Chapter Six

Discussion and conclusions

6.1 Introduction

The presence in the market of quadbikes since the '80s has presented an opportunity for farm owners and contractors to improve transportation into remote areas, reduce labour costs, and cut capital outlay on vehicles. They achieve this by having a single machine that can to a large degree (although not entirely) replace horses, two-wheeled motorbikes, light tractors, and four wheel drive light trucks.

Approximately 70,000 quadbikes are now in use on New Zealand, but unfortunately, this high uptake has been accompanied by marked rates of injury and damage, prompting the New Zealand Department of Labour to identify quadbikes (Ward, 2002) as their single greatest area of concern in farm safety. ACC alone are now paying out in excess of NZ$3.6 million for new and on-going quadbike-related claims, and there continue to be on average seven deaths a year involving quadbikes on farms.

This research was a response to the serious lack of knowledge about the extent, nature and aetiology of quadbike LCE on farms. An ACC funded literature review (ACC, 2000) had concluded that 'current information available in Australia and New Zealand is insufficient to establish the cost, frequency and nature of ATV injuries, or even to confidently adopt research findings based on US statistics.'

The aims of the research reported in this thesis were therefore to:

1. Establish the scale of the problem of loss of control events (LCE) involving quadbikes on New Zealand farms
2. Establish an understanding of the context of quadbike use on New Zealand farms, including the functional requirements of the tasks relating to the quadbike
3. Develop a suitable investigative method for the analysis of quadbike LCE on New Zealand farms
4. Identify risk factors for LCE and their interactions
5. Identify potential interventions that would reduce the incidence and/or severity of quadbike-related LCE on New Zealand farms.

An ancillary aim was to also compare the characteristics of the LCE on New Zealand farms with those reported in North America to assess whether or not the practice of importing intervention ideas was supported by the evidence base.

To meet these aims, the researcher adopted an ergonomics or systems approach in investigating the problem of quadbike LCE on farms. LCE were considered from the perspective of the interactions between the user, their equipment, the task and their physical, regulatory and social environment. This is the first study to apply a systems perspective to quadbike LCE, and draws together elements from a number of disciplines to help study off-road occupational vehicle loss of control events.

In this chapter the key findings are discussed and the unique contribution to knowledge of both the method and findings are described. Directions for future research are also outlined.

6.2 Discussion of key findings

6.2.1 The scale and cost of the problem of loss of control events

The research findings provided a clearer understanding of the scale and cost of quadbike LCE on farms. During the process of the studies, some limitations with the available data sources were also identified.

The literature available at the outset of the study contained more material on the direct compensated costs associated with injury than it did on any other aspect of quadbike LCE on New Zealand farms, but it still did not provide a clear picture, primarily due to the limitations experienced by previous researchers in positively identifying quadbikes in the available data.

There were also limitations of the data collected specifically for the studies reported in this thesis. The data on scale and cost came almost exclusively from centralised ACC and OSH sources, where accuracy is reliant on faithful reporting, and comprehensive and reliable data gathering, capture and analysis. There is clearly scope for omission, contamination and loss of data at these various stages – as indeed there would have been from private insurance providers had this data been available. Finally, the indirect costs to the riders affected – most of whom are self employed - remain uncalculated. This is an area needing further study.

In recent years the costs of new claims for injuries has risen markedly, and the costs of ongoing claims even more so (ACC, 2004). ACC costs are approximately NZ$3.6 million per year for both new and ongoing costs combined.

Previous studies in New Zealand had highlighted the problem of positively identifying quadbikes from two-wheeled motorbikes, trikes and other farm vehicles in epidemiological data (Langley et al, 1995). This made it difficult to answer commonly posed questions from industry on the relative risks of quadbike use as opposed to other forms of transportation. The methods of analysis conducted during these studies allowed more confident comparisons to be made with other claimant

populations as the ACC data were individually screened by case, to positively identify farm quadbike LCE cases. Both the researcher conducting the initial screening and the cross-checker were familiar with vernacular farming terminology which brought greater certainty to the task of narrative interpretation.

