

Development of the Safe Tractor Assessment Rating System

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ABSTRACT. *We describe the development of the Safe Tractor Assessment and Rating System (STARS), a design-based tractor safety rating system that can be applied to new or used tractors to provide an objective assessment of their inherent safety features. A predictive rating system model, based on technical inspection, was used. Key principles underlying the system included the potential for design features to reduce the risk of an injury event occurring, and to reduce the risk of injury if such an event did occur. The rating system was based on current standards, research literature, injury and fatality data, and farmer input via focus groups. Development was an iterative process involving field, pilot, and inter-rater reliability tests. The final system was divided into six domains: rollover protection, runover protection, user protection, information and controls, pedestrian protection, and options. Within each domain, optimum design features were described for the common or serious potential injury risks, and a score was assigned for each feature. Scores were translated into a star rating, from zero stars for virtually no inherent safety features to five stars for the highest inherent safety, for each of the six domains. STARS distinguished well between older tractor models known to have few inherent safety features and newer tractor models known to have higher levels of inherent safety. STARS can provide tractor manufacturers, dealers, and users with information critical for managing tractor-associated injury risk. In Australia, it is initially being implemented within the curriculum of the technical education and training sector.*

Keywords. *Accident prevention, Agricultural injuries, Agricultural machinery industry, Design, Passive protection, Tractor.*

The burden of injury within agriculture is significant, as reflected in fatality rates that are 3.5 to 6 times higher than those for other industries in Australia and the U.S. (NOHSC, 1998; U.S. Department of Labor, 2001). Tractors remain a leading contributor to this burden in many industrialized countries, accounting for 15% to 45% of work-related fatalities among those employed in agriculture (Myers et al., 1998; Brisson et al., 1998; Langley et al., 1997; Clarke and Coleman, 1995; Day, 1999).

Current programs to reduce tractor-related deaths and serious injuries include the development of standards and regulations (Donham et al., 1997; Farmsafe Australia,

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1998; Myers, 2002; Day and Rechnitzer, 2004), application of new technology to design solutions (Shutske et al., 2001; Guo et al., 2002), promotion of rollover protective structures and development of alternative designs (Powers et al., 2001; Harris et al., 2002), retrofitting of safe access platforms (Day and Rechnitzer, 2004), and competency-based tractor operations training programs. Acceptance of the need, and stimulation of demand, for tractor safety improvements may be generated by cognitive-behavioral approaches and social marketing (Cole, 2002).

In the area of motor vehicle safety, consumer demand for safety features has been a driving force in improving motor vehicle occupant protection, in parallel with the somewhat slower mechanism of regulatory change. Crash worthiness ratings, which indicate the relative levels of inherent protection offered by various car models, have played a key role in the increasing sophistication of motor vehicle occupant protection systems and the associated reduction in deaths and serious injuries (Griffiths et al., 1994; Tingvall et al., 1996).

There has been no similar, systematic, independent mechanism to stimulate safety design modifications to tractors. The Kondinin Group, a national independent farm improvement organization of 10,000 farmers, regularly rates tractors for features and performance, but the rating does not include safety (Boyle, 2001). Some farm safety assessment and management programs include tractor safety checklists, but these are necessarily brief and usually do not provide tractor specific scores. The Iowa Certified Safe Farm Program includes a tractor safety checklist, which facilitates a pass/fail score for tractors (Jaspersen et al., 1999), but this type of system would not provide an assessment of the relative safety of tractors receiving a pass score. Checklists and audit tools generally do not specifically identify the safety issues with tractors or provide strategies for managing the identified risks.

Generally, new tractors have relatively high safety and ergonomic standards. However, some features, such as operator access to the cab and access for servicing or maintenance, have improved very little over time, and therefore scope remains for improvement in safety features of new model tractors. Unfortunately, the impact that newer, safer tractor models have on modifying injury risk is limited by the slow rate of turnover in the tractor pool. A systematic mechanism for identifying inadequate design features on older tractors could stimulate the development of appropriate retrospective modifications for safety enhancement. It would provide information to tractor owners and operators that could assist in risk management, particularly as the Kondinin Group increasingly recognizes tractor safety as an issue for farmers (Walsh et al., 2003).

