – All sites used loaders and there were many instances where an impression of time pressure was gained; this was most apparent during Study One. Here loaders had a number of concurrent demands upon their time, such as operation of the static delimber, movement of stems/logs to or from the bearers or between stacks, loading trucks and clearing waste. For this study there was also the additional problem with the hauler/cable operation and one of the hauler drivers (also the Supervisor) spent a significant portion of his time away from the hauler role dealing with this. The problems relating to concurrent demands for loader operators, although to a lesser extent, were also present during Studies Two and Three.

Supplementary Data – Skid Site Layout

A loader was used only for truck loading during Study Four (with a Bell Logger moving and stacking logs and servicing the log maker), thus it was not possible to evaluate time pressure. However this skid site layout differed from the other sites in that the layout for the log stacks was roughly circular (the stacks formed the 'wall' of the circle), with skidder access/egress incorporated. With this configuration, when trucks arrived, they loaded from outside the circular log stack layout – a roadside landing. The Bell Logger and log maker were able to continue their work uninterrupted during truck loading (Figure 1 provides a plan view, not to scale).

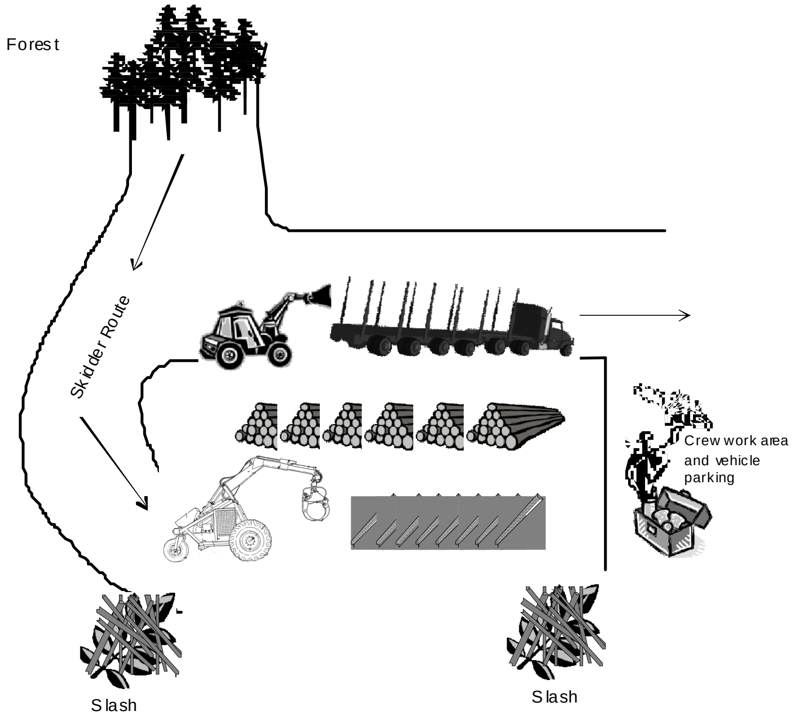

Figure 1: Roadside landing - where truck entry to the operational area is avoided

Analysis of 'Time Pressure' Activities – Collated Observation and GPS Data

The process flow analysis identified the most likely areas of time pressure being through hauler operation, Waratah operation and loader operation. These operations were further observed and a timeline of their activities was recorded for between 1 and 3 hours. Duration of observation was influenced by the range and accessibility of operations available for observation.

Analysis was achieved through a combination of methods, including further observation (incorporating video recording), data logging of varied events at 5-minute intervals, and estimation of work rates and movements from the machinery-mounted GPS units that recorded speed, travel distances and altitude change. These data summaries are shown in Tables 4 – 6 and, together, provided greater detail concerning the time pressure activities.

The data served as a 'snapshot' of the activities under observation and so were of short duration (as opposed to extensive time studies), and assisted in illustrating the anomalies already identified within task activities or interaction between different operations.

Hauler Associated Problems

Although causing some delay, cable movement (rigging changes) caused less downtime during Study Two, and a relatively trouble free operation was reported at Study Three. However, there was clear evidence of time pressure on Studies One and Four; there was one instance of electrical problems with the hauler itself, otherwise the problems arose through breakdown of the system and/or problems with cable quality and movement.

The problems included a number of adverse factors such as: difficulties fixing straw line to the tower; needing to fully extend and rewind the cable; mechanical problems with the skyline carriage (eventually being changed to a slack line system); cable breakage when run over unseen obstacles; and long drag distances creating difficulties with cable tension and control. It was also reported that, due to difficulties and time involved in setting up the hauler, hauler placement on the skid site could lead to workflow and access difficulties.

Waratah Associated Problems

Although there was only one example of process flow of operations either side of a Waratah operation, this illustrated the likely time pressure that the operator would experience.

Using the average ($\bar{x}$) rate data from Study Two, Table 4 shows that, if the hauler pulled ~ 3 stems every 6 minutes, this would allow 2 minutes/stem for the Waratah to operate without causing a stem build-up at the hauler drop zone (chute). However, the Waratah took on average 2.5 minutes per stem, which over time could lead to the creation of a backlog / time pressure for the Waratah operator. NB: no micro break allowances here.

Table 4: Comparison of hauler, Waratah and forwarder work rates (Study Two)

	Hauler rate / minute (m)	**Waratah rate / minute (m)**	**Forwarder rate**
Duration measured	**30 minutes**	**30 minutes**	
Operation rate / minute (m) / circuit (c)	3 stems every 4 – 9m ($\bar{x}$ 6m)	1 – 6 minutes ($\bar{x}$ 2.5m) per stem	21 minutes per circuit
- cuts per stem	-	Cuts per stem = 4-7 ($\bar{x}$ 4.5)	35-40 stems per load

Cuts per stem generally resulted in one less log produced (i.e., an average of 4.5 cuts per stem resulted in 3 – 4 logs, as the first cut always removed waste wood at one end). Accordingly at least 10 stems needed to be processed by the Waratah to create a minimum forwarder load. At an average 2.5 minutes per stem this required at least 25 minutes work by the Waratah operator, yet the forwarder rate of 21 minutes per circuit suggested that the Waratah operator was pressured to try to increase his production rate in order to meet the demands of the forwarder.

Loader Associated Problems

As noted, during identification of time pressure activities, loader drivers have wide ranging responsibilities that place a number of concurrent demands upon their time and which could divide attention. During observation a number of key activities were identified during the data capture period (Table 5).

A Truck Interaction.

Between 34% - 50% of loader time was spent interacting with trucks; each truck loading operation lasted approximately 30 minutes.

Study One, loader 1, Study Two loader and Study Three loader 2 spent between 34 and 50% of their time (average 43%) at truck loading. For the remaining loader activities Study One loader 2 dealt almost exclusively with hauler breakdown, thus it was only Study Three loader 1 that did not interact with trucks during the data collection period.

Table 5: Loader task and activity breakdown

* = GPS data	Study One				Study Two		Study Three				Study Four
Loaders	**Loader 1**		**Loader 2**		**Loader**		**Loader 1**		**Loader 2**		
Duration of data collection	**3 hours**				**1 hour**		**65 minutes**				
- delimbing	15	9%	0	0%	-	-	-	-	-	-	No data - loader used only with trucks
- hauler breakdown management	30	17%	120	68%	-	-	-	-	-	-	
- housekeeping	5	3%	10	6%	-	-	5	8%	-	-	
- log movement - moving along	20	11%	5	3%	10	17%	10	15%	10	15%	
- log movement – on/off bearers	10	6%	5	5%	-	-	5	8%	-	-	
- log movement – stack to stack	20	11%	10	6%	15	25%	25	39%	5	8%	
- log tidying – tweaking	10	6%	0	0%	-	-	10	15%	-	-	
- truck interaction	60	34%	0	0%	30	50%	-	-	30	46%	
- stop	5	3%	25	14%	5	8%	10	15%	20	31%	

B Log Movement

Between 14% and 77% of loader time (average 38%) was spent undertaking some form of log movement

There was wide variation in loader times spent on log movement activities. Such activities included moving logs or stems along the skid site, on and off bearers, stacking or re-stacking and tidying / marrying up the ends of logs on stacks (tweaking). These processes incorporate a large amount of double handling, particularly when the distance of log / stem travel was beyond the reach of the boom, or where finely tuned movement were required in order to achieve a precision activity (such as marrying up ends of logs in a stack). In addition there were many occasions where the grapple hook failed to make the fine tuned activities required of it, i.e. to make a firm grasp upon the logs; there were also balance / control problems when logs moved during transfer or when handling longer stems.