The analysis revealed that quadbike riders on farms with average usage have a higher risk of injury than average-use car drivers, but less chance of death. One in 10,000 riders will die from quad-related incidents per year, as opposed to one in four thousand car drivers. However, one in 29 quadbike riders on farms will file a claim to ACC in a 12 month period, as opposed to one in every 43 car drivers. This underlines the lack of intrinsic protection for riders, and the impact of speed on severity.

Combining official fatality figures (OSH, 2006) with findings from this research on total numbers of quadbikes in use would indicate that between 1998 and 2002 there was an average of 10 deaths per 100,000 machines per year in NZ related to quadbikes. This is the same rate as the USA for that period, but similarities between the two countries appear to be predominantly relating to issues of scale, such as this, rather than nature of LCE or their context of use.

As a minor element in the context study, the ACC data and media review data were examined for comparative evidence of quadbike LCE in other fields of use in New Zealand. No peer reviewed publications at all were revealed on the topic of quadbikes in horticulture, adventure tourism or golf course maintenance – areas of known activity. Exploratory analysis of the ACC database and a number of interviews with adventure tourism operators and horticulturalists generated some interesting questions for further study. These are noted in Table 6.1. Of particular interest is the (apparent) complete absence of compensated injury due to quadbike LCE on golf courses – despite their widespread use in the country with the highest ratio of courses to people in the world. Future research could test the proposition that without the interacting factors of distraction (monitoring animal movement), and

unpredicted micro-surface changes (ruts and holes a few inches deep), overall risks of rollover diminish considerably.

At the outset of this research some limited figures on quadbike LCE injury costs were already in the public domain, and indeed the impact of these had been instrumental in stimulating the release of funding for this research (ACC, 2006). These studies advanced our knowledge on the true scale and cost of the problem in a number of ways - firstly by providing a more informed and detailed analysis of the same database, secondly, by identifying systematic biases, potential patterns of under-reporting and likely avenues for claim migration. This was achieved through the context study and by indicative testing of the reliability of the ACC data as an incidental output of the follow up investigations.

And finally, this research provided a description for the first time in New Zealand of the full quadbike rider population on farms with estimates of total numbers, personal characteristics and numbers per machine. Indirect costs per LCE remain uncalculated as this was beyond the scope of this study, but were this to be studied, the amalgamation of the two would provide a very valuable indication of the burden of cost being borne by the rural communities and the country as a whole.

6.2.2 The context of quadbike LCE on New Zealand farms

No literature at all was found on the context of occupational quadbike use on New Zealand farms prior to this study. There were no peer reviewed papers, significant media items or relevant marketing releases. Enquiries made directly to distributors revealed nothing further than the unsupported statement that approximately 90% were sold to farmers. There were no existing ACC publications describing the occupations or incident locations as stated by claimants who had been hurt while using quadbikes.

The epidemiological study reported in Chapter Three produced some basic findings on the context of occupational quadbike LCE on farms, but the ACC database system by its nature is more suitable for broadly focussed analysis of trends than for detailed

qualitative explorations. The most relevant and consistently reliable ACC data were found in this research to be those categories such as gender, age, and region where the claimant has little reason or opportunity to report inaccurately and where the data capture process does not require interpretation and/or coding. The weakest data therefore was found to include categories either requiring more description than can be entered in the space allowed, or where systematic reporting biases may be at play; for example: event details, scene of the incident, and occupation. This study therefore provided useful guidance for the subsequent context and investigation studies on site by identifying some specific points to explore in greater depth, such as: the high number of cases involving middle aged males, and the unexpected peak of cases reported in the hot dry conditions of January.

None of the studies in New Zealand conducted prior to this research had explored the wider organisational factors beyond the incident itself. The wide industry consultation and participative interaction with the farm populations during these studies generated not only fuller understanding of the immediate context surrounding the LCE but also revealed some of the more distal socio-economic factors. Examples of this are the data that emerged regarding LCE prevalence on different farm types. Mixed sheep and beef units appear to be over-represented and a possible explanation that emerged is that this type of farm is the sort of property that new entrants to the industry buy. They are generally financially stretched and tempted to try and make-do with less vehicles and labour. As a result, a number of the people interviewed in this research admitted that they push the quadbike beyond the safe limits more often – and with less human back-up should they experience a rollover and entrapment.

