

FINAL PROJECT SUMMARY REPORT: QUAD BIKE PERFORMANCE PROJECT TEST RESULTS, CONCLUSIONS, AND RECOMMENDATIONS

REPORT 4

by

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¹ <http://www.dynres.com/>

² <http://www.enginst.org/>

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Disclaimer

The analyses, conclusions and/or opinions presented in this report are those of the Authors and are based on information noted and made available to the Authors at the time of its writing. Further review and analyses may be required should additional information become available, which may affect the analyses, conclusions and/or opinions expressed in this report.

While the project has been widely researched and developed, with much input from many sources worldwide, the research methods, ratings system, conclusions and recommendations are the responsibility of the Authors. Any views expressed are not necessarily those of the funding agencies, the Project Reference Group (Appendix A), FCAI or others who have assisted with this Project.

This report, the associated reports and the results presented are made in good faith and are for information only. The conclusions and recommendations in this final report, if in conflict with any given in supporting reports, take precedence over all the other associated reports. It is the responsibility of the user to ensure the appropriate application of these results if any, for their own requirements. While the Authors have made every effort to ensure that the information in this report was correct at the time of publication, the Authors do not assume and hereby disclaim any liability to any party for any loss, damage, or disruption caused by errors or omissions, whether such errors or omissions result from accident, or any other cause.

Further Information

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1. Executive Summary

The Heads of Workplace Safety Authorities (HWSA) identified in 2011 Quad bike safety to be a major issue on farms in Australia and New Zealand. They stated that *“In Australia, more than 64 per cent of quad bike deaths occur on farms and in the last 10 years there have been 130 quad bike fatalities across the country. In New Zealand, five people (on average) are killed on farms and over 845 injuries reported each year.”*

The Authors also note that Quad bikes and Side by Side Vehicles (SSVs) are classified as mobile plant in the Work Health and Safety legislation. The hierarchy of controls for managing risks within that legislation specifies that engineering controls which design out the hazard are considered more effective control measures than administrative controls such as training courses which seek to change human behaviour and personal protection measures (e.g. helmets).

This report presents a range of recommendations covering vehicle design, a vehicle star rating, helmets, passengers and loads, child and ageing riders, the supply chain, and retrofitable safety devices and community awareness.

The Star Rating System developed and presented in this report is capable of informing both consumers and workplace plant managers and controllers which Quad bikes and SSVs provide improved rollover resistance and rollover crashworthiness protection in the event of a rollover crash.

The Quad Bike Performance Project (QBPP) is aimed at improving the safety of Quad bikes, in the workplace and farm environment by critically evaluating, conducting research, and carrying out testing, to identify the engineering and design features required for improved vehicle Static Stability, Dynamic Handling and Rollover Crashworthiness including operator protective devices and accessories.

Improving the engineering and design features of Quad bikes is critical in reducing fatalities and injury rates. It is recommended that this is best done through the application of a Quad bike and Side by Side Vehicle Star Rating system (ATVAP: Australian Terrain Vehicle Assessment Program). Such a program would inform consumers purchasing vehicles or accessories for use in the workplace. The Star Rating system is intended to provide ‘a safety rating’ in that vehicles with higher star ratings will represent a lower risk of rollover and subsequent potential injury in the event of a rollover incident in the workplace environment based on the best currently available information.

This report provides a summary overview of the whole project along with the conclusions, recommendations and rankings of the vehicles tested. There are four main reports, namely **Part 1: Static Stability Test Results (Report 1)**; **Part 2: Dynamic Handling Test Results (Report 2)**; **Part 3: Rollover Crashworthiness Test Results (Report 3)** and this **Final Project Summary Report: Quad Bike Performance Project Test Results, Conclusions and Recommendations (Report 4)**. There is also a **Supplemental Report** that presents a summary of the ‘**Examination and Analysis of Quad Bike and Side By Side Vehicle (SSV) Fatalities and Injuries**’ carried out by McIntosh and Patton (2014a) and Mitchell (2014) and some further analysis by the Authors Grzebieta, Rechner and Simmons.

The reader is referred to Part 1: Static Stability Test Results report for the detailed introduction and background to the Quad Bike Performance Project (QBPP) and ATVAP (also see Rechnitzer et al., 2013), which is not repeated here.

The (more than) 18 month project comprised a comprehensive research and physical test program involving over 1,000 tests carried out at the NSW Roads and Maritime Services, Crashlab facility at Huntingwood, NSW, Australia. The various tests (Parts 1 to 3) were carried out on 16 production vehicles and one prototype Quad bike. This extensive project also involved the examination and analysis of 109 selected Coronial case files collected from all Australian States and Territories for the period 2000 to 2012, and workplace injury and hospital admissions data from NSW and elsewhere (Supplemental Report).

The focus of the test program on rollover prevention and injury mitigation were based on the findings from the fatality data which indicated that rollover was involved in over 71% of the fatalities (77 of 109). This is also consistent with McIntosh and Patton’s (2014b) analysis of the US CPSC’s All-Terrain Vehicle Deaths (ATVD) database (Supplemental Report), also identified around 72% of Quad bike (ATV) fatality cases involved a rollover, being consistent with Australian data.