To facilitate this, we have developed the Safe Tractor Assessment Rating System (STARS): a comprehensive, design-based, tractor safety evaluation system that can be applied to both new and used tractors. The system allows comparison of the inherent safety features of individual tractors, thereby providing critical information for tractor manufacturers, dealers, and operators. The aim of developing such a system is to stimulate consumer demand for tractor safety features, and motivate improved design.

Development Process

Safety rating systems are generally either retrospective, based on actual incident statistics, or predictive, based on either technical inspections or laboratory testing (Tingvall et al., 1996). A retrospective rating system, as has been used for motor vehicles, would not be a feasible option for a tractor safety rating system since detailed information on the make and model of tractors involved in serious injury incidents is not routinely collected or readily accessible. Further, sufficient numbers of cases for the various tractor

makes and models would not be available for robust statistical analysis. Therefore, a predictive rating system model, based on technical inspection, was selected.

The project team was formed through a unique collaboration between Monash University and the Kondinin Group, which linked research to farming operations. The rating system was developed in three stages (fig. 1), which are described in detail in the

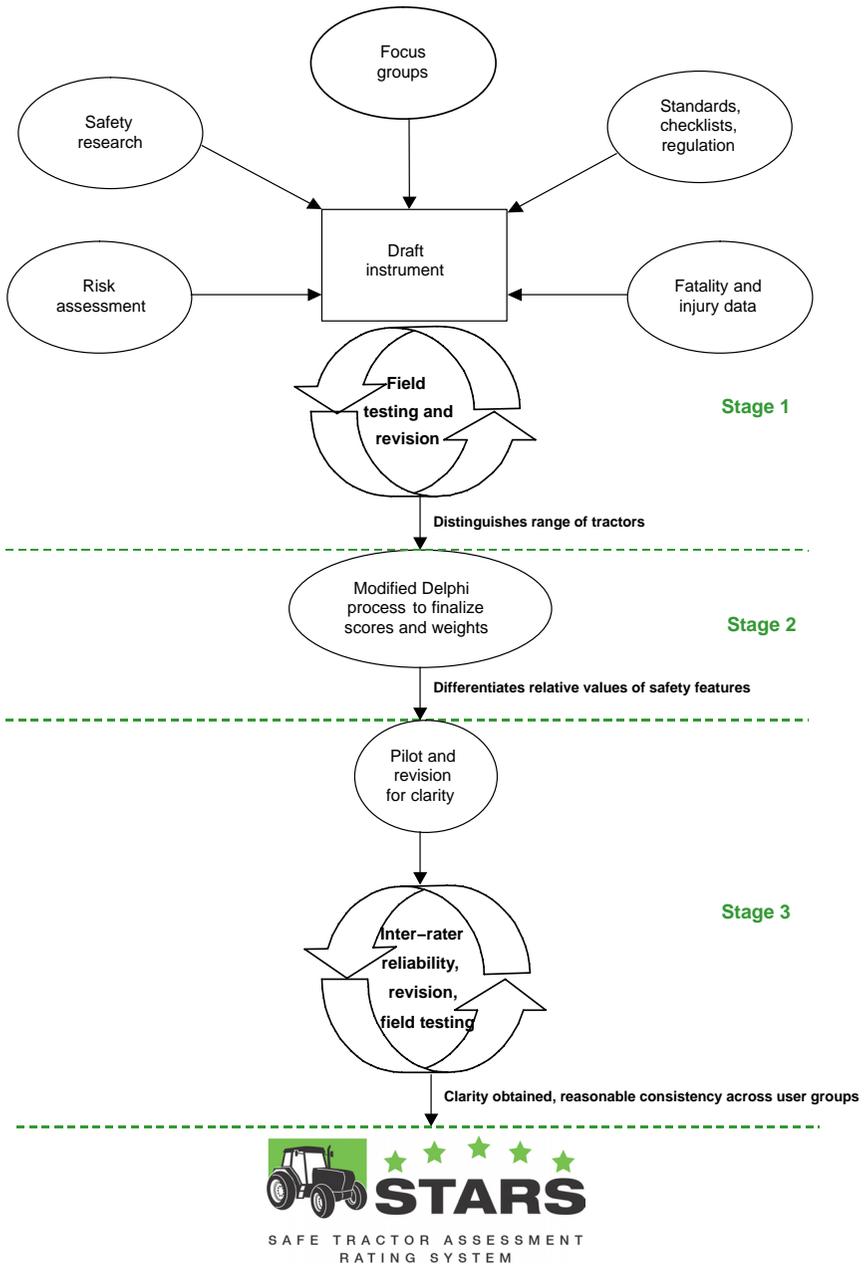


Figure 1. Developmental stages of the Safe Tractor Assessment Rating System.