Where 'log movement' time was low this was primarily because the loader driver had left the vehicle and was undertaking maintenance elsewhere (Study One), or because they had stopped (to talk with co-workers, or were unable to proceed because of space restrictions during truck loading - Study Two).

C Operational Delay

Between 3% and 31% of loader time (average 14%) was time delay (stopped and not using the equipment)

Typically these 'stopped' delay periods arose because the driver was interacting with others in the crew, helping to solve a breakdown problem or because access was blocked as a result of a truck on the skid site.

D Work Balance

The forwarder appeared to operate at a greater work rate than the loader, resulting in double handling of logs when unloading. As the forwarder was emptied by the loader its logs were temporarily placed on the ground, before later being transferred to the desired stacking position. NB: The forwarder unloaded its own logs only when the loader was busy with trucks.

Although not apparent during Study Three (the skidder didn't deliver stems directly to the Waratah operator) or Study Four (flow rate was considerably impeded by cable / hauler problems), further data on loader capacity to handle skidder delivery would have been desirable.

To illustrate the greater capacity of the forwarder, using the average ($\bar{x}$) load volume and trip frequency data from Studies Two and Three (Table 6), continuous operation of the forwarder for one hour would result in carriage of up to 120 logs (3 loads of 21 minutes per circuit, at up to 40 logs / load). For the same time period a skidder (15 loads of 4 minutes per circuit, at up to 3 stems / load) would have carried only 45 stems. In spite of the differences in wood presentation and drag distances the forwarder data suggests a much greater carrying capacity than the skidder.

Table 6: Skidder and forwarder carrying capacities (* = GPS estimate).

	Study One	**Study Two**	**Study Three**	**Study Four**
Skidder / forwarder		**Forwarder**	**Skidder**	**Skidder**
Duration measured		**6 ½ hrs**	**1 hr**	**4 hrs**
- load volume	None on site	35-40 logs /load	2-3 stems / load	~ 1 stem / load
- trip frequency		11 trips in 6 ½ hrs*	10 drags in 1 hr*	14 trips in 4 hrs*
- travel per lap		0.22 km/lap*	0.1 km/lap*	0.33 km/lap*
- travel time per circuit		$\bar{x}$ time = 21min*	$\bar{x}$ time = 4 min*	-

Analysis of Crew Interview Data

Site studies included interviews with 19 crew members with varied responsibilities. These interviews were limited to those that were based on or returned at some stage to the skid site / parking areas during the work day. The questions concerned a variety of aspects influenced by, or that themselves influenced, the temporal nature of their work.

Time Planning – Work and Home

Hours – Seven interviewees (37%) worked 07.00 – 15.30pm, although one crew (n=4) continued until 16.30 (yet also took a longer break during the day). Of the four loader operators interviewed, three described a start time of either 03.30 (2) or 04.00 (1) and all finished at 16.00; this did not necessarily happen on a daily basis, but when trucks were scheduled to arrive early for loading. Some mentioned earlier start and finish times during the summer and others noted an early finish time on Friday afternoons.

Overtime – All worked a 5-day week, yet over half (58%) reported working overtime: eight (42%) worked an additional extra day per week as overtime; a further 3 (16%) described working an extra day on either alternate week-ends (2) or less often (1).

Breaks – One crew took an hour break from ~11.30 (n=4), whereas most (68%) took breaks of 30 minutes at some stage between 11.00 and 12.00 (n=13). One machinery worker reported that he took no break, whereas others stated that they fitted them in where possible or when the work stopped (3). It was also indicated that on occasions breaks would be staggered to allow production to continue.

Sleep time – Most felt that they had good quality sleep, although some reported being disturbed by family members (5) or environmental noise (1). Interviewees went to bed at any time from 20.00, with some retiring at or before 21.00 (7), or between 21.30 and 22.00 (7), or between 10.30 and 23.00 (4). Interviewees rose from 02.00 to 02.30 (3), 03.30 to 03.45 (2), 04.00 to 04.45 (5), 05.00 (5) or between 05.30 and 06.00 (3). Average number of hours sleep per night was just over 7 hours (range 4.0 hours – 8.5 hours). Those getting up the earliest were not necessarily those that retired the earliest; average hours of sleep for those rising before 04.00 was 5 hours 20 minutes (range 4.0 – 6.75 hours).

Driving time – Travel time to work varied; the longest was 2 hours each way (n=1), whilst the travel for others was between 1 – 1.5 hours (n=10, or 53%), 40 – 50 minutes (n=4), or up to 30 minutes (n=4).

Holiday time – Some had not been employed long enough to take a holiday; the majority took 4 weeks (n=9), whereas a couple took only 2 ½ weeks.

Barriers to Optimum Work Scheduling

Factors that could lengthen the work day – Interviewees described a range of tasks, events or activities that could lengthen their work day. For the most part these concerned activities associated with machinery, such as hauler breakdown / maintenance (6), staying late / early start to service machines (3), setting up / moving hauler ropes (5) and dealing with mistakes (such as not setting the straw line properly) (1). To a lesser extent these were also related to skid site work, such as moving logs on the skid site (2), ensuring QC is complete if trucks are anticipated (1), and loading / waiting for trucks (1). Only three interviewees (16%) responded that there was nothing that lengthened the work day.

Barriers to taking breaks – Whilst over one-third felt that nothing would inhibit break taking (n=7) other interviewees described a range of contributory aspects such as: fixing a broken hauler / making up time after breakdown (3), trucks arriving at "smoko" time (2), high loader workload (1), unfinished or delayed work (3) and bad weather (1).

Influence of cost-cutting / incentives on workload – The majority of interviewees (n=16, 84%) felt that cost cutting or the introduction of incentives had not influenced their work. Of the remainder one complained that the chainsaw allowance was insufficient for saw maintenance, whereas one other reported getting a bonus for introducing good ideas that proved successful.

Factors Influencing Work Pace

Identification of peaks in work pace – Interviewees were asked if there were events that made them work harder, faster or for longer. Four (21%) felt that there were none, whereas other comments included stockpile / high wood flow (6), forwarder use / speed (2), Waratah use (2), very short drags (2), dealing with breakdown / rope breakage (2), dealing with trucks / forwarders simultaneously (3), and lack of space if on a small skid site. Whilst most felt that they did not struggle to get their work done in the time available (12) there were isolated comments concerning problems arising from truck arrival (1), being short staffed (1), or if unusual problems arose (1).

Task interdependency – The impact of increased or reduced speed of others in the work flow was discussed, with almost half (n=8) feeling that this did not have an impact upon their workload. However, the remainder felt that this could occur either due to environmental conditions such as a steep slope (1), or if those elsewhere in the process slowed / speeded up (10).

Roles under greatest pressure – Interviewees were asked if there were any jobs that were more pressured than others. Responses included falling (if the feller buncher needed access) (1), breaking out (5), line setting (1), skid work (2), machinery operation (1), and hauler driving (3).

Rotation to other jobs – Almost half of interviewees (n=9, 47%) reported no rotation to other jobs. Where a reason was given this was as a result of nobody else being suitable to take on their role (2), being in training (1), or because of injury (1). For those who did rotate jobs, the main reason for this was to cover absence (7) or because their own role wasn't needed at all times (2).

Site conditions – Some thought that the weather did not affect their work pace (n=6) whereas most (10, or 53%) felt that extremes of hot ("can't pull so much wood") or poor weather (causing machines to slip in mud, blunting saws etc.) impeded pace. Apart from two interviewees, most felt that poor housekeeping (site tidiness) adversely influenced work pace (13), led to slips / fatigue (3), or (concerning log stacks) increase loading time (1). The majority (11, or 58%) felt that their role carried responsibilities for housekeeping.

Barriers to work production

The interview was completed with an open question "What gets in the way of your work production – what can slow down your work?". Responses concerned machinery, people, wood flow and site conditions / layout and largely reinforced the range of information captured during data collection (Table 7).

