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Short Report 145

Making Farm Machinery Safer

Lessons from injured farmers

This report focuses on farm machinery injury. The work reported here identifies individual and machine characteristics that are associated with an increased risk of a serious farm work related injury. A comprehensive analysis of a series of farm machinery events is reported, and through the application of a human factors and systems approach, recommendations are made in relation to improving machinery design to reduce the potential for injury events to occur, and to reduce the severity of resulting injury when such events do occur.

This report is expected to be of interest to the agricultural industry, farm machinery manufacturers and dealers, occupational health and safety authorities, and those involved in farm safety programs.



*People have been injured by this type of machinery while undertaking maintenance activities.
 Source: Agricultural Machinery Design and Operation Safety Study, Victoria, 2003–2006*

Background

Farm machinery related injury has been identified as a priority in Farmsafe Australia's National Goals, Targets and Strategies, as this type of injury accounts for just over 20% of injury related deaths in agriculture. A unique opportunity to specifically examine risk factors for serious farm machinery injury arose several years ago within the context of a study of all types of unintentional farm injury among men – the Farm Injury Risk among Men (FIRM) study,

funded by the National Health and Medical

Research Council. The FIRM study recruited seriously injured farmers and farm workers from south-east Australia and collected information about themselves, their working life and the property on which they work. This information was compared with randomly selected farmers and farm workers who were not seriously injured to determine which personal, work and environmental factors were over-represented among those



This type of machinery has caused injury to people during routine maintenance procedures

who were injured. This kind of farm injury study had not been conducted in Australia, as earlier studies did not have the benefit of a comparison group of uninjured farmers.

Aims/Objectives

The aim of the Agricultural Machinery Design and Operation Safety Study (AMDOSS) was to identify the individual, farm and machinery characteristics associated with serious work-related farm machinery injury. A secondary aim was to explore the interaction between individual and machinery characteristics. The three hypotheses tested were that:

- individual characteristics, such as previous personal farm injury, low level of education, less than 10 years' farming experience, and no previous safety training, tend to increase the risk of serious injury associated with farm machinery
- farm machinery associated with serious injuries does not meet current legal standards
- design changes, beyond features required by current legal standards, can be devised to prevent, or reduce the severity of, serious farm machinery injuries.

The intended beneficiaries of the study are farmers, machinery manufacturers and dealers.

Methods used

The study had a case-control design. Farmers and farm workers who sustained a serious farm work related machinery injury (cases) were recruited via hospital emergency departments. Information was collected about themselves, their working life and the property on which they worked (Stage 1). Where the participant agreed, an on-site inspection of the machine was conducted, to collect information about the characteristics of the machine (Stage 2). A group of randomly selected farmers and farm workers who were not seriously injured (controls) were also recruited and comparable information was collected about them and a similar type of machinery to that involved in the case injury event. The study was restricted to men, who make up the substantial proportions of farmers who are fatally and seriously injured.

It is important to consider some implications of the case-control study designs. These studies describe associations between risk factors and health outcomes. An association does not necessarily imply a cause and effect relationship. Other evidence may be required to establish whether there is a cause and effect relationship. Similarly, the finding of no association between a risk factor and a health

outcome does not necessarily mean that an association does not exist – the correct interpretation is that there is no evidence for an association.

Contemporary human factors systems analysis was used to examine the incident events and associated machinery to identify potential design changes to prevent, or reduce the severity of, serious farm machinery injuries. Several specific design outcomes as well as suggested strategies for hazard management are forthcoming from this means of incident and design investigation.

Results/Key findings

A total of 85 injured farmers and 205 age-matched uninjured control farmers participated in the study, among whom 37 and 71 respectively took part in Stage 2 – the on-site machinery inspection component. The first stage of the analysis examined the association of each specific hypothesised risk factor with farm machinery injury. The results showed that the following factors were statistically associated with farm machinery injury:

- not having attended farm training courses
- being less experienced in farming (i.e. having 1–4 years' farming experience)
- having had a hospital stay for a farm work related injury in the previous 3 years
- having a medical condition requiring medication
- being an employee or contractor
- being engaged in seasonal farm work
- using a machine that had not been purchased new.