following sections. A project advisory committee provided advice on, and review of, the development process. It comprised 13 experts in occupational health and safety as applied in agriculture, tractor manufacturing, law, agricultural science and engineering, and motor vehicle crashworthiness. The system was designed for experienced tractor operators, machinery dealers and manufacturers, tractor instructors, and machinery inspectors.

Stage One: Initial Development

Key principles adopted at stage one included the potential for design features to reduce the risk of an injury event occurring, and to reduce the risk of injury if such an event did occur. The potential for design changes to reduce the need for, or the ease of, unsafe work practices, was also considered. A draft of the system (including potential safety design features), a procedure, and definitions were prepared based on:

- Current standards and existing checklists (listed in Scott et al., 2002).
- Specific research that identified tractor design issues (Day and McGrath, 1999; NOHSC, 2000; Edwards and Neale, 2000; Davidson, 1995).
- Injury and fatality data (Ashby and Day, 1995; Day et al., 1997; Myers et al., 1998; Franklin et al., 2000).
- Farmer and farm worker input.

Input was obtained from 97 farm owners and employees. Focus groups consisting of convenience samples of farm owner/operators were conducted in Australia (7 farming organization members) and New Zealand (84 delegates at an agricultural conference). Discussion topics included the concept of a rating system and nomination of the key areas of tractor safety as perceived by the participants. In addition, a combined phone and mail survey was conducted of a convenience sample of six farm employees working in four of the eight Australian states and territories. The participants were asked to: (1) comment on the most important safety features and the most dangerous features of tractors, (2) suggest ways to improve tractor safety, and (3) comment on aspects of developing a rating system and the items that should be included.

The draft system was prepared by combining the above information with the project team's knowledge of the fundamental principles of risk assessment and safety design. Circumstances leading to fatal and serious injury events were extracted from the injury and fatality data and relevant publications. The role of the tractor in the cause of the event and subsequent injury were examined for the contribution that design features make to injury occurrence and for the potential for design changes to improve passive safety. Design solutions for causes of common and serious injuries were identified in existing standards, checklists, research, and from the design of new model tractors.

The major tractor-associated injury categories provided a framework for the system. The rating system was divided into six domains: rollover, runover, user protection, information and controls, pedestrian protection, and options. The options domain includes aspects that may not necessarily be present on every tractor, such as a three-point linkage or a passenger seat. The domains were divided into risk categories, each of which had an optimum suite of design features to protect the operator (fig. 2 illustrates the rollover domain as an example). Notional scores were assigned for each design feature at this stage.

The draft system was further developed in an iterative process involving field tests with new and used tractors and revisions of the system. New tractor models with a reputation for safety features, and older models with known poorer safety standards, were included in these tests. The first test series was conducted jointly by the project team on Ford 3600, Ferguson F-35, Massey Ferguson 2675, and Massey Ferguson 6270 tractors.

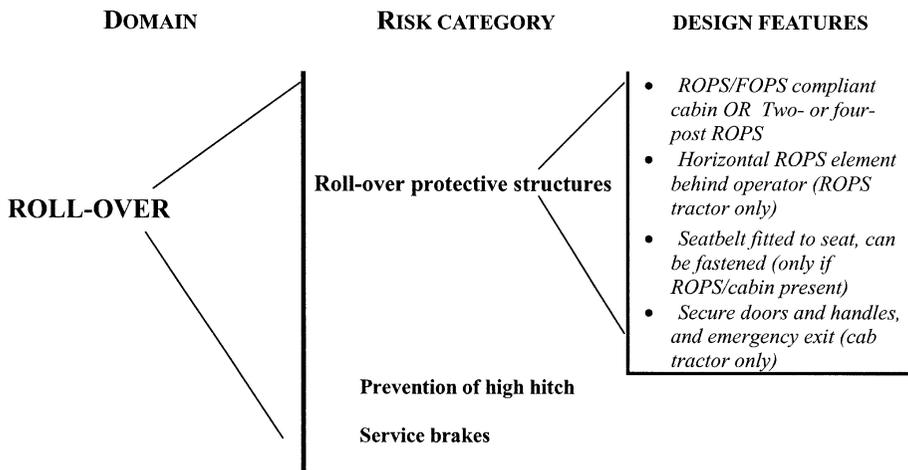


Figure 2. Example structure of the Safe Tractor Assessment and Rating System, illustrated by the risk categories and design features for the rollover domain.