Table 7: Aspects of the logging operation that slow down work – Crew members

Conditions / layout	**Wood flow**
• Poor terrain / slash (3) Weather (1) Stuck trees (1) • Inadequate space – small skid (2) • Poor skidder access (1) • Hauler and Waratah space if working together (1)	• Speed of breaker outs (2) • Greater work speed in summer (1) • Slow wood flow (1) • Incorrect decision making by Waratah (1) • No bunched wood (1) • Stress with keeping up with hauler (1) • Too many trucks at once (2),
People • Managing absenteeism (1) • Forest management rep on site (1) • Poor communication (2) • Accident (1)	**Machinery** • Hauler stopping (1) • Forwarder not being able to keep up (1) • Machinery breakdown (4) • Use of old equipment / 2nd hand parts (1)

Analysis of Contractor / Supervisor Interview Data

Interviews were conducted with either the crew Supervisor (Study One) or the contractor (Studies Two, Three and Four) and lasted approximately 20 – 40 minutes each. The questions concerned a variety of aspects influenced by, or that influenced, the temporal nature of the process flow and work management.

Production and Log Uplift

Cut plan specification and log stack layout – Interviewees reported that the cut plan could change at any time; that they may continue with the same plan for a number of weeks, or that it could change on a daily basis. Any changes to the cut plan would be determined by the forest company or market demands, but the skid site and stack layout was generally determined by either the contractor (1) or the lead loader driver (3). This was determined according to which grades they produced most and which ones were in most demand; if a log specification was a priority then it was stored as accessibly as possible (to ensure moving wood as little as possible), otherwise it was stored further away.

Log turnover – There were differing reports about the number of trucks arriving on site per day – a couple of operations had a predictable number (7 or 10 trucks), whereas the others felt that it was out of their control and depended on the dispatcher. Although trucks could be held up due to adverse weather, there was concern about inadequate numbers, or unpredictability / inconsistency in truck arrival times (with 3 to 20 arriving on any one day, or with a glut arriving at the end of the week). It was reported that such unpredictability resulted in either the need to work Saturdays / double shift, or a build-up of wood / high stacks on the skid.

Liaison with truck companies – For all interviewees, trucks could arrive on site at any time from 04.00 if collection had been organised between the loader driver and dispatch (depending on stock, load type, priority, truck availability). Manning of the early start varied – in one case the contractor preferred to do the loading himself; in another the dispatch company provided their own night shift or loader driver; for the others the crew loader drivers made an early start when needed. In a couple of cases it was indicated that the dispatcher stipulated the start times that the loader drivers should be available; in one case the early start was requested by a contractor in order to free up crews during the day. Factors considered to influence truck arrival were: prioritising according to volume of wood in stock; favouritism between truck companies and specific crews; or 1 – 2-hour delays at the ports while logs were scaled.

Equipment and 2-staging

There were few comments about modifications to the existing equipment, although a couple noted that they had raised the cab of the loader / digger. While costs were a concern regarding acquiring preferred machinery types, some preferences were shown for: use of the ‘Skycar’ (to facilitate the breaker out work); higher weight capacity and air conditioned loaders; and the use of a Waratah (to reduce the need for two processing areas on smaller landings). One interviewee spoke very positively about the benefits of two-staging, whereas two others felt that it could be more difficult or more costly.

Location

Only two interviewees provided details about skid site dimensions, but these varied from 30 x 60 m to 60 m x 60 m. Placing the harvester at the side of the road was reported as a possible way to work around limited space, but three interviewees reported that they had had to alter a worksite (roading / skid site) in the past, one of which concerned their current site. Typical revisions included: increasing the landing size (especially for manual processing); insertion of standards around the landing periphery to stop logs rolling downhill; and road reinforcement to reduce gradient and facilitate machinery access. There were concerns that skid sites were not always well thought out, that the Regional Council restricts skid site allowances, and that road lining crews were not appropriately paid to remove sufficient volume of wood.

Contractual

All contractors paid their crews on a fixed rate, relative to experience and training, and overtime was offered to all crew members. Two crews offered bonus payments (relative to volume of wood pulled).

When describing their greatest financial burdens, varied reports were given. Two interviewees reported ‘wages’, whereas other reports concerned ‘competitive tendering’, ‘breakdowns’, ‘fuel’, ‘cost and maintenance of new equipment’, and ‘compliance’.

Barriers to Optimum Work Scheduling

The interview was completed with an open question “What gets in the way of scheduling – what can slow down the work?” The following responses were gathered, and largely reinforced the range of information captured during data collection.

Table 8: Aspects of the logging operation that slow down work – Contractor / Supervisor

Conditions / layout • Inadequate space (1) • Weather (1)	**Wood flow** • Inconsistent truck arrival (1) • Timber demand – if have to cut shorter rather than longer lengths (1)
People • Inexperienced crews (2) • Absenteeism (3)	**Machinery** • Machinery breakdown (2)

INTERPRETATION OF FINDINGS

Findings have both confirmed and extended existing knowledge of the range of factors that impact upon scheduling and inhibit process flow. Initial observation enabled isolation of operations likely to experience time pressure in the process flow – hauler, Waratah and loader operations. These operations were then analysed in greater detail, with the inclusion of GPS data findings where possible. The site data collection also included interviews with crew members and contractor / supervisors, and these data both support and provide new insights into scheduling-related problems. Findings from all three sources have been collated and are reported here. Where relevant, material from the initial literature search or relevant new material has been incorporated. New material has also been introduced where this is relevant to findings and assists in interpretation or development of recommendations. Each of the following four sections is followed by a series of recommendations to be considered in future interventions.

Equipment, Tooling, Machinery

<table>
<tr><th colspan="2">Data from previous research</th></tr>
<tr><td colspan="2">• Varied machinery preferences may impact upon work pace
• Machinery style preferences have changed over the years
• Variable condition of equipment
• Concern re physical and mental stressors among machinery drivers</td></tr>
<tr><th colspan="2">Summary of findings</th></tr>
<tr><td>Process flow and task analysis</td><td>• Faller, log making, pole man and forwarder/skidder operator roles appeared least likely to experience time pressure.
• There was insufficient information to identify time pressure demands of a buncher operator.
• Difficulties experienced by breaker outs whilst training & working on awkward terrain may have incorporated some time pressure, but hauler problems prohibited a fuller evaluation.
Disruption to process flow and contribution to time pressure was most prevalent among:
• Hauler operations
- Difficulties with rope movement and cable quality / rope breakages caused significant problems and delays for two of four sites studied.
- Mechanical / electrical problems with the hauler / skyline
- Cable tension and control difficulties with long drag distances / poor terrain were reported.
• Waratah operations
- The rate of hauler delivery and forwarder removal suggested time pressure for the Waratah driver working within this configuration; this was confirmed through the example calculation using GPS data.
- The only rest opportunities were when either of the pre/aft activities reduced their work rate and task interdependency abated.
- Time pressure upon workload appeared reduced where a buffer stock was available.
• Loader operations
- There are concurrent demands upon loader operators' time and attention demands – they have a number of competing tasks.
- Three of the five loaders spent 34% - 50% of their work time occupied with truck loading
- All loaders spent 14% - 77% (average 38%) of their time on non-truck related log movements.
- Log movements around the skid site incorporated double handling; this arose through having to traverse stems / logs beyond the reach of the boom, and through the number of finely tuned movements needed to effect outcome.
- The grapple hook design did not appear to facilitate the range of detailed and controlled movements required of it.
- Where a loader was being served by a forwarder, this appeared to induce some time pressure, given its faster work rate.
- It was not possible to identify whether this would also occur with a skidder, even though this did not match the carrying capacity of the forwarder.</td></tr>
<tr><td>Crew interview data</td><td>• There were 14 comments that the work day is lengthened by managing hauler breakdown / maintenance, machine servicing and setting up / moving hauler ropes.
• Work pace peaks (working harder, faster and for longer) were associated with forwarders, or trucks and forwarders simultaneously, Waratahs, and managing breakdown / rope breakage for 9 interviewees.
• Over half the interviewees felt that their work pace was dependent upon that of co-workers (although the remainder did not).
• Breaking out was considered the most pressured job of all those in a crew, followed by hauler driving and skid work.</td></tr>
</table>