We also found that the odds of injury increased by 3–4% for each year increase in the age of the machine.

Case farmers with farm machinery injury were statistically less likely to display the following features than were the control farmers who had not recently sustained a machinery injury:

- have asthma
- have had back pain in the previous 12 months
- be using a machine in above average state of repair.

One of the limitations of the above univariate analysis is that the influence of each factor on farm machinery injury risk were considered in isolation from each other. As some of these factors are correlated (e.g. having asthma and having a medical condition requiring medication), it would be helpful to be able to identify those factors which, independent of any other factors in the analysis, are associated with farm machinery injury risk. Therefore, logistic regression modelling was conducted to simultaneously examine the relationship between a selected number of these personal and machine characteristics.

When the relationship between these variables was taken into

account through the modelling, the following factors maintained statistical significance and were independently associated with machinery related injury:

- being an employee or contractor
- being engaged in seasonal farm work
- using a machine that had not been purchased new.

When these other factors were considered simultaneously, the odds of injury increased by 4% for each year increase in the age of the machine, compared with 3% in the first stage (univariate) analysis.

In addition, results for three further factors, while not reaching conventional statistical significance, suggested that they may be of interest. There was some evidence that having had a hospital stay in the previous 3 years increased the odds of injury, and that having asthma, and having had back pain in the previous 12 months were associated with a decreased odds of machinery related injury.

Several factors identified in the first stage analysis were no longer significant in the multivariable

analysis. These include not having attended farm training courses, having 1–4 years' farming experience, and having a medical condition requiring medication. This means that these factors were less important than the remaining factors above in their association with farm machinery injury.

There was no evidence for the association of any of the design or safety related features with the odds of injury. The safety feature score, or performance of formal safety checks, were not associated with a decreased odds of injury. Previous modifications, inconvenient safety features, safety features hampering function or inconsistency with standards and regulations were not associated with increased odds of injury.

Associations observed in this study do not necessarily imply a cause and effect relationship. Further, the finding of no association between a risk factor and farm machinery injury does not necessarily mean that an association does not exist – the correct interpretation is that there is no evidence for an association.

We found that there is significant potential to address a number of specific risks that exist with current new and old agricultural machinery by advocating design interventions. In addition, systematic design and machinery management issues have been identified, with the intention of encouraging innovative and industry-relevant solutions to be developed from a number of suggested practical solutions. These designs, presented in the context of safe system design principles, serve to not only improve the safe working life of new and existing machines, but also lift the state of knowledge in the agricultural machinery industry.

Implications

This report aims to inform change at various levels of the agricultural and agricultural machinery industries, advocating a combined effort amongst stakeholders to enhance the state of



*Injuries have been sustained when clothing has been caught in this type of machinery.
Source: Agricultural Machinery Design and Operation Safety Study, Victoria, 2003–2006*



Examples of pinch and shear points that caused injury when being assembled or or maintained. Source: Agricultural Machinery Design and Operation Safety Study, Victoria, 2003–2006

knowledge by innovation, discussion, and implementation of solutions to key machinery design and machinery management issues.

Machinery manufacturers, importers and suppliers will be encouraged that some of the injuries in this study resulted from design aspects that no longer exist on newer machines, and can learn from the many for which the design features are similar on new machines.

There are specific actions recommended for occupational health and safety regulatory authorities, and there are implications for both the regulatory and prevention programs of these agencies. The work of Farmsafe Australia, and the National Farm Machinery Reference Group will be supported and enhanced by the findings and recommendations of this report. There are implications of this work for farmers and farm families regarding the ongoing utilisation of older farm machinery, and the associated risk management.

Recommendations

The following recommendations from the study have been developed with the intention of providing direction for the benefit of the agricultural machinery industry, based on the evidence discussed in this and other studies.