The second series was conducted by one team member using a second panel of four tractors ranging from those manufactured in the late 1960s through to current models. This second series of field tests showed that the rating system had reached a critical point in the development pathway, at which different levels of inherent safety features were reflected by the different scores obtained for each tractor (table 1).

Stage Two: Refinement and Scoring

As indicated, the rating system consists of a number of risk categories grouped into six domains (fig. 2 illustrates the rollover domain as an example). A summary score for each domain was derived from the sum of the scores for the various risk categories within each domain. However, since the operational environment of a particular tractor can vary from farm to farm, and from task to task, the domain ratings were not collapsed into one summary measure. By providing a rating for each of the six domains, the relative safety of a particular tractor in a range of different operating environments can be evaluated.

However, each design feature of each risk category was weighted according to the degree of effectiveness provided by each feature relative to the other features within that particular risk category. Representative injury data from incidents involving tractors with the various rating system features, which would be required to most accurately assign

Table 1. Stage 1 STARS results for four example tractors.

Domain	Tractor			
	1969-79	1982-92	1992-97	1998-current
	No Cab 56-86 kW	No Cab 60 kW	Cab 75 kW	Cab 75 kW
Rollover (total out of possible 15)	2	6	13	13
Runover (total out of possible 20)	0	8.5	15	15.5
User protection (total out of possible 15)	6	6	14	14
Information and controls (total out of possible 7)	3	4	7	6
Pedestrian (total out of possible 10)	0.5	3.5	4.5	6

Note: Scoring structure and weighting had not been finalized at this stage.

these weighted scores, was not readily available. Therefore, a modified Delphi process (Linstone and Turoff, 1975; Adler and Ziglio, 1996) was conducted to derive design feature scores based on expert opinion.

Ten people participated in the Delphi process, all of whom had expert knowledge in the area of tractor design and injury causation and prevention. Eight participants were from Australia, four of whom were from state workers compensation authorities, two were researchers with considerable experience with in-depth investigations of fatal and serious tractor-related incidents, and two were from the project team (one agricultural engineer and one agricultural occupational health and safety expert). Two overseas experts (both agricultural engineers) also participated, one from the U.S. and one from Canada.

Participants were asked to rank the various features within each risk category in order of importance for prevention and give each feature an effectiveness score from 1 to 10, with 1 being the least effective and 10 being the most effective (i.e., providing almost complete protection for the particular injury). Participants were instructed to assume that each feature is always used as intended, and although some of the suggested features were novel, to assume that these features were possible to design and would perform accordingly.

Among the 69 features, there were 57 for which at least 5 of the 10 participants assigned a score within one count of the mean for that feature, and 24 features for which at least 7 participants assigned a score within this range. For these 57 features, the average panel score was used in the rating system to indicate the relative importance of the feature. There were 12 remaining features for which less than 5 participants assigned a score within this range. Consensus on the appropriate values for these features was reached by a teleconference between the eight Australian-based Delphi panel members.

The total possible score for each risk category was set at 20, and the scores for each feature were assigned according to the relative weights agreed upon in the Delphi process. This resulted in the total possible score for the rollover, runover, and user protection domains being 60, while that for the information and controls and pedestrian protection domains was 40. The total possible score for the options domain was 80, although few tractors would have all of characteristics included in the options domain. The actual score assigned to each domain was ultimately translated to a star rating, where five stars indicated the highest safety performance.

Stage Three: Finalization

Pilot

Pilot tests were undertaken with a small number of potential end-users to gain feedback prior to inter-rater reliability testing. The pilot was conducted with convenience samples of two groups of agricultural college students and four individual practicing farmers recruited through local networks. The farmers were selected to provide a range of tractors in terms of age and manufacturer.

The students were given two different versions of the rating system worksheet to use in assessing a particular tractor available at the agricultural college. One group was given the full version with extended notes and illustrations. The second group was given a brief version with less extensive notes. The farmers were asked to conduct a rating on one of their own tractors and were given the full-length notes. No additional instructions were given beyond those in the rating system itself.