Contractor interview data	• Machinery type preferences were described such as improved carriages (such as a Skycar to aid breaking out, larger machines, and air conditioned loaders and Waratahs.
Interpretation	The site data collection process enabled identification of time pressure and inconsistencies in handling capacity; operational speeds of equipment used sequentially in the process flow appeared to contribute towards time pressure. Of the three key processes identified, the hauler-related problems appeared the most significant as they stopped process flow from breaker-outs through to much of the skid site operations. There were also many complaints from crew interviewees of being slowed down, work pace peaks and the adverse impact on their work day length from managing maintenance and hauler-related problems such as rope breakages and movements. Time pressure for a Waratah operator was identified when working at a pace to match output of the hauler and demand of a forwarder. Although only an isolated example, when compared with Waratah operation from a buffer stock, work pace appeared less strained. Nevertheless Waratah operations were also associated with causing work peaks. Site data collection identified a number of concerns about the potential for time pressure in loader operations – primarily as a result of concurrent demands upon their time. Chances to take shorter breaks / get out of the cab and move around appeared limited, unless they arose opportunistically because their route on the skid was blocked and they were unable to move. The task analysis also identified potential design: task incompatibilities with the loader, firstly in double handling needed to move stems / logs any distance along the skid, secondly arising from the poor control of (especially longer) logs by the pincer grasp of the grapple, and thirdly in the amount of fine tuning movements undertaken by the grapple to position logs in stacks. It is not known whether there are design alternatives for these tasks, or whether alternative design / techniques might alleviate some of these task components. In assessment of all the operations, breaking out seemed likely to experience time pressure only when terrain was particularly poor, or when training was in progress. However, that five crew members considered this one of the most pressured jobs indicates that further information would be required. From a generic perspective process flow in cable logging is similar to machine-paced work. The problem with a work pace arising from the rate of work of pre and aft functions is that this can introduce time pressure. Where workers are not able to select their own work rate they are vulnerable to either physical or mental under load / overload (ILO 1996). Preferred work pace will vary between operators and, for any one operator performance will fluctuate over a work day. Crew complaints of workload that induced longer work days or created work pace peaks reinforces the researcher observations of time pressure.

	Recommendations regarding Equipment, Tooling, Machinery • As a priority, review design of hauler / rope configurations, rope quality and techniques adopted for rope movements. Establish what scoping for further improvement or redesign of this system has been proposed and undertaken, and identify ongoing intervention needs. • Introduce buffer stocks to minimise time pressure between interdependent tasks; this will need to be trialled and supported with education and attention to necessary space requirements. • As interviewees reported greatest pressures amongst breaker outs (whereas this was generally observed to experience low pressure due to rest opportunities between hauling), further analysis is advised. • Opportunities to relieve loader operators' workload and facilitate tasks should be explored. Ideas for consideration should include: - whether development of the loader grapple design, from single to multiple opposable prongs, would be advantageous for better controlled log / stem manipulation; - whether there is alternative equipment, such as an over-head gantry or conveyor, that could be used for longer distance movements on the skid; - whether self-loading log trucks could be used; - whether all fine tuning / tweaking manoeuvres are necessary – what is the tolerance in alignment of the ends of logs when stacking logs? Where this is a priority early 'packaging' together of logs on the skid site may be appropriate. This could be achieved through alternative storage means such as using stillages (storage frames) to contain logs, jigs to upend and align ends of) and/or strapping together of logs. In turn, if logs are bundled or stored together, these methods may also facilitate later log movement operations – e.g., the speed and efficiency of log truck loading, etc. • Further research and information provision concerning the relative merits / cost benefit of using different machinery types would be advantageous.	

Layout / Space / Environment

Data from previous research	
• Poor ground conditions of shared machinery / transit routes • Small skid site size for log storage, machinery and truck access • Impact of adverse weather on work progress • Inappropriate site plans / site preparation • Varied preferences for and uptake of 2-staging • Log stack height adversely affected by production pressures & limited landing space	
Summary of findings	
Task Analysis	• Hauler presence can contribute towards site inaccessibility. • Truck presence can contribute towards site inaccessibility. • An alternative 'road-side' skid layout (avoiding truck access to the working area) avoided interruption to other skid site operations, whereas some work stoppage / interruption was observed with 'drive-through' sites.
Crew interview data	• Many interviewees considered that poor housekeeping (site tidiness) would impede work pace. • Over half also thought that weather extremes would adversely affect work pace.
Contractor interview data	• The loader driver is generally responsible for determining the skid site and stack placement layout (according to frequency of demand, volume, priority of a particular grade). • There is unpredictability in determining skid site layout, as the cut plan can change without notice. • Two-staging was seen both from positive and negative (more difficult & costly) perspectives. • Alteration of roading / skid site is sometimes necessary to improve access, prohibit risk of rolling logs and increase the size of the working area. • Influences on skid sites inadequacy are thought to be poor planning, Regional Council restrictions and inadequate road lining crew payments.

Interpretation	Previous research of factors influencing landing size identified a number of variables influencing requirements (such as extraction system, geography, manning levels), and it was proposed that the landing size should increase to accommodate irregularities in truck scheduling and future needs for storing longer lengths and greater volumes (Raymond 1987). It is not known whether such increases have occurred in this time period, however complaints about small skid size persist. Neither is it clear how the formulae for "roughly" calculating skid site sizes (Larcombe 1999) were determined, and whether or not their adequacy has been reviewed in the light of current concerns such as unpredictable log uplift frequency by trucks, or rapidly changing cut plan requirements. In addition to complaints regarding small skid sites, there were concerns that the layout and the presence of other vehicles / equipment can inhibit accessibility and opportunities to move around site, which inhibited work progress on occasions. Although the Forest Roading Manual (Larcombe 1999) suggests that the drive-through skid site layout style allows better access for truck loading, the adverse impact upon other skid site activities suggests that establishing factors that define the most desirable landing style warrant further consideration. Opportunities for extending the work area to a 2-staging process were available to these crews, yet these layout configurations have a mixed reception with contractors. It is not known what information is available concerning costing and problem management with these alternative layouts. An alternative practice is that crews extend the site / roading themselves, yet this can compromise their production time. That sites and roading are being revised suggests that the necessary communication and planning for contractor needs are not being met. Skid site log stack layouts are generally determined by the loader driver, yet the Best Practice Guidelines for skid layouts (FITEC 2000) (although they describe optimum design features), do not provide example pictorial guidance or suggest how adverse conditions might best be managed. It is not known how process of devising skid site log stack layouts is learnt.
	Recommendations regarding Layout / Space / Environment • Alternatives in skid-site layouts should be explored and the range of optimum layouts evaluated in the context of concurrent demands by all skid site users, to manage access issues arising from trucks on site, wood placement needs and hauler position. If optimum designs, and means of accommodating a fluctuating cut plan can be established, these should be communicated through training materials and other industry communication • The relative advantages and disadvantages, and cost-benefit analyses, of alternative skid layouts should be identified and communicated to industry. This may also incorporate cost-benefit of alternative equipment uses. • Further work into improved planning and building appropriate quality, access and layout of skid sites and roading is necessary.