Design solutions

1. Hazards that exist on many mobile grain augers can be controlled by the following commercially available retrofit components:
 - installing jockey wheels that have a lever to “walk” them into position removes a lifting and moving manual handling hazard, and makes the job much easier
 - where required, guarding or a fine mesh cage should be installed over stationary engines attached to the mobile auger. According to AS 4024.1801:2006, a 25 mm (one inch) mesh constructed 120mm from hazards on plant is sufficient to prevent access

beyond the knuckle joint

- installing a hand winch that incorporates an automatic clutch to prevent the handle from flicking back
 - guarding over the flighting according to the recommendations of the recently published “Grain Augers” Industry Safety Standard from NSW Workcover.
2. Both rollover and run-over hazards on tractors can be better controlled by maintaining the operator in the protected zone with the use of seat belts, in addition to a roll-over protection system (ROPS) installation. While it is recognised that many farm workers may choose not to use a seat belt on all occasions, it is considered important that one is at least available for use. Development of a seat belt attachment system that is married to a retrofit seat for older tractors, for bolting on to existing seat mounts where applicable, is recommended.
 3. It is recommended that agricultural machinery industry bodies consider means to address apparent issues with the location of the tractor exhaust:
 - located on the right hand side of the bonnet, which creates a blind spot when travelling on the left hand side of public roads
 - located in such a way that exhaust tends to enter the cabin.

Management of design issues

4. It is recommended that state workplace health and safety authorities mandate the installation of a falling object protection system (FOPS) on tractors that are fitted with a front end loader (FEL).
5. It is recommended that state workplace health and safety authorities advise of the various risks of jump starting vehicles. Related advice should also be provided regarding the risk of explosion with non-sealed batteries that are located in a confined area.
6. It is recommended that Farmsafe Australia contact the manufacturers

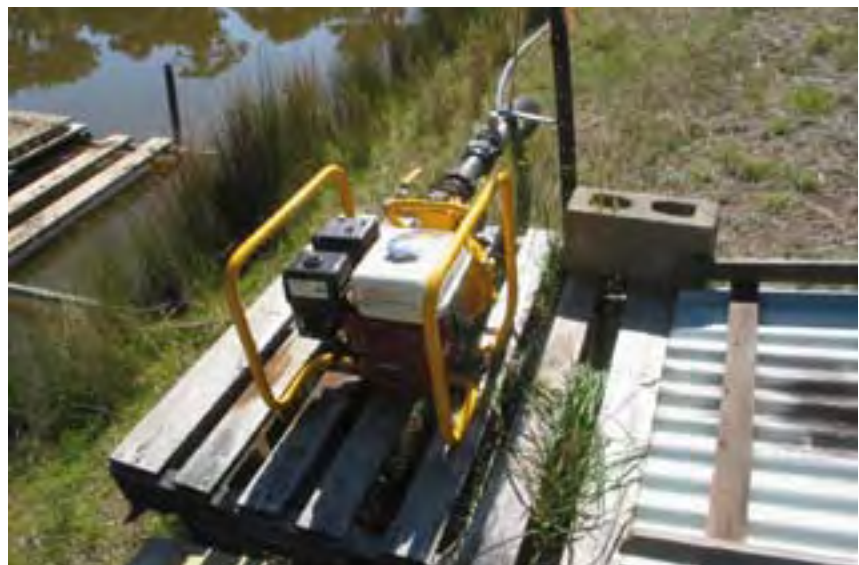
of the mobile grain silo involved in the incident wherein a farm worker was struck by the wheel lifting lever, which occurred largely due to a poorly designed control lever mechanism.

7. It is recommended that all those involved in the agricultural industry give high priority to addressing design and risk management issues associated with older machinery, given our finding that the risk of farm machinery injury increases by 3-4% with each year of increase in machine age, and that farm machinery tends to provide a long service life on Australian farms.
8. Farmers with older machinery, or machinery which has not been purchased new, should be encouraged to undertake risk assessments and implement risk management strategies for this equipment. Farm machinery dealers could play a role in assisting this process. Various retrofit options are available to enable safe use of older machinery, although in some instances the most appropriate risk management may be to develop a plan for replacement of equipment. Other strategies could include using different equipment to undertake the task, upgrading guarding or other safety features, or regular preventative maintenance schedules.
9. It is recommended that resources be made available for a national body such as Farmsafe Australia

to develop a means to gather independent feedback from farmers about the ergonomics and other health and safety aspects of machinery design. This could contribute to an educational database of user experience to inform design improvements, and enhance management of current farm machinery risks. While research organisations are able to provide monitoring over time of the consequences of farm workplace incidents, it would be more effective from a design perspective to have access to direct feedback and ideas from farmers who are invariably intuitive and innovative. In addition to this, the same database could record the details of near misses and incident events.