The context studies also established for the first time a clear description of the tasks for which these machines are being used and their interaction with other elements of the wider system within which they operate. Conflicts previously unreported were shown to arise when other systems developed without consideration of the quadbike were used in conjunction with the quadbike. For example, the decades-old use of long loops of polypropylene-type twine for holding bales together is largely

unproblematic until combined with delivery by quadbike - a vehicle low to the ground and with exposed moving parts. The handlebars and rack tubing afford excellent places to temporarily loosely loop the twine as the bales are fed out, but reports of near misses and actual harm to limbs are numerous as the twine frequently escapes and one end becomes snagged on the wheels, axles or drive chain – the other over wrists or feet.

This subtle but significant interaction between two separate systems that had been designed in isolation but brought together with unfortunate consequences had not been identified at all either in literature prior to this research, nor in the ACC narrative analysis reported in Chapter Three. The discovery of such mismatches underlines the importance of not relying solely on epidemiological level studies for hazard identification and intervention development.

Most significantly of all, the context study showed that in New Zealand these tools are not bought for the purposes for which they were designed. The systems prompt two of the three types of human error identified by Charlton (2002). The unintentional type – lapses – are too heavily punished, and type three errors (violations) are made almost unavoidable as the mismatch between the needs of the farm user and the stated limits imposed by the designer's results in the manuals being almost entirely ignored. The study reveals a persistent demand for error-tolerant devices in New Zealand farming, whereby the user can experiment with novel applications of the implement and to establish the performance limits themselves. This is unlikely to change in the short term as not only is the improvising (number eight wire) spirit seen as an asset in the national character, but it is also a traditional method of obtaining competitive advantage in rural industry. Despite over twenty years of application in the agricultural industry, the quadbike appears to still be too error-intolerant for this market.

This could be because the context of use overseas is still predominantly recreational and so the evolution of the quadbike remains most closely linked to recreational needs and desires. However, occupational use in the USA appears to be rising and so

designers could be motivated to tailor models more towards farm and ranch user needs (Rodgers, 1999). There may also be pockets of quadbike use, such as in Alaska, Australia, and Europe where there are already closer parallels in context of use.

At the beginning of this research project, the state of knowledge regarding the context of occupational quadbike use on New Zealand farms was built upon a combination of: a small number of (mostly dated) studies of limited relevance and/or substantial political biases, impressions received via the media, marketing messages from the distributors, personal experiences and overseas data of questionable relevance.

The Southland study by Brown (1998) was the only piece of work that gave genuinely useful insights on how they were really being used and what some of the intrinsic problems might be. But this was not widely published nor read.

This study therefore provides a useful description of the context of quadbike use which can be used in a number of ways: to inform contemporary policy, to assist more precise design development to meet the market, and to guide research priorities. It allows overseas injury prevention researchers to gauge the extent to which interventions developed here may be of relevance in their own country, and serves as a benchmark against which future trends in quadbike use on NZ farms can be observed.

6.2.3 Development of the investigative method

The literature review produced no single existing method that could be employed to answer the research questions posed on LCE. In particular it was noted that no specific methods were found for the delayed investigation of incidents involving off-road vehicles.

The existing methodologies in the obviously comparable fields, as for example road and air transport, all had shortcomings of one kind or another. The road transport accident investigation methods assumed fast response and immediate access to the scene, plus the availability of witnesses and other sources of evidence. Air accident investigation methods were of greater overall relevance, as remote rural locations and the absence of witnesses were taken into account. However, they still assumed that despite significant delays where the plane had crashed in remote bush, the wreckage once found would still be left untouched until the investigators had combed it for evidence. This was not going to be the case for the quadbike LCE study.

Methods used previously for the study of quadbike incidents specifically were inadequate for addressing the research questions posed in this study. The Southland study in 1992 by OSH Inspector Brown (1998) was the only attempt to investigate non-fatal LCE in New Zealand prior to this research. While providing some very valuable clues on potential lines of questioning for the interviews, it did not adopt a systems approach. Interactions between risk factors are not explored, or if they were, they were not recorded by the interviewers, or captured for analysis. Organisational factors were similarly downplayed in favour of more proximal factors. This was in line with the observations made by Carol Slappendel in (Slappendel, 1995.243) that the incident investigators in New Zealand industry - while adopting an interactive approach in theory, had not developed the tools to really apply these more complex models to field work. The (over) simplicity and ease of application of investigative tools based on Heinrich's Domino Theory and later derivatives have made the non-interactive analysis methods durable features in New Zealand workplaces. Brown's data collection method in Southland reflected this, using checklists of individual factors from which the interviewers selected the most relevant.