Work Scheduling, Pace and Procurement

<table>
<tr><th colspan="2">Data from previous research</th></tr>
<tr><td colspan="2">• Early start times and one-break/day (especially North Island crews)
• Machinery operators – inconsistent break taking, long work days
• Inconsistent adoption of short breaks by machinery drivers
• Routine overtime for many crews
• Lengthy travel times
• Inconsistent / very early truck arrival times
• Volume-based payments may pressure output
• Production target calculation methods unknown</td></tr>
<tr><th colspan="2">Summary of findings</th></tr>
<tr><td>Crew interview data</td><td>• Crew interview data concerning time planning reinforced earlier findings:
- Early rising (most commonly between 04.00 and 05.00)
- One 30-minute break per day for three of the four crews. Breaks can be interrupted by truck arrivals, work delays and bad weather.
- Routine overtime (almost half worked an extra day/week)
• Loader drivers regularly rose (from 02.00) and started earlier (from 03.30), work longer days and take fewer breaks.
• Driving time is most commonly 1-1½ hours each way.
• Not all take the full holiday complement.
• Having to work harder, faster and for longer was associated with high wood flow for six interviewees.</td></tr>
<tr><td>Contractor interview data</td><td>• Preparing logs and the skid site for truck pick-up can lengthen the work day.
• There were varied reports of truck numbers arriving on site – both of consistent and inadequate numbers.
• There can be predictable and unpredictable arrival times – during the day or week.
• Inconsistent truck arrival influences the need to work overtime and the height of log stacks
• There were reports both of the contractor requesting early truck arrivals (to allow unhindered work processes during the day) and of truck companies stipulating that loader drivers should be available for an early start.
• Early starts are manned both by the logging crew or by night drivers from the truck company.
• External influences to truck arrivals were reported to be stock demand, priority, truck availability, favouritism of different contractors and delays at port while logs are scaled.
• The were equal reports of crews both receiving and not receiving bonus payments by volume.
• Contractors experienced different financial burdens – two described ‘wages’, whereas other individual reports included ‘competitive tendering’, ‘breakdown’, ‘fuel’, cost and maintenance of new equipment’, and ‘compliance’.</td></tr>
</table>

Interpretation	The interview data identified that crews, and especially machinery operators, are not taking breaks recommended for those undertaking harvesting tasks. Neither are they formally taking the minimum time allowance stipulated in the Employment Relations Amendment Act, 2008. Diminished output may result from improperly scheduled work pauses (Apud and Meyer 2004), and this suggests that the advantages of rest and impact upon performance are not well understood. Whilst the workload of machinery operators is not physically demanding they are still vulnerable to more isolated risk factors (such as OOS potential) and mental workload demands. The literature search revealed a temporal relationship between varied machinery operations and adverse health effects, and while this does not necessarily define the specific equipment observed during these studies, it does draw attention to the potential of ill health risk factors amongst this workforce. Health investigations of 1174 Swedish forest machine operators indicated that 50% experienced one-sided overload syndrome from operating vehicle controls (Axelsson and Ponten 1990) and, although likely concerning equipment that would have been more dated in design, illustrates the problems that can occur. The restrictions on truck driver work hours offer an example of how an associated industry with similar work conditions is managed. In a study of the health and fitness of log truck drivers it was proposed that, as well as some direct initiatives to deal with wellbeing, larger supply chain issues (such as co-operation with mills, ports, forest owners) need to be addressed (Mackie 2008). However, given the wide range of logging machinery operator tasks and responsibilities, it is likely that the mental workload for these operators is greater than that of truck drivers. The adoption of truck driver minimum standards would not necessarily be adequate for these operators. Nevertheless machinery drivers work up to 12 hours a day on an early start, and (including driving time) this is close to truck driver limits. Literature concerning circadian rhythm indicates changes in daily patterns of sleepiness and wakefulness. A review of shift work, safety and productivity indicates lower levels of alertness before 07.00, with industrial efficiency at its lowest between 03.00 and 04.00 (Folkard and Tucker 2003). Whilst there are individual differences in performance, this highlights a concerning issue for those driving in the night/early morning. A questionnaire survey of 367 New Zealand forest workers identified that 78% experienced ‘fatigue’ at least sometimes (Lilley *et al*. 2002), and that fatigue is significantly associated with involvement in a near-miss injury event. Of this sample, they reported that $^{1}/_{3}$ of forestry workers take one break/ day or less, and that many machinery operators work up to 15½ hours per day. They also reported research findings indicating that sleep of six hours is insufficient for daytime alertness (Gillberg 1995, cited by Lilley *et al*. 2002) . It was elsewhere reported that fatigue is responsible not only for safety concerns and machine damage, but also damage to stands through careless processing (Nicholls *et al*. 2004). The previous landing study, although over 20 years old (Mythen 1987) also identified problems arising from inconsistent arrival of trucks and pressures dissipated to the gang from a glut of arrivals within a two-hour time period. Better truck scheduling was recommended, but in spite of the problems currently identified it is not known whether there have been any improvements in the intervening years. While the focus of this research was on work scheduling, there appears to be widespread lack of acknowledgement concerning apparent inadequacies of existing systems in setting or agreeing to achievable production targets. Underlying reasons to this are unknown, but the need for payment of competitive and realistic harvesting rates based on realistic productivity expectations has previously been called for (Nicholls *et al*. 2004).

	Recommendations regarding Work Scheduling, Pace and Procurement • Assess the mental workload and risk factors for occupational ill health of machine operated tasks and work-related driving in order to explore optimum work: rest regimes. • The need for incorporating a time concession into working hours for those driving to and from work should be considered. • As a priority, the underlying theory, criteria and culture relating to establishing an acceptable production target needs to be explored and addressed. In determining such criteria all barriers to production must be accommodated. At the very least, this must incorporate increased workload arising from the cut plan and reasonable time allowances for machinery breakdown / cable movement, until such time as remedial action can be sought for these problems. It must also ensure that recommended break allowances and a standard working week that does not require overtime is accommodated. Measures to manage any cultural resistance / changes, through all levels of industry, that will accompany revised work scheduling will also be needed • Work in common, to explore common solutions to early starts and poor truck scheduling, should be undertaken as a collaborative project with representation from both the forest and trucking industries

Job Design

<table>
<tr><th colspan="2">Data from previous research</th></tr>
<tr><td colspan="2">• Limited job rotation (extending exposure to any specific risks)
• Personnel shortages & holiday / absence cover difficulties</td></tr>
<tr><th colspan="2">Summary of findings</th></tr>
<tr><td>Crew data</td><td>• Just under half the interviewees rotated to other jobs, primarily to cover absence or because their normal role wasn't needed at all times</td></tr>
<tr><td>Interpretation</td><td>In a questionnaire survey of 358 forest machine operators in Europe, it was identified that job rotation has a positive effect on job satisfaction and musculoskeletal symptoms (Hanse and Winkel 2008). Research into the development of work-shift rosters, work load assessment and job rotation rosters for mechanised operations has been undertaken by LIRO (Gellerstedt 1997), but there is no evidence that this is being applied. Evaluation of job rotation initiatives within the Swedish logging industry showed improvements in production, reduced health risks and more specialised teams (Synwoldt and Gellerstedt 2003).
Data from crew interviews indicate that where job rotation occurs this is a generally a reactive process to absence – the potential advantages from alternative job designs are not realised here in New Zealand.</td></tr>
<tr><td></td><td>Recommendations regarding Job Design
• Further research into logging crew job design is suggested. At the very least this should incorporate a review of the Gellerstedt (1997) research to determine why it was not adopted, whether it remains applicable and, if so, how its use, understanding and application can be disseminated
• Industry may also increase communication concerning existing management measures to mitigate the impact of scheduling breakdowns within the current work systems. The appropriateness of these intervention measures, especially with the development of the report recommendations, would require further review.</td></tr>
</table>

EVALUATION OF METHODS

The research generated both findings that reinforced those from the earlier research (such as concerns regarding skid site size and layout, job design, and the impact of production pressures) and others that have produced new material. The new material concerned identification of time pressure activities in the process flow – notably those relating to hauler use and, to a certain extent, loader operations. Although the sample size for this research was relatively small, these observations were reinforced by comments made during operator interviews. It is important however, where findings are unexpected or contrary to industry experience, that further investigation is undertaken. A drawback of this work is that the data collected related only to the conditions experienced at the time of the study, and it is acknowledged that there may be data variations arising from different conditions (weather, tree size, haul distances, etc).

As a new area of work, adoption and characterisation (specific for assessment of logging activities) of core methods proposed for use in the manufacturing sector has been effective. Those methods not adopted from the 'toolkit' generally involved much more on-task discussion and site time with workers, and this was considered undesirable for these work conditions.

CONCLUSION

The research has explored work organisational and scheduling factors that may contribute to the development of fatigue. Four cable logging crews using varied skid site layouts and organisational methods were studied. The research was undertaken through the adaptation of a methodology used in the manufacturing sector. The data collection techniques were developed specifically for the target group and to ensure that a range of known problems were explored. These methods included interviews with crews and contractors, process flow assessment and analysis of roles and activities deemed to experience time pressure.