The 16 production vehicles, the prototype Quad bike and the Operator Protection Devices (OPDs) tested are shown in Figure 2 and Figure 3.

Proposed ATVAP Star Rating of 16 Production Quad bikes and SSVs

The final ATVAP Star Rating for the 16 tested vehicles is shown in Figure 1 below. The maximum rating score is out of 85 points, and from one to five Stars.

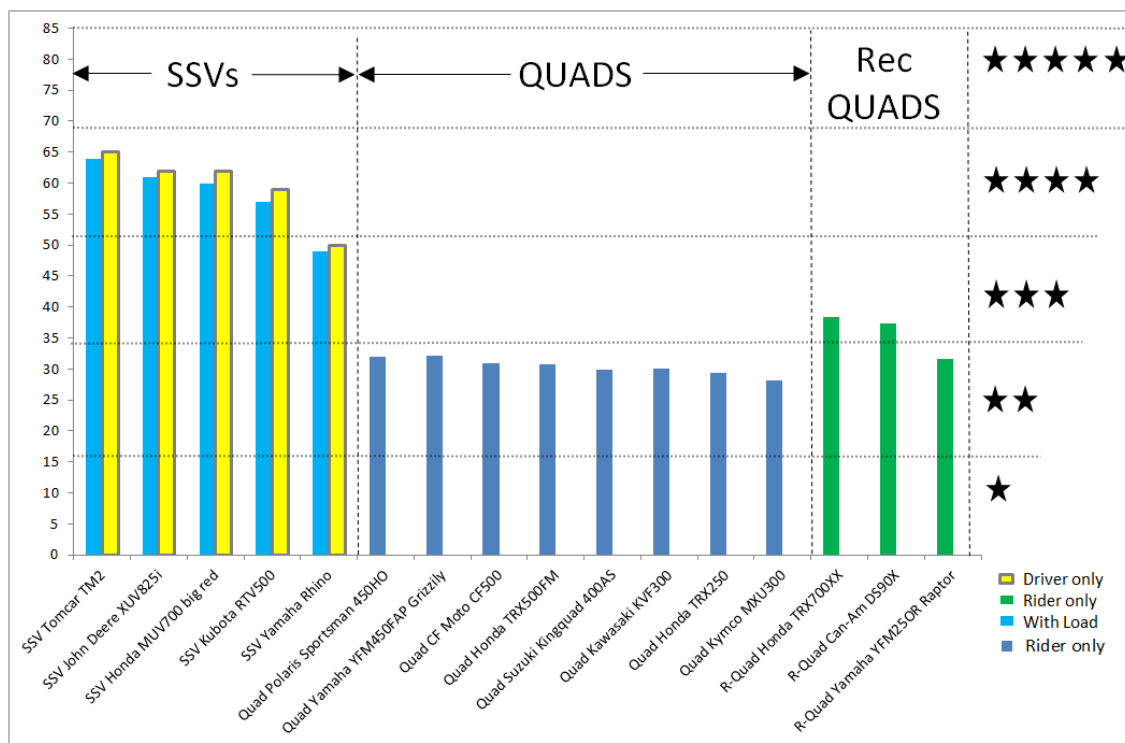


Figure 1: Final Points and Star Rating of the 16 production Quad bikes and SSVs tested. (see also Table 10 and Figure 19).

Four Star ratings were achieved by four of the five SSVs in the following order: by the Tomcar TM2 (max 65pts), the John Deere XUV825i (62pts); the Honda MUV700 Big Red (62pts) and the Kubota RTV500 (59pts).

Three Star ratings were achieved by the Yamaha Rhino SSV (50pts), and two of the 'Recreational' Quad bikes: the Honda TRX700XX (38pts) and the Can-Am DS90X (37pts).

Two Star Ratings were achieved by all the other Quad bikes (28pts to 32pts).

It is recognised that in the time elapsed since testing these vehicles, new models may have been released which incorporate better engineering and design features that may deliver a higher star rating.

CONCLUSIONS

The following conclusions have been drawn from the QBPP's review of Australian Quad bike and SSV fatality and injury data and the extensive test program (Parts 1 to 3) on Static Stability, Dynamic Handling and Rollover Crashworthiness.

The main conclusions from the study are listed as follows:

CONCLUSION 1: Quad bike Fatalities and Injuries in Australia for the period 2000-2012. Rollover and being pinned were the most frequent injury mechanisms for Quad bike related fatalities on farms.