It was therefore considered necessary to develop a new investigative method for the purpose that allowed risk factor interactions, including organisational ones, to be captured in the field. The use of an ergonomics approach allowed consideration of LCE from the perspective of the interactions between the user, their equipment, the

task and their physical, regulatory and social environment. It is the first study to apply a systems perspective to quadbike LCE, and made possible the identification of latent organisational risk factors. The information processing component in the model developed during the study provided valuable understanding relating to the interactions of the risk factors.

The overall method sought to establish why the decisions of the riders involved in the LCE 'had made sense to them at the time' (Dekker, **2003).** This philosophical approach not only made sense to the researcher, but also proved robust in appealing to the study participants who appreciated that their competence was not being unreasonably questioned with the benefit of hindsight. This further encouraged the participative exploration of the context of the events that day for the rider; what pressures they were under, what constraints they believed to be acting upon them, and so forth.

The literature on account reliability and methods of assisting recall of episodic memory was drawn principally from the psychology, forensic psychology and aviation human factors disciplines. No material at all was found on these aspects of investigation in the Occupational Health and Safety. **A** recurrent theme from the recall literature was that whilst it was unrealistic to aim for 100% complete and accurate accounts for a variety of reasons, usefully factual versions of the truth could be gained through triangulation of the data sources; testing the same variables, but with different methods - each with their own methodological weaknesses (Webb et al, 1966).

In combination, the methods described in this thesis represent an advance in the injury prevention literature. The event charts that can be participatively completed and the interactive quadbike LCE model developed for the data collection and analysis have contributed to practical ergonomics field methods that address the shortcomings identified by Slappendel (1995) and others. The method of administration – utilising account recall optimisation techniques - further raises the quality and completeness of the data.

6.2.4 Risk factors for LCE and their interactions

The aim of this section was to explore the nature of the quadbike LCE on New Zealand farms through establishing the risk factors and their interactions. A secondary aim was to review the circumstances of those LCE being reported in North America, draw comparisons with the New Zealand situation and to conclude whether or not they are similar enough to confidently transfer interventions.

Prior to the study commencing in 2002, the risk factors commonly offered during discussion within industry centred on the combined effects of youth, speed, poor supervision of minors and general recklessness. These themes were reinforced by the media coverage in New Zealand and reflected the concerns prevalent in the USA and in the imported technical manuals provided with the new quadbikes.

The literature review reported in Chapter One, showed there to be little reliable information on LCE of clear and current relevance in the public domain. Brown's (1998) work in Southland had provided some useful leads on potentially fruitful lines of enquiry, but the findings of a very localised study in a climatically extreme corner of the country could not be generalised to the New Zealand population of users as a whole. The findings were also ten years old by the time this research commenced.

The Federated Farmers study (1998) had set out to 'gather the opinions' of New Zealand farm owners and managers belonging to the organisation – and was not an attempt to establish actual risk factors and their interactions through rigorous triangulated study. Their findings, perhaps predictably, emphasised unsafe behaviour of the individual riders. There was very little discussion focussing on deficient work organisation issues. This contrasted with the more system-wide risk factor interaction patterns reported in this thesis.

In contrast to the impression created by the New Zealand media that quadbike-incident victims are predominantly children and sometimes the very elderly, the findings on the characteristics of riders experiencing LCE highlighted middle aged users as most frequently injured. The finding that serious injuries are clustered

around the 46 year old age group would appear to support the concerns expressed during the industry consultation that middle aged men with marked business and family pressures are a high risk group. Further study is needed to see if stress factors are indeed influencing the incidence or severity of quadbike LCE in New Zealand, and to more clearly understand the reasons behind the marked differences in reported levels of injury between men and women.

In New Zealand mustering and other jobs working with stock was the major task group implicated in the LCE. Quads may have successfully replaced small tractors and utes for some jobs such as light feeding out and personal year-round transport, but appear to have been less successful in replacing the dogs that can turn hard at speed on unpredictable surfaces.