The results from all sources were collated and findings compared with relevant literature. The findings concerned shortcomings in many areas of the work system, such as equipment and machinery design; layout, space and environment; work scheduling, pace and procurement; and job design. For some aspects findings were relatively isolated, and this may have arisen as a result of the relatively small sample size – in these cases further data collection and analysis is proposed.

A number of recommendations for intervention at both site and organisational level were made. At site level these concerned improvements to equipment used for hauling, skid site layout and to job design (especially machinery operators). At an organisational level these include the development of cost-benefit analyses (of the various machinery / layout choices), and review of the criteria used in determining production targets.

Logging crews regularly work undesirable and long hours, rise early, work overtime to meet production targets, and often take only one break per day (especially North Island crews). In order to combat these risk factors for fatigue the highest importance is placed on addressing these systems and cultural failures that have made these undesirable work conditions 'the norm' in the logging industry.

REFERENCES

Apud, E. and F. Meyer (2004). Operations: Logistics in Forest Operations. Encyclopedia of Forest Sciences, Four-Volume Set. J. Evans, J. Burley and J. Youngquist. London, Elsevier: 639-645.

Axelsson, S.-A. and B. Ponten (1990). "New ergonomic problems in mechanised logging operations." International Journal of Industrial Ergonomics 5: 267-273.

Bergstrand, K.-G. (1991). Planning and analysis of forestry operations studies. The Forest Operations Institute of Sweden. Kista, Forskningsstiftelsen Skogsarbeten. Bulletin no:17.

Bjorheden, R., K. Apel, M. Shiba and M. A. Thompson (1995). Forest work study nomenclature - test edition valid 1995-2000. International Union of Forestry Research Organisations. Garpenberg, Sweden. WP 3.04.02.

Bovenzi, M. (2008). "A follow up study of vascular disorders in vibration-exposed forestry workers." International Archives of Occupational and Environmental Health 81: 401-408.

Bunger, J., F. Bombosch, U. Mesecke and E. Hallier (1997). "Monitoring and analysis of occupational exposure to chain saw exhausts." American Industrial Hygiene Association Journal 58: 747-751.

Byers, J. (1997). Operator health - A survey of feller-buncher operators. LIRO Report Vol 22(17). Logging Industry Research Organisation Rotorua.

Cation, S., R. Jack, M. Oliver, J. P. Dickey and N. K. Lee-Shee (2008). "Six degree of freedom whole-body vibration during forestry skidder operations." International Journal of Industrial Ergonomics 38(9-10): 739-757.

Civil Aviation Authority of New Zealand (2006). Air operations - fatigue of flight crew. Lower Hutt, Civil Aviation Authority. Advisory circular AC119-2.

Crawford, S., B. MacCarthy, J. Wilson and C. Vernon (1999). "Investigating the work of industrial schedulers through field study." Cognition, Technology and Work 1: 63-77.

Cummins, T. (1998). Logmaking from a cab: Improving operator performance. LIRO Report Vol 23(11). Logging Industry Research Organisation Rotorua.

Cummins, T. (1999). Back to basics: Better ways to manage your back to reduce injury. LIRO Report Vol 24(1). Logging Industry Research Organisation Rotorua.

FITEC (2000). Best practice guidelines for loading. FITEC, PO Box 137067, Parnell, Auckland.

FITEC (2001). Best practice guidelines for manual log-making and processing. FITEC, PO Box 137067, Parnell, Auckland.

Folkard, S. and P. Tucker (2003). "Shift work, safety and productivity." Occupational Medicine 53: 95-101.

Gellerstedt, S. (1997). Job-rotation rosters for mechanised operations. LIRO Report Vol 22(10). Logging Industry Research Organisation Rotorua.

Gillberg, M. (1995). "Sleep and its relation to the length, content and continuity of sleep." Sleep Research 4 (supplement) (2): 37-40.

Hanse, J. J. and J. Winkel (2008). "Work organisation constructs and ergonomics outcomes among European forest machine operators." Ergonomics 51(7): 968-981.

Hide, S. A., L. Ashby, R. J. Parker and B. Baillie (2008). Forestry initiative - Exploring incident causation and intervention needs. Final report of research findings. ACC project no: A56820 - 16th December 2008. Centre for Human Factors and Ergonomics, Scion.

Hide, S. A., R. J. Parker and D. J. Moore (2009). The Uptake of Human Factors and Ergonomics Research. FFR Report H002. Harvesting and Logistics Theme, Future Forests Research. Rotorua.

ILO (1996). Ergonomics checkpoints - Practical and easy-to-implement solutions for improving safety, health and working conditions. Geneva, International Labour Office.

Inoue, K. (1996). "Operators' mental strain in operating the high proficient forestry machine." Journal of Forest Research 1: 195-197.

Jackson, S., J. Wilson and B. MacCarthy (2004). "A new model of scheduling in manufacturing: Tasks, roles and monitoring." Human Factors 46(3): 533-550.

Kirk, P. (1996). Reducing the impacts of fatigue on forest workers. LIRO Report Vol 21(3). Logging Industry Research Organisation Rotorua.

Kirk, P. (1998). The impact of shift length on process operator fatigue. LIRO Report Vol 23(18). Logging Industry Research Organisation Rotorua.

Kirk, P., M. Sullman and R. Parker (1996). Fatigue levels in motor-manual tree felling and delimbing operations. LIRO Report Vol 21(18). Logging Industry Research Organisation Rotorua.

Kumm, J. and S. Gellerstedt (2005). Implementation plan for ErgoWood. Uppsats. European Commission - Quality of life and Management, Swedish University of Agricultural Sciences (SLU). 5.

Larcombe, G. (1999). Forest Roading Manual. LIRO Forestry Solutions. Logging Industry Research Organisation Rotorua.

Lilley, R., A.-M. Feyer, P. Kirk and P. Gander (2002). "A survey of forest workers in New Zealand. Do hours of work, rest and recovery play a role in accidents and injury." Journal of Safety Research Vol 33(1) : 53-71.

MacCarthy, B. L., J. Wilson and S. Crawford (2001). "Human performance in industrial scheduling: A framework for understanding." Human Factors and Ergonomics in Manufacturing 11(4): 299-320.

Mackie, H. (2008). The health and fitness of log truck drivers: An evaluation of the industry and recommendations for action. L. T. S. Council. Auckland, Transport Engineering Research New Zealand Limited (TERNZ).

Moores, B. (1972). "Ergonomics - or Work Study?" Applied Ergonomics 3(3): 147-154.

Mythen, N. (1987). Landing activity. Rotorua, Forest Research Institute. Project no: ES 6. Unpublished.

Neitzel, R. and M. Yost (2002). "Task-based assessment of occupational vibration and noise exposures in forestry workers." American Industrial Hygiene Association Journal, 63(September / October 2002): 617-627.

Nicholls, A., L. Bren and N. Humphreys (2004). "Harvester productivity and operator fatigue: Working extended hours." International Journal of Forest Engineering, 15(2): 57-65.

Ostensvik, T., K. B. Veiersted, E. Cuchet, P. Nilsen, J. J. Hanse, C. Carlzon and J. Winkel (2008). "A search for risk factors of upper extremity disorders among forest machine operators: A comparison between France and Norway." International Journal of Industrial Ergonomics 38: 1017-1027.

Ostensvik, T., K. B. Veiersted and P. Nilsen (2009). "A method to quantify frequency and duration of sustained low-level muscle activity as a risk factor for musculoskeletal discomfort." Journal of Electromyography and Kinesiology 19: 283-294.

Parker, R., P. Cossens and M. Strang (1993). Human factors in log making. LIRO Report Vol 18(17). Logging Industry Research Organisation Rotorua.

Parker, R. and P. Kirk (1994). Physiological workload of forest work. LIRO Report Vol 19(4). Logging Industry Research Organisation Rotorua.

Raymond, K. A. (1987). Factors influencing landing size. LIRA Report Vol 12(1). Logging Industry Research Association Rotorua.

Samset, I. (1990). Some observations on time and performance studies in forestry. Norwegian Forestry Research Institute. Skogforsk As. 43(5).