Safe workplace system initiatives

10. It is recommended that agricultural machinery industry bodies consider the provision of practical and cost effective means to access higher sections of agricultural machinery that require occasional access. Currently, features on the machinery such as wheels, mud guards and implements are being used, where there is a risk of falls. Attention is drawn to the need for solutions to address a wide demographic, including older farmers. Suggestions to consider are:
 - An access frame with steps situated over the wheels to



*Poorly configured machinery that suddenly releases energy can cause injury.
Source: Agricultural Machinery Design and Operation Safety Study, Victoria, 2003–2006*

allow enough reach to clean windows, and access the roof.

- Provision through agricultural machinery dealerships of stable ladders of suitable height. Wide base ladders would need to be used, as the tractor roof is often not suitable to prevent the ladder slipping sideways.
- Provision through agricultural machinery dealerships of suitable long-reach tools tailored for specific aspects on machinery that require attention, such as cleaning windows.

11. It is recommended that agricultural machinery industry bodies consider means to address risks with lifting tillage equipment to carry out periodic maintenance such as replacement of consumables. Cost effective and practical design solutions are required in order to provide a secondary load path to allow for the failure of the mechanism, such as hydraulics, that are used to lift the equipment. One way of achieving this could be to attach components to machinery (including retrofit) that can provide the secondary load path. For some machines these

components could also serve to provide the lifting force.

12. It is recommended that agricultural machinery industry bodies consider means to address risks when accessing areas underneath components held up by hydraulics. While manual hydraulic lock-out devices are commonplace, it was widely reported by farmers in this study that they were never used. Means of establishing lock-out systems that allow for this and other human factors with the use of hydraulics is required. Other industries that use hydraulics would also stand to benefit from such systems.

13. It was found that several farmers with serious injuries could have died had it not been for help arriving in time, either by coincidence, or by others on the farm noting their absence. Farm workplaces should establish means to ensure that communication is available to make arrangements for periodic contact to be made such that an absence is noted within a reasonable time frame.

Standards

14. It is recommended that agricultural machinery industry bodies continue to consider

means to ensure the availability and widely understood interpretation of various machinery standards. While current standards should not be seen as perfect, and are subject to continual improvement, they do provide advice toward a reasonable state of knowledge and some minimum design criteria.

In particular, the industry should continue to make themselves aware of the expected levels of safety of equipment under state OHS law, which has been tested in a number of pertinent cases in recent years. These cases make it clear that the operator protective devices used, including guarding and sensor switch systems, are expected to be generally more thorough than the requirements of Australian Standard AS 2153.1:1996 – Tractors and machinery or agricultural and forestry – Technical means for ensuring safety. Attention is drawn to the recently revised Australian Standard AS 4024:2006 – Safety of Machinery.

15. For a number of specific machines particular to agricultural applications there is ambiguity with the interpretation of various standards and other safety requirements. The best means to control risks needs to be determined and disseminated in a way that recognises compliance and promotes national uniformity.

It is recommended that a discussion paper be developed to consider the potential for the uniform provision of standards for agricultural machinery, which may draw from, but be independent of, existing guidance and standards regimes. A key function of this discussion paper would be to canvas options to determine the best way to achieve national uniform compliance. One model to consider is that of the



Farmers have fallen and been injured from this type of machinery during cleaning or maintenance activities. Source: Agricultural Machinery Design and Operation Safety Study, Victoria, 2003–2006

Australian Design Rules (ADR). An ADR series for agricultural machinery could be developed over time in close consultation with the industry to promote uniform continual improvement to machinery safety, enforce minimum standards with clear guidelines, and encourage the development and uptake of innovative solutions to problematic hazard control issues.