Not only was the context of use found to differ between New Zealand and overseas, but so was the nature of serious injury. Unlike the pattern of injuries reported for North American recreational riders, crushing/pinning and entrapment between the machine and the ground were far more common than head injuries in this New Zealand study. Lack of speed may be a factor in this, as it was found that a high proportion of the New Zealand LCE happened slowly enough for the rider to not be thrown forward clear of the machine. More recreational riders appear to exit at speed, landing on rocks or trees well clear of risk of entrapment.

The research findings also ran counter to some commonly held beliefs concerning where the major risks lie for quadbike users in the New Zealand farming industry. Firstly, LCE are clearly not just a problem on the hills. Micro-terrain variation was found to be highly critical as well, with 39% of stockwork-related LCE taking place on flattish terrain. A higher proportion of those LCE on flattish ground also resulted in entrapment and therefore more serious outcomes for the rider.

There were also two very interesting findings relating to temporal factors, which were not expected and warrant further work. The expected peaks of LCE at dawn and dusk were not found; instead the peaks appeared just before lunch and at mid-

afternoon. Secondly, wet, muddy conditions are generally difficult for farm vehicles but the hard ground in January/February was found to interact with other factors to produce peaks in LCE incidence. The wide soft knobble tyres cannot gain traction when the surface is unyielding and even less so when made slick on top by moisture or lush grass. Research findings with good face validity are important for training organisations such as FarmSafe who are engaged in challenging commonly held beliefs among the farmers attending their courses.

The event chart method also enabled analysis to be carried out of factors for each task being carried out at the time. Previous studies had not undertaken analysis with this specificity. There are differences in the underlying factors, for example, between LCE during spraying and LCE during work with animals, which indicates the need for conceptual diversification in quadbike design. The same tool is used for both but is currently doing neither job well enough.

The problems identified with the 'almost universal' use of a trailer behind quadbikes in the Southland study (1998) were not addressed by any interventions in the decade between that study and the one reported in this thesis. Trailer-related incidents are common but rarely identified in epidemiological studies. The ACC surveillance system does not lend itself to the capturing of data on implements attached to the quadbike at the time of the LCE. Such details would need to be mentioned in the narrative and there is rarely that level of detail provided. LCE related to trailer use were found through the site investigations in this research to be 35 times more common than the ACC data reported in Chapter Three indicated.

The site work included the recording of quadbike make and model. This had not been done in any previous New Zealand studies. It was seen as relevant as there were some significant design differences among the 100 or so types of machine in common usage in 2002. This level of detailed analysis enabled model-specific interventions to be designed. For example, park brake failures were found to be common with particular models of Honda quadbike due to the design of the cable

lock at the handlebars which did not allow for adjustment to increase tension between servicings.

The analysis of the events differed from previous studies of this type due to the interactive model that was adopted. While personal haste and machine speed were the two single factors most strongly linked to serious injury, the spread of identified single risk factor elements was very wide and the incidence numbers of even the most common risk factors therefore was relatively small. The analysis may not appear to yield the same apparent strength of findings as often found in incident investigative studies as the coding of elements in each case was less gross – the uniqueness of each scenario being more fully recognised. The approach drew on 'pattern matching' – as used in case study methodology (Yin, 1994), and resisted as far as possible the simple route of 'cherry picking' a selection of single factors from each unique scenario and aggregating these into apparently homogenous groups.

As the next step, further specific experimentation is needed that investigates the interactions involved in greater detail. This cannot be laboratory-based single variable study as it is the network of interacting factors being examined as a whole, not simply one element in isolation. For example, the hypothesis that working with stock is inherently more risky because of the need to watch the animals moving as well as the route in front could be tested by the eye tracking devices. Farms with regular LCE could be compared with a sample of more resilient operations that are proven to have low LCE rates despite performing similar task functions.

The importance of prompt attention following serious incidents has been established in a number of related areas such as road traffic accident research. Entrapment of the rider following a quadbike LCE was similarly found in this study to aggravate injuries and delay the receiving of medical attention.