Following the tractor evaluations, de-briefing sessions were held to gather feedback on the clarity of the rating system, the format and layout, ease of use, and suggestions for improvement. A semi-structured format of closed and open questions for the sessions was followed. Closed questions gathered feedback on specific pre-identified issues,

while open questions provided participants the opportunity to make unstructured comments on any issue. Feedback indicated that the full version of the worksheet was required and preferred. Both the students and the farmers indicated a strong desire to assign partial points, for which the rating system was not designed, and the instructions were modified accordingly.

Inter-Rater Reliability

Since the rating system was intended to be freely available for use by a range of consumers, the reliability of the system when used by different types of consumers was tested. A panel of six people was recruited through the project team networks to reflect the range of anticipated end-users. The panel included farm owner/operators familiar with large and small tractor operations, a farm worker, a farm machinery dealer, an occupational health and safety consultant to the rural industry, and an agricultural college instructor. The rating system documents were distributed to the panel members one week prior to the testing. No additional instructions regarding the actual rating process itself were provided.

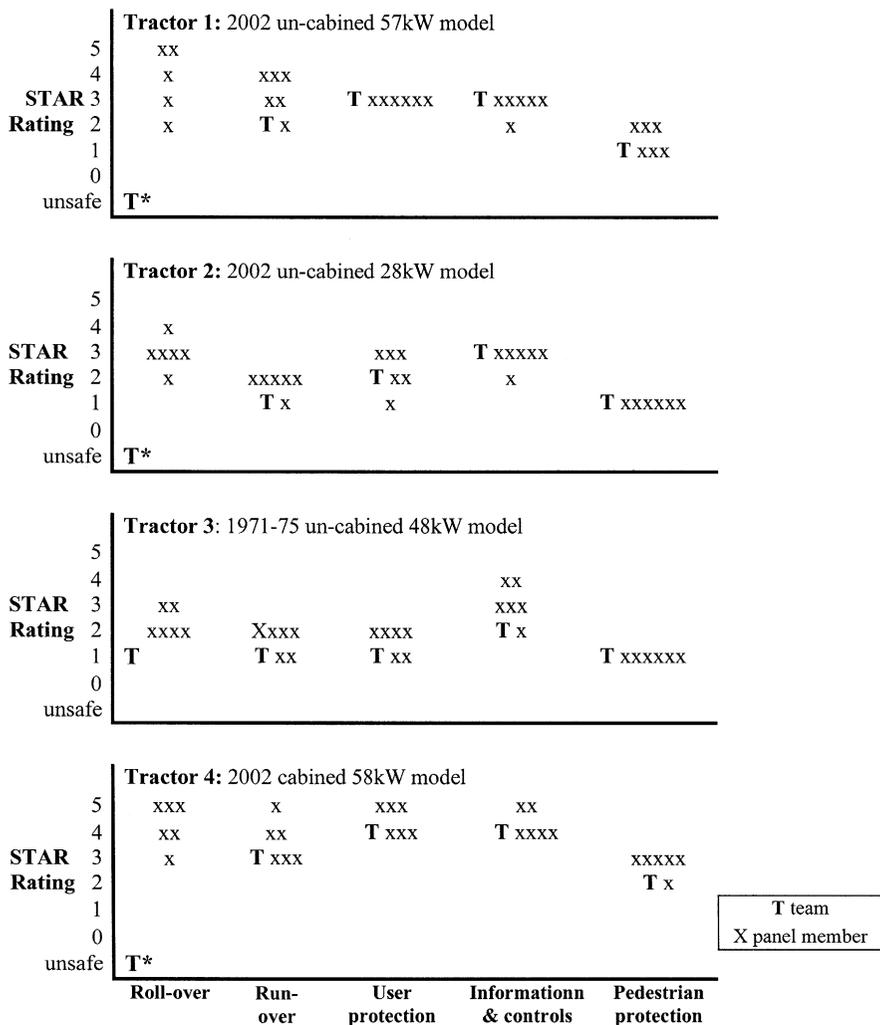
A panel of four tractors was selected to represent a range of tractors in use: a 2002 un-cabbed 57 kW model, a 2002 un-cabbed 28 kW model, a 1971-1975 un-cabbed 48 kW model, and a 2002 cabbed 58 kW model. Manufacturers have not been disclosed, as this was an undertaking given to the dealers who made the tractors available for the panel assessment. A consensus rating was conducted for each tractor by three project team members prior to panel assessment. Each panel participant assessed each tractor in the same preset order, as listed above. After each person had completed their evaluations, a short de-briefing session was held to discuss those features for which the scores varied significantly from the team assessment.