Sullman, M., K. Darry and T. Paterson (1997). Heavy vehicle driver fatigue - How to prevent it! LIRO Report Vol 22(6). Logging Industry Research Organisation Rotorua.

Sullman, M. and P. Kirk (1998). Mental workload of mechanised processing with a single grip harvester. LIRO Report Vol 23(17). Logging Industry Research Organisation Rotorua.

Sutinen, P., E. Toppila, J. Starck, A. Brammer, J. Zou and I. Pyykko (2006). "Hand-arm vibration syndrome with use of anti-vibration chain saws: 19 year follow-up study of forestry workers." International Archives of Occupational and Environmental Health 79: 665-671.

Synwoldt, U. and S. Gellerstedt (2003). "Ergonomic initiatives for machine operators by the Swedish logging industry." Applied Ergonomics 34: 149-156.

Wästerlund, D. S. (1998). "A review of heat stress research with application to forestry." Applied Ergonomics 29(3): 179-183.

APPENDIX ONE- Physical and Psychological Work Loadings

	Adverse impact- health / performance	Agent(s)	General risk factors	Temporal risk factor	Temporal Recommendations
	Noise	Chainsaws. Heavy machinery	Forty-three forestry workers were assessed for noise exposure, and mean noise levels were above 85dB(A) for tree falling and choker man tasks (Neitzel and Yost 2002)		None
	Whole body vibration	Skidder operations	Rotational vibration was measured amongst 7 skidder machines in 2006 (Cation *et a*l. 2008). • Acceleration data indicated a very uncomfortable ride • Data are similar to findings from the past 20 years, indicting little change in seat design or operator adjustment	• Acceleration data exceed upper exposure limit for a 4-hour work day (ISO 2631-1:1997) and health effects are likely	None
		Chainsaws. Heavy machinery	Forest machinery workers were assessed for WBV exposure and the potential for adverse health effects were identified (Neitzel and Yost 2002)		None
	Hand-arm vibration	Chainsaw	Seventy-one forestry workers (with daily exposure of ~ 2.5hrs) were assessed between 1990 and 1999 for the occurrence of vibration-induced white finger (Bovenzi 2008) • Forestry workers with work experience limited to Anti-Vibration chain saws are still at risk of developing VWF	• An increased risk of developing VWF among anti-vibration chainsaw users over a 9-year follow-up period	None
		Chainsaws. Heavy machinery	Forty-three forestry workers were assessed for vibration exposure (Neitzel and Yost 2002) • HAV levels of anti-vibration saw users are high compared with recommended standards, and HAV reports are anticipated amongst those with intensive chain-saw use • Heavy vehicle equipment controls are also seen as HAV risk factors		None
		Anti-vibration chainsaws	A 19 year follow-up study of 52 AV chainsaw users (Sutinen *et al*. 2006) showed:- • A reduced and low incidence of VWF although numbness was increased • Musculoskeletal disorders in the R upper extremity, of which the contribution of vibration is relevant		None

	Adverse impact-health / performance	Agent(s)	General risk factors	Temporal risk factor	Temporal Recommendations
	Upper extremity disorder / Occupational Overuse Injuries (OOS)	Machinery operations	A comparison was made between groups of French and Norwegian harvesting machine operators; they performed equal tasks in order to identify risk factors for upper extremity disorders (Ostensvik *et al*. 2008) • French workers reported less neck pain than the Norwegians • One measure of shoulder muscle activity was significantly higher amongst French drivers than Norwegians	• There were fewer symptoms among French drivers who took more frequent short breaks • Lunch breaks amongst French drivers were x 3 longer than the Norwegians	None
			A sample group with 19 harvesting and 20 forwarder operators were tested for low level muscle activity during operations (Ostensvik *et al*. 2009) • Periods of low level muscle activity greater than 10 minutes per hour were positively correlated to complaints in the neck region		None
		Feller buncher operation	A survey of OOS symptoms among 23 feller-buncher operators identified that 43% had pain all the time and mostly in the wrists and hands (Byers 1997). Work features of those injured included:- • Working an average of one hour extra per day, a slightly longer week and slightly longer years' experience than those workers without injury • Considerably less training (0.7 days) than those uninjured (2.7 days) • Greater perception of isolation and stress than those uninjured	• Being sub-contracted to other crews was perceived as stressful due to inability to take breaks when in pain and being timed on the job • Injured operators generally felt less able to dictate their own work pace • 53% never reduced their work pace when in pain	• Job rotation • Micro pauses • Get out of cab, walk around & stretch – preferably hourly
	Musculoskeletal disorders - general	Harvester machine operators	Reporting a European survey with 6 participating countries (Liden, E. cited by Kumm, 2005) identified health complaints of the lower back and neck by 84% of machine owners and 80% of employed operators. These data compared with a ~ 60% reporting rate in the late 1980s. The report also indicates changes from the late 80s to time of reporting as:- • No improvement in exercise habits • No decrease in average machine age	• Average weekly work hours of machinery owners of 55 hrs/week and 46 hours among machinery operators • 22% of operators work more than 50 hours/week • Decreased level of control and high time pressure	
	Back injury	All harvesting tasks	In describing risks for back injury (Cummins 1999)identified risks for back injury arising from:-		• Limit shift length to less than 4

	Adverse impact- health / performance	Agent(s)	General risk factors	Temporal risk factor	Temporal Recommendations
			• Vibration effects from machinery driving • Incorrect lifting techniques		hours • Frequent short breaks • Leave machine and stretch back and legs at least hourly
	Heat stress	Environment	A literature review of heat stress research (Wästerlund 1998) identified:- • Lack of consideration of women's' heat stress exposure in ISO standards • Potential adverse effects of heat and dehydration on performance • Protective clothing can adversely affect heat exchange	Self-chosen rest periods are too short to dissipate heat – rest allowances should be pre-determined (Vogt *et al*, 1983)	Yes
	Heart and vascular disorders	Exhaust fume	Chainsaw exhaust exposure was measured through air monitoring and determining logger carboxyhaemaglobin (COHb) levels (Bunger *et al*. 1997) • The biological exposure index for COHb was exceeded by forced ventilation arising from physical workload • Levels were highest associated with leaning / squatting, low wind speed and density of the forest	• Under piecework conditions maximum values were reached after 2-3 hrs in coniferous stands and then declined	None
	Mental strain and stress	Machinery operations	Mental strain was evaluated through surveying machine operators' reports of fatigue symptoms and stress (Inoue 1996) • Harvester and excavator workers rate 'sleepiness and dullness ' as especially high, yet harvesting is seen as complicated (leading to mental fatigue), whereas excavator operation is seen as monotonous (leading to mental strain) • Stress intensity increased after work for processor and excavator drivers, and especially so for harvester and forwarder operators • Tower yarders' work has greater physical demands and is seen as less stressful. • The overall strain complaint ratio (combining fatigue symptoms and stress complaints) identified excavator and harvester work as the most demanding activities,	• Process operator work was reported as less stressful as waiting times allow periods of rest • Reports of rushing amongst forwarder operators to keep up with harvesting machine work rate • Pressure of meeting deadlines for contract work.	None

	Adverse impact-health / performance	Agent(s)	General risk factors	Temporal risk factor	Temporal Recommendations
			with tower yarder and processor work less so		
		Harvesting operations	Mental workload was evaluated for three harvester operators (Sullman and Kirk 1998). Findings indicated:- • Mental workload was considerably higher than that experienced by airline pilots & the simulated flying f a helicopter		None
	Boredom	Log making	Evaluation of human factors in log making explored value recovery, boredom and physiological workload (Parker, 1993)	• Log maker work pace is tied to the cycle of skidder arrival	• Rest breaks → greater value recovery • Potential to rotate jobs at every break
		Forestry work	In explaining theories of physiological workload measurement the following workloads were described (Parker and Kirk, 1994) • Motor manual felling & delimbing = very high workload tasks • Breaking out = heavy, with periods of very heavy workload during periods of pulling strops and rapid movement to safety • Log making = moderate to heavy		• Be aware of the importance of rest breaks
	Fatigue	Forestry work	In identifying measures to reduce the impacts of fatigue on forestry workers (Kirk 1996) identified risk factors relating to inadequate:- • Nutrition, alcohol intake, hydration and body condition.	• Work with fewer breaks results in a higher average heart rate with more fatigue and less production • Risk of cumulative fatigue with early summer starts	• At least 2 x 30 min rest breaks / day (at ~ 10.30 & 1.30), with the pm break being fundamental • Replace lost sleep
		Heavy vehicle drivers	In identifying measures to reduce the impacts of fatigue on heavy vehicle drivers (Sullman *et al*. 1997) identified risk factors relating to inadequate:- • Environment (long haul / unchanging conditions, poor truck quality and weather) • Individual (age, medical conditions, sleep debt/ disorders, smoking, poor diet, dehydration and inadequate exercise	• Driving when normally asleep (especially between 2-5am) • After lunch drowsiness • Hours awake before trip • Length of work before trip • Length of time since starting trip	• 6-8 hours quality sleep/night