In the 1980s and 1990s there was debate in the literature on the potential for using rollover protective structures (ROPS) on quadbikes. This largely ended after two sets of computer simulation studies were conducted, the first in the USA (Zellner & Van Auken, 1998), the later one being a government-funded report from the UK (HSE, 1999). The findings from the independent UK study suggested that the absence of rider restraints on active-riding vehicles made the fitting of ROPS to be of mixed benefit. Chances of serious injury for the rider appeared to increase when ROPS were used in high speed LCE. At low speed the may be of help, or conversely they may add to impact injury and entrapment.

However, despite the intense pressure from manufacturers to discredit ROPS of any design as described earlier, there was considerable interest in the findings from this study regarding the usefulness or otherwise of roll over protective structures. Many individual farmers are still in favour on the basis of their personal experiences. From the detailed findings of the LCE investigations, it is clear that the ROPS fitted did act as injury and damage agents in some LCE, and as protective and cost saving devices in others – dependant upon the circumstances. This is broadly in accord with the computer simulation studies conducted in the 1990s. The findings of this research support the idea of retrofitting existing quadbikes with devices of some description to protect riders from crushing injuries inflicted by the machine, but not necessarily tubular metal frame structures. A logical direction for future study is the development of LCE-activated soft protection and self or assisted righting systems.

The findings also support the argument for new conceptual directions in farm vehicle systems that design out some of the key risk factor combinations. In the longer term new light vehicle types without the inherent conceptual mismatches of quadbikes are needed for key tasks in the New Zealand agricultural industry. In the meantime, interventions such as the anti-crushing/entrapment protection mentioned above are required to reduce the incidence and severity of LCE for those riding the 70,000 or so machines already in use.

At the outset of this research, the evidence base for the commonly accepted set of risk factors was very thin, dated, regionally skewed and politically influenced. The influence of overseas research findings and overseas-generated commercial marketing information was substantial and its relevance overstated – as the findings of this research show. This research provides a New Zealand specific evidence base of risk factors and their interactions, upon which to more confidently base policy decisions, interventions and priorities for further research.

6.2.5 Interventions

The final aim of this series of studies was to identify potential interventions that would reduce the incidence and/or severity of quadbike-related LCE on New Zealand farms.

Few interventions were reported to have been implemented in New Zealand at the outset of this study. Apart from experiments with a variety of types of ROPS, these were predominantly behaviour modification efforts via: training, educational leaflets and videos, and warning stickers placed on machines. As previous sections in this thesis have already shown, the evidence base supporting the few interventions that had been attempted was not a compelling one. In addition, none of the ideas tried had been evaluated for their effectiveness in reducing the incidence or severity of injuries. Efforts by isolated individuals (for example Low, 2000) to tackle this deficiency did not gain sufficient support at a national level, for reasons that remain unclear. The uncertainty in how to act at government agency higher levels may well have been fuelled by a number of factors including: conflicting information on risk factors being provided from the USA researchers in comparison to those stories emerging anecdotally from farms in New Zealand, effective resistance to any increase in regulation of quadbike use by the farming lobby, and the steady efforts of a body of motorcycle distributors backed by powerful overseas corporate funds and lawyers experienced in resisting criticisms of their vehicle designs.

Without an evidence base of New Zealand-specific data on risk factors and their interactions it is understandable that intervention efforts would have lacked momentum. Without any study at all of organisational or other latent factors, it is also unsurprising that there were no interventions aimed at this aspect of the systems. By its systems approach, this research therefore expands the scope as well as the depth of potential evidence-based interventions identified.

Through this series of studies, 72 specific system-wide interventions were identified that address the observed system weaknesses and mismatches in the current quadbikes being offered to New Zealand farmers; they include:

- Error intolerance – the quadbike designs afford insufficient opportunity to learn their performance limits by trial and error (a method that appears prevalent on farms) without unacceptable injury and damage
- Affordance mismatch – the quadbike being less of a stable platform than it appears to be, which leads to LCE, especially when working with stock in paddocks with surface damage
- Task demands, abilities and limitations of the 60+ age group – the quadbike operation does not match prior learning and stereotypes entrenched in older users. The slow speed turn technique, requiring the opposite lean to a bike, is counter-intuitive for most if not all new riders
- Marketing of false affordances – they are not built for All terrain, just most. The name encourages users to venture onto types of country where the machine is poorly matched to the environment.
- Entrapment potential following LCE appears too great for users working alone in remote locations, often without cellphone or other communications to call for assistance
- Load carriage in excess of weights/bulks safely handled by quads is a farm need. Quads are a fast effective means of personal transport, but need to be part of a system that has other realistic provision for load carriage
- Features and fittings need to better match the detail of daily farm use eg. Stop/start work through gates, stowage of farming gear, shelter from weather,