The scores assigned to the tractors by the panel members were compared with the scores assigned by the team, and a degree of variation was noted. As five domains were scored for four tractors, there were 20 sets of scores. In 12 of these sets, the panel member scores were no more than one star rating away from the team consensus, and four sets were within two stars of the consensus score (fig. 3). The remaining four sets of observations were all for the rollover domain, for which the panel members consistently assigned a higher level of safety than the team consensus. Observations during the testing and de-briefing sessions indicated that sources of the variation included:

- Not having read the reference manual.
- Not having read the notes at the beginning of each table.
- Misunderstanding the nature of the design feature described.
- Not conducting measurements where these were required.
- Assigning a full score if a feature almost met the criteria, or awarding partial points.
- Not understanding that some of the scoring involved point deduction.
- Difficulty in locating ROPS compliance plates, and in determining equivalence with the Australian standard.
- Higher degree of familiarity than the project team with the features of some tractors.

Consequently, the rating system was further edited, and the changes made included:

- Development of a "how to use the rating system" section.
- Addition of pictorials (and a key) to indicate things such as where measurements are required, features that render the tractor unsafe, alternative features, where scores within a range can be assigned, and where point deduction is required.
- Insertion of a numbering system in the worksheet notes to facilitate movement between an item in the scoring table and the relevant explanatory notes.
- Clarification of items that were misinterpreted.



* Low roll-over scores given by the team for the newer model tractors were due to inability to determine equivalence to the Australian standard, a feature which was corrected in the subsequent revision.

Figure 3. Summary ratings of inter-rater reliability testing (options excluded), Safe Tractor Assessment and Rating System.

- Inclusion of a list of overseas standards equivalent to the Australian standard for ROPS.

As a second full inter-rater test was not possible, further field testing of the revised rating system with a convenience sample of agricultural college instructors was conducted. This field testing indicated that the final revisions had addressed a number of the issues that arose during the inter-rater reliability testing. However, subsequent experience with STARS suggests that inter-rater reliability will be maximized if the intended users receive a short training session, during which the underlying principles

outlined in the reference manual are explained and the process of rating a tractor is demonstrated.

The Final System

The STARS package consists of two documents: the STARS Technical Reference Document, which includes the system, rationale, definitions, limitations, and technical references; and the STARS Worksheet, which is used to conduct a rating, and includes summary and feedback sheets. The Worksheet presents a table of the optimum design features for each risk category, along with the score for each feature. Numbers and pictorials guide the user. Total scores obtained for each domain are transferred to a summary sheet, which then indicates the STARS rating (from no stars to five stars) for each domain. A series of features that would render a tractor unsafe for use are defined in the system, and strategies for management and subsequent use of such tractors are outlined. The STARS package differs to other assessment and audit tools in that it has an inbuilt diagnostic and problem-solving capability, since the Technical Reference Document includes sufficient information to allow users to control the risks that the rating system has revealed.

Copies of the STARS package, along with ratings for nine tractors in common use on Australian farms, are available at: www.monash.edu.au/muarc/projects/stars.html.

Outcomes and Discussion

An overall strategy targeting specific issues through education and training, improved risk management, and appropriate legislation is required to address agricultural health and safety. The STARS rating system fits into this broad strategy by providing a means of comparing the inherent safety features of individual tractors and by giving tractor manufacturers, dealers, and users information critical in managing tractor-associated injury risk.

Family farms could use STARS as a tool to systematically assess the level of risk associated with the farm tractors and as an aid to managing their safe operation. STARS therefore provides a mechanism to assist in meeting the legal obligations included in state occupational health and safety laws, which impose an obligation on designers, manufacturers, suppliers and employers to assess and control the risks associated with the operation of mobile plant, particularly tractors. Family farms could also use STARS as an aid to decision-making when purchasing new or used tractors. Similar uses would apply to corporate farms, in addition to providing an objective measure as a basis for discussions between employers and employees. Other sectors, such as agricultural education, occupational health and safety consulting, and those in which tractors are used, could also benefit from the use of STARS as an evidence-based assessment tool.