	Adverse impact-health / performance	Agent(s)	General risk factors	Temporal risk factor	Temporal Recommendations
				• Driving under time pressure	
		Motor-manual tree felling & delimbing	Workload of 6 fallers was evaluated (Kirk *et al*. 1996). Findings indicated:- • Felling and delimbing entail heavy to moderate workload • Mental fatigue not apparent • Fatigue and discomfort increased as the day progressed	• Production decreases from 13 m^3 in the morning to 11 m^3 in the afternoon • 2 fallers who took an hour lunch break were (i) able to return to full production immediately, whereas those taking only 30 minutes had difficulties. They also (ii) experienced significantly lower hazard frequencies in the afternoon, but with no decrease in productivity	Use breaks to rest
		Processor operators	A study of alternative shift schedules on 3 processor operators were evaluated through measurements of subjective fatigue, stress level, physical workload and muscular discomfort (Kirk 1998).	• Increased fatigue, body part discomfort and mental demands as the day progressed	• More frequent breaks (rest or at alternative & varied tasks) • Limit shift length to a maximum of 4 hours • 40 minute break every 3 – 4 hours continuous operation • Get off the machine for 5 minutes each hour • Break the work day every 3-4 hours by rest, meal, or maintenance breaks, or include job rotation / enlargement • A minimum of 2

	Adverse impact-health / performance	Agent(s)	General risk factors	Temporal risk factor	Temporal Recommendations
					operators / shift on an extended work day
	Operator performance	Single-grip processor operators	A survey of 23 excavator based single-grip processor operators (Cummins 1998) identified:- • Poor visibility and difficulties measuring sweep & knot size	• Extended working hours – most commonly 9-10 hours (up to 13) • Isolated instances of few / no breaks taken	• More frequent breaks combined with job rotation, physical workload & getting off the machine

APPENDIX TWO – Literature Search Terms

The literature search was undertaken from September - November 2009 using the National Forest Library "OPAC" and also its online databases Scopus, ISI World of Science and Informaworld.

The core search terms "logging", "harvesting" and "forestry" were compared against the following search terms:-

<table>
<tr><td>Logging</td><td rowspan="3">Shift work
Schedule
Work*
Hour*
Work* organisation
Fatigue
Job rotation
Workload
Time study
Work study
Performance
Performance study
Work phase
logistic</td></tr>
<tr><td>Harvesting</td></tr>
<tr><td>Forestry</td></tr>
</table>

APPENDIX THREE – Interview Proforma

CONTRACTOR INTERVIEW

A. Production

1) How many stems are delivered to the landing per day
   a) What are the delivery intervals and numbers per bunch
   b) What are the approx / average drag distances / obstacles (geography, windthrow, other influences?)
2) Regarding grade specification, log storage and removal
   a) How many grade / length combinations are there in your cut plan (how many different stacks do you need to maintain)?
   b) How often does the cut plan change?
   c) Are there any issues with log turnover (e.g. frequency of uplift, carrying old stock)?
   d) How is the skid site layout and log stack position determined?

B. Equipment

1) What equipment is being used (type of hauler, processing head, forwarders etc.)
   a) Any comment re. style, age, modification, task type of each
   b) Do you have any preferences for preferred machinery types (why)?
2) Are there any restrictions / drivers to machinery selected / available?
3) How is log making undertaken – processing head, manual processing
   a) What are the advantages of each method

C. Location

1) What are the skid site dimensions
   a) Any comment on shape, surface quality (soil type / water-logging)

2) Road access –
   a) What is the access in and out of forest / to the skid area;
   b) What distances are travelled

3) Has the crew altered / increased the worksite (roading / skid site) since site handover

D. Truck arrival / Log removal

1) How many trucks arrive per day
   a) What are the arrival times
   b) Do you liaise with company / drivers *re* arrival times, and how much influence do you have on these times)?
   c) Is there any influence arising from ports, sawmills, other?
   d) Is there anything about trucks that influences their performance?

E. Contractual

1) What are the volume expectations of the contract and per day?

2) Are there any performance measures that affect the crew (such as payment by volume, terrain, quality, machinery – what is considered?

3) What is the payment criteria for the workforce? – by fixed rate, piece work, job type, skills, experience, responsibility, incentive / bonus payments, other?

a) Is a bonus available and what are the payment criteria?

4) What are the greatest financial burdens – bank repayments, wages, competitive tendering, fluctuating trade value of the NZ$, statutory requirements (H&S, environment, forest company)?

F. What gets in the way of scheduling – what can slow down the work?

CREW MEMBER INTERVIEW

A. Crew organisation

1) How many are in the crew and for each task type?

2) Working hours
   a) What is your shift / work day length and how does this vary over the year?

   b) Are there any specific tasks, events or activities that can lengthen your work day?

   c) How many days on / off per week?

   d) Is there overtime (how much and is it voluntary or not)?

   e) Are you involved in deciding your work hours?

   f) What is your driving time per day?

3) Work pace
   a) Are there any peaks in your work pace (events that make you work harder, faster, longer)?

   b) Among all crew jobs are there any jobs that are more pressured than others?

   c) Does it affect you if you/ others in the work flow slow down or speed up?

   d) Do you ever struggle to get your job done on time (why and how often)?

4) What breaks do you take per day?

   a) Consider duration, location, frequency

   b) Are there any barriers to taking breaks?

   c) Do you feel that you have enough breaks?

5) Sleep: How many hours of sleep do you get per night?
   a) Do you have good sleep quality?

b) What time do you go to bed / get up?

6) Holiday
   a) How many weeks holiday do you get per year?

   b) How are holidays / absences managed?

7) Job rotation / enlargement
   a) Are crew members rotating to other jobs?

   b) What are the criteria for organising this?

8) Is your work pace varied for work in the dark, wet, poor terrain etc?

9) Housekeeping
   a) Does site tidiness have any influence on your work pace?

   b) Are there any standards or responsibilities for housekeeping you have to adhere to?

10) Cost related
   a) Have there been any cost cutting moves or incentives that affect your crew?

   b) Have these had any influences on your own workload?

11). What gets in the way of your work production – what can slow down your work?

APPENDIX FOUR - Crews and Equipment for Each Study

- Study One
    - Crew (10) = faller (1), breaker outs (3), hauler driver (1), loader drivers (2), log maker (1), skid worker (2)
    - Equipment = Mobile hauler, static delimber, 200 excavator grapple loader, 300 excavator grapple loader
- Study Two
    - Crew (10) = faller (1), buncher operator (1), breaker outs (3), hauler driver (1), pole man (1), Waratah operator (1), forwarder driver (1), loader driver (1), skid worker (1)
    - Equipment = Buncher, swing yarder, Waratah, forwarder, loader
- Study Three
    - Crew (12) = fallers (2), breaker outs (2), hauler driver (1), floater / straw lines (1), skidder driver (1), loader drivers (2), Waratah operator (1), QC (2)
    - Equipment = Mobile hauler, skidder, loaders x 2
- Study Four
    - Crew (7) = faller (1), breaker out (2), pole man (1), skidder driver (1), loader / bell driver (1), log maker / skid worker (1)
    - Equipment = Mobile hauler, skidder, static delimber, Bell logger, loaders x 1

Crew roles included in interviews
Skid worker / log maker / QC – 7
Breaker out – 2
Waratah driver – 2
Bell / loader driver – 4
Hauler driver – 1
Poleman – 2
Skidder driver - 2