Task specific interventions were also identified, as quadbikes were shown during the context study to be used in a variety of quite different applications on New Zealand farms. This research generated interventions targeted at the critical interactions featuring latent, active, and natural factors acting before, during and after LCE in specific tasks. Examples of these interventions for the major task areas - stockwork, spraying and fencing were discussed in Chapter Five.

The method by which these interventions were developed, as described earlier (see page 204), also emerged as a natural part of the process of gaining the trust, confidence and cooperation of the people interviewed during the studies. It was not just desirable, but in fact essential, to provide a vehicle for the compiling of their intervention ideas and the building of positive strategies to address the issues that they raised. These formed a valuable part of the findings in their own right as intended, but the process was also found to provide a stronger rapport and thereby a better quality of data overall. The research programme as a whole, including methods of reporting to maximise impact, made sense to the people taking part as well as to the researcher, improving cooperation and buy-in.

The absence of any literature at all on the development and success of occupational quadbike LCE interventions on farms in New Zealand is noteworthy, given the number of years that these machines have been recognised as problematic. This study therefore makes an important and overdue contribution.

6.3 Directions for further research

Prior to this research, there had been very few studies on quadbike use in New Zealand and even less with the detail, face validity and sufficient rigour to provide a sound evidence base for intervention design. Internationally, the bulk of the literature published since **2002** continues to be epidemiological studies monitoring the patterns of injuries and fatalities occurring in North America.

Amongst the most conspicuous gaps in the international literature, and one which still remains, is the lack of comparative studies that investigate the differences in system design and operation between those farms/organisations that experience unacceptable numbers of costly quadbike LCE, and those that do not – the more resilient (Cook & Nemeth, **2006)** organisations. The reasons for the lack of research attention may reflect the significant differences between private recreational use in the bigger markets versus occupational use in New Zealand. The first stage in any such study would need to be an objectively supported screening exercise that quantifiably demonstrated that the better performing operations were exactly that, and not simply better at suppressing LCE reports. Long term data collection through instrumentation fitted to the quadbike would seem appropriate. In the period since this research commenced, the technology has become increasingly available to carry this out. The recommendation is that this study would take a community-wide approach, investigating the wider social context within which resilience had been established.

Other areas needing further study and covering a broad span were identified during the course of the research. These were discussed at the relevant points throughout the thesis but are included here in summary form in Table **6.1.** Those considered most urgent by the researcher are shown in bold.

Table 6.1 Directions for future research

Level	Pre-LCE	During LCE	Post-LCE
Government	• Encouragement of concept redesign • Rural access to child care and its effect on quadbike LCE for families	• National investigation database • Comparison of LCE cases between occupational sectors including high risk (farming contractors) and apparent low risk (eg. golf c o m e maintenance) • Feasibility of enhanced search features and data coding to include vehicle type on ACC database	• Rural access to medical care • Rapid growth of on-going costs for quadbike LCE injury cases • Measurement of costs by other methods – not just ACC data • The costs of error-intolerance in such a widely used vehicle
Regulatory environment	• Control of accessories and restriction of load carriage by design • Warrant of Fitness for quadbikes • Licensing of machines and riders	• Test modifications • Supplier investigations of LCE • Point load avoidance guidelines	• Search & Rescue in-built alarms for new machines • Investigation methodologies – formalisation and the use of props and cues
Social environment	• Stress and LCE, especially among those with family and financial pressures • Older riders capabilities and limitations • Male v female factors in LCE incidence and severity • Effectiveness of media campaigns timed to annual risks • Identification of pockets of similar quadbike use on farms in other countries – for sharing of research ideas and findings	• Awareness of older users on the need to bail out	• Effects of regular family contact during the day on severe LCE • Indirect costs to the families of riders injured • Implement and evaluate the use of CAA – type incident reports in the media each month
Organisation	• LCE by farm type and the reasons for the possibly higher incidence of LCE on mixed sheep/beef operations • Optimising track design • Comparative studies to help with choosing the right machine for the job • Planning for fatigue effects and managing peak workloads • Pre-lunch peaks for LCE, why? • Objective measures of quadbike activity using GPS and other data logging methods	• Impact of entrapment features through medical records study	• Formalisation of Search & Rescue policy