Farm machinery dealers and manufacturers could use STARS to provide objective information on the safety of tractors for marketing purposes and to indicate the safety benefits of new tractors. STARS could provide model-specific information so that different models could be marketed as being particularly suited, from a safety perspective, to certain applications. In some jurisdictions, STARS may assist dealers in meeting their legal obligations to provide safe products or to advise purchasers on the likely safety performance of a particular product. STARS may assist manufacturers in particular in identifying new safety-related design features.

The rating system has some limitations. It was designed with particular reference to conventional tractors; therefore, there may be some specific-application tractors for

which the rating system will be less applicable. Maintenance, including tires, engine servicing, and repairs, which also influences safety performance, is not included in this system, with the exception of brake performance. Attachments are not included, except for front-end loaders in the options domain. Cab ergonomics are not rated as a separate domain, but many ergonomic elements, such as location, identification, and operation of controls, cab access, and exposure to sun and noise, are included in other domains. However, the major causes of fatal and serious non-fatal acute injury are covered by the rating system. A rating produced at any one point in time will apply to that particular tractor only in its condition at that time, since some features (e.g., brakes, guards) may change over time.

Predictive rating systems based on technical inspections may be limited in that some aspects of design can best be assessed by performance testing. However, in the area of motor vehicle crashworthiness ratings, good correlation has been shown between retrospective rating systems (based on actual incident data in mass databases) and predictive rating systems based on technical inspections (Newstead and Cameron, 1999). Although STARS has not been validated on tractors involved in fatal events, older model tractors of the type frequently involved in fatal events generally obtain a low rating with STARS. Further, STARS readily distinguishes between older tractors, which generally have fewer safe design features, and newer tractors, which generally have significantly improved safe design features, as demonstrated during the development of STARS.

During the development of STARS, a number of issues were raised by representatives of tractor manufacturers (V. Delahunty, personal communication). STARS includes some design features that are not currently available and are not included in international standards, which is viewed as problematic by manufacturers. However, this reflects that there are serious injury issues that are not adequately addressed by current design features.

Tractor manufacturers were also concerned that STARS would not be readily adopted by the agricultural industry and would therefore represent a wasted resource. While it is true the uptake of occupational health and safety in agriculture has lagged behind that for other industries, demand for safety systems in agriculture is certainly increasing in Australia. For example, state farmer organizations have called for rollover protection legislation for all tractors, which has actually been promulgated in some states. STARS is already being incorporated into some organizational structures. A nationally accredited training package for STARS is being developed for the technical and further education sector. The training package will also be available to accredited trainers operating outside the technical and further education system. At least one state (New South Wales) requires that all agricultural and horticultural teachers undertake STARS training, and the use of STARS will be incorporated into the curriculum for agricultural students. STARS is also included as resource material in the rural occupational health and safety risk management course delivered throughout New South Wales. In 2003, elements of STARS were incorporated into the tender for the purchase of several hundred new tractors for rural high schools in New South Wales, indicating that recognition of STARS as a useful resource is beginning to occur. A major rural training organization in a second state (South Australia) has incorporated STARS into machinery operations and management units across all relevant courses, in addition to incorporation into any occupational health and safety units in all rural training packages.

Tractor manufacturers also asserted that STARS will increase tractor cost without leading to any identifiable improvement in farm safety. Some of the elements of STARS will certainly increase the cost of tractor manufacture, and in some cases these costs will not be inconsequential. However, if consumer demand for these safety features increases, then market forces may come into effect, which has been the experience in the motor

vehicle industry. The majority of safety features included in STARS can be related directly back to the patterns of fatalities and serious injuries and therefore, if used appropriately, would be expected to lead to improvements in farm safety in the future.

Conclusion

STARS provides a useful tool for objective assessment of the inherent safety features of new and used tractors. It was developed in a systematic process with reference to fatality and injury patterns, current standards, and tractor safety research, and included farmer input. It is readily available to farmers, tractor manufacturers, and dealers via the internet. In Australia, it is initially being implemented within the technical education and training sector. STARS has a role to play in improving occupational health and safety in agriculture.

Acknowledgements

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