16. Australian agricultural machinery designers and professionals who purchase and import agricultural machinery could consider better consolidating their skills and knowledge base by developing a professional body or negotiating equivalent relationships with existing organisations. Existing organisations that provide a similar role in enhancing professional standing are:

- Engineers Australia, and the Society for Engineering in Agriculture
- American Society of Agricultural and Biological Engineers
- Tractor and Machinery Association
- Farm and Industrial Machinery Dealers' Association
- The Kondinin Group

17. Funding should be made available to develop and support Farmsafe Australia's National Farm Machinery Safety Reference Group to provide for ongoing national initiatives to advocate and promote:

- nationally coordinated programs, including working closely with state workplace health and safety authorities and state farmer representative organisations
- reduction of duplication of agricultural machinery injury prevention programs
- development of shared



Farmers have fallen and been injured from this type of machinery during cleaning or maintenance activities. Source: Agricultural Machinery Design and Operation Safety Study, Victoria, 2003–2006

resources for the benefit of agricultural machinery safety.

Education and training

18. The design and implementation of error tolerant systems in agricultural practice and agricultural machinery design could be viewed as an important element of risk management within the industry. Machinery design education, agricultural workplace training, as well as stand alone OHS education and training curricula, should incorporate the principles of error tolerant systems. Farmers as innovators in the agricultural machinery industry are a very important target group for such educational initiatives.

Further research

19. There appears to be considerable potential to improve machinery safety with sensors and interlocks. An engineering issue exists with the introduction of multiple node sensor systems, such as interlocks, on complex machinery such as headers and balers. Each new sensor introduces another failure mode for the machine. This is particularly an issue when interlocks should be designed to fail safely – i.e. if the interlock fails, it should preclude

the function of interest from occurring. Methods to overcome this issue have known problems.

- One way to overcome reliability issues is to introduce redundant wiring or other systems that assists with fault diagnosis, resulting in minimal down time in the event of a sensor failing safely. This comes at a cost that must be passed on to machinery owners.
- Increasing reliability by making sensor systems more robust and higher quality also comes at additional expense, and does not guarantee that problems will not occur throughout the life of the machine.

The best way to address this problem of safety systems introducing multiple failure modes could be to use both of the above strategies, and other approaches. This design issue could benefit from further research to find ways of introducing effective operator protection systems that are cost effective and reliable.

20. Further research is required to understand the mechanism by which those with a previous farm

work related injury severe enough to require hospital admission may be at increased risk for a subsequent injury. In the interim, patients being discharged from hospital following a farm work related injury should be advised of their possible increased risk of a subsequent injury. Patients likely to have an ongoing physical limitation may benefit from occupational therapy assessment and support during the initial return to work phase. In instances where a physical limitation persists over a longer period, regular assessments may be required.

21. Further research may also be required to understand the mechanism by which employees, contractors and seasonal workers are more likely to sustain a machine related injury. This finding could be related to their increased exposure to machine use, or more risky

machinery related tasks, than owners/managers. It could also be related to a lower prevalence of having attended agricultural training courses among this category of farm worker, since this study found that injured farm workers were less likely to have undertaken agricultural training courses.

22. Many mechanisms are possible for the continued development of safe design innovations for agricultural machinery. One of these is Australian Standards. Notwithstanding their important role, standards can also limit innovation, and are subject to sometimes lengthy review processes. Consequently, improvements in standards (and similar instruments such as industry codes of practice), are not seen as the only means to bring about change. Some design issues require serious research and development commitment to

ensure that solutions have been well considered, and properly evaluated, in a way that is more thorough than an expert Standard or Code committee can provide. The industry would benefit from research that seeks to optimise the process for designing, evaluating, and translating safe machine innovations to end users, in the agricultural machinery context. Such an investigation would take into account national, international, and hypothetical models for the process.

23. This study has demonstrated the value of an in-depth analysis of incident events, using an approach that uses the most contemporary incident prevention theory as a benchmark for hazard management. Further research of incident events is required to build on this body of knowledge.



This type of machinery can fall on people and cause serious injury. Source: Agricultural Machinery Design and Operation Safety Study, Victoria, 2003–2006