Physical environment	• Benefits of land management to reduce risks: Track maintenance, Shorter grass on routes across paddocks, Soil erosion control and Fence line planning	•	• Tele-Communication links
Cargo	• Improved spray system • Customised compartmented trailers • Control of cargo width • Conflicting systems – tangling of old style baling twine with exposed moving parts of new quadbikes	• Tank baffles • Lowered stowage • Trailer behaviour in LCE and the potential for braked trailers for quadbikes	
Machine	• Creeper gear • Reverse gear warning beeper • Throttle protection • Effective park brakes • Assess wst of poor maintenance and develop plans to improve this • Redesign the quadbike operating manual to give it relevance to NZ farming users	• Stabiity devices – active and passive system • Swivel couplings on trailers and implement drawbars • Throttle de-sensitisation	• Air-bag with linked alarm
Rider	• Effectivenessof user guidelines • Specific young rider education • Expert user video • Purchasing decisions – what really influences farmers when selecting a new machine	• PPE – optimal design and uptake	• Personal GPS alarm
Level	**Pre-LCE**	**During LCE**	**Post-LCE**

6.4 Contribution of the research

The research contributed to the body of knowledge in a number of ways. Firstly, through addressing significant gaps in the scholarly literature. Few studies had been carried out in New Zealand, and none had previously adopted a systems approach to build an understanding of the more distal risk factors at an organisational or social level interacting in quadbike LCE amongst farm workers.

The extent of the participative engagement with the farming community and wider industry also sets this research apart from previous studies. It is the first major set of investigations into quadbike LCE to be conducted at the site of the incident – rather than via telephone interviews.

To achieve this system-wide perspective, a new method of investigation was developed for the study which built on established methodological elements and approaches from occupational health and safety, ergonomics, air accident investigation and forensic science. The use of props and context-dependent memory cues was introduced, despite there being no evidence in the literature of prior use in a health and safety investigation setting; it proved beneficial. For analysis and interpretation, a new interactive model of quadbike LCE was developed incorporating information processing steps.

While a substantial step forward, the value of the findings from this research will become less relevant with time as models of quadbike change and the systems within which they are used change also. The methodological advances however will be more durable, and therefore in my view form the more significant contribution.

6.5 Conclusion

This research was the first carried out in any country that explored quadbike LCE problems on farms using both incident-dependent and incident-independent methods. It was also the first to employ an ergonomics systems approach. The investigation method that was developed added specific modifications to existing established techniques to produce an original method tailored to the off-road occupational vehicle sector.

An interactive causation model incorporating information processing elements was developed for data analysis of the quadbike LCE. This built on existing models with established validity and credibility in the New Zealand primary industries but included significant additional features.

The method developed was successful, but in retrospect, it is now evident where improvements could have been made to improve the overall economy, and sharpen the focus of the work. However, a very low level of understanding existed regarding quadbike use on New Zealand farms at the start of the exercise, and the decisions on method design - to quote Sidney Dekker (2002) - 'made sense at the time'.

Aircraft in the early days of flying were 'exciting and useful but intrinsically unforgiving' Wiegmann and Shappell (2003). The same may be said of quadbikes on New Zealand farms today, the design concepts are less than 30 years old and would still be in their relative infancy even if the designers had been focussed on optimisation for occupational users instead of recreational ones. The farming environment is a dynamic one where, as with flying, risk factors change continuously and their interactions can therefore never be fully anticipated. The findings of this research suggest that the aim should be for quadbike riders in New Zealand to be equipped to make an informed analysis of all aspects of their system, and make changes to the work organisation, physical design of tools and environment, and

training that will 'stack the odds in their favour'. The case for increased regulation in specific areas is also supported.

This research contributes in a number of important ways to the knowledge needed for design mismatches to be addressed, and for safer, more effective work systems involving quadbikes on New Zealand farms to be achieved. More importantly for the long term, it represents advances in methodology which may have benefit not only in this specific field, but also in related areas of ergonomics research.