1. 141 fatalities were identified from the Australian National Coronial Information System (NCIS) dataset. Approximately 10 to 15 fatalities per annum.
2. 109 fatal cases were relevant, the other 32 cases involved public road crashes or other vehicle types.
3. The 109 cases constituted 106 Quad bikes, and 2 SSVs and one six wheel bike.
4. 86% of deaths were male.
5. Approximately 50% of the 109 fatalities were related to workplace activity (n=54; 53 farms and 1 forestry) and 50% (n=55) to recreational activity. The majority of cases involved riders on their own and remote from immediate help.
6. Approximately 75% of the 109 fatalities occurred on Farms.
7. Rollover occurred in 71% of the 109 cases. Of the 109 cases 85% of the work related fatal cases involved a rollover compared to 56% of recreational cases.
8. Loss of control on a slope and/or driving over an object was a factor in 58% of the farm cases and 33% of recreational cases.
9. In work related fatal cases, a higher percentage of these were older riders, namely: 78% were 50 years or older; 50% were 60 years or older; 42% were 65 years or older; and 33% were 70 years or older. In comparison, for all fatal cases, 43% were 50 years or older, and only 9% of recreational riders killed were 50 years or older.
10. The main cause of death for farm workers was chest injury (59%) compared to head injury for recreational riders (49%).
11. Around 13% of farm workers died as a result of head injury. A helmet was found to be worn in 22% of the 109 cases.

12. The dominant injury mechanism for farm cases was rollover followed by being pinned by the vehicle resulting in crush injury and/or mechanical asphyxia. 70% were pinned under the Quad bike. Most of the pinned events were with the vehicle on its side not upside down, by a factor of approximately two to one (2:1).
13. Almost 50% of the farm work fatalities were caused by mechanical asphyxia, with approximately 77% of these estimated to have been survivable incidents if the rider did not remain pinned.
14. For recreational riders, a smaller number were pinned under the Quad bike, about 33% of cases.
15. Regarding Quad bike & SSV injuries, based on hospital and other injury databases, it is estimated that there are approximately 1,400 presentations per annum at hospitals in Australia, from minor to severe injuries.

CONCLUSION 2: The performance tests and ATVAP Star Rating system developed in this project rated four of the five SSV vehicles significantly ahead of Quad bikes in terms of higher resistance to rollover, and likely³ reduced injury risk in a rollover. However, it also identified lower performance SSVs and Quad bikes.

CONCLUSION 3: There is a clear need to distinguish and treat differently the safety requirements for Quad bikes used in the workplace/farms compared with those for recreational use due to different usage requirements. However, there is a common need for improved stability, dynamic handling and rollover crashworthiness safety for both workplace and recreational Quad bike usage.

CONCLUSION 4: The findings support the view that multiple controls need to be applied, with a hierarchy based approach. Vehicles should first be selected on a 'Fit For Purpose' criterion, to ensure that the correct vehicle is chosen for the work task.

CONCLUSION 5: Long term, effective improvement in Quad bike/ SSV safety requires a Vision Zero based 'Safe System Approach' (safer vehicles, safer environment, and safer people where deaths or serious injuries in the workplace that results in a permanent disability are not acceptable). That is – a multifaceted holistic approach to safety.

CONCLUSION 6: The rollover resistance of Quad bikes is typically low, and provides low margins of safety against rollover, particularly when compared with SSVs. Similarly, the carrying of relatively small loads adversely affects the Quad bike's stability more than that of the SSVs.

CONCLUSION 7: Well-designed SSVs are likely to have higher rollover resistance, better handling and lower severe injury risk than Quad bikes when drivers and passengers wear (three point or harness) seat belts, helmets and use the other restraint systems (head and shoulder barriers) included on the vehicles. SSVs should also have a seat belt interlock

³ Refer for example US CPSC (2014) proposing a safety standard for SSVs regarding the Yamaha Rhino and reduced incidents due to a repair program initiated by the CPSC to improve the vehicle's handling and stability for SSVs.

system, i.e. the vehicle should be disabled or only travel at 10 km/h or less if seat belts are not locked in.⁴ This would similarly apply to a Quad bike should a design with a ROPS and seat belt become available in the future.

CONCLUSION 8: Dynamic Handling. The dynamic handling tests were innovative and showed that, contrary to industry opinion, Quad bikes could be subjected to scientifically reliable, repeatable, and meaningful dynamic handling tests.

CONCLUSION 9: Dynamic Handling. In contrast to Quad bikes, SSVs generally had more forgiving handling and higher stability characteristics (i.e. higher resistance to rollover), and were less reliant on the operator's vehicle handling skills. The performance of the prototype vehicle indicates Quad bikes can reach the same level of forgiving handling and higher stability characteristics as SSVs.

CONCLUSION 10: Crashworthiness. Quad bikes without a Rollover Protection System (ROPS) have a limited ability to prevent severe injury risk in either low or high speed rollovers, although this also applies to poorly designed SSVs with substandard ROPS and inadequate seatbelts and interlocks, and poor containment to prevent partial ejection.

CONCLUSION 11: Operator Protection Devices (OPDs)⁵. The static stability and dynamic handling tests identified that the Quadbar and Lifeguard (Figure 3) were not detrimental while a third (Quickfix) was found to be detrimental to the stability or handling of the Quad bikes.

CONCLUSION 12: OPDs. In regard to injury prevention in rollovers for the workplace environment, two OPDs (Quadbar and Lifeguard) are likely to be beneficial in terms of severe injury and pinned prevention in some low speed rollovers typical of farm incidents. They do not reduce the incidents of rollover. In some specific cases injury risk could be increased although there is currently no real world recorded evidence of this. The findings support the view that multiple controls need to be applied. Of course there is scope for improvements to OPD designs in future.

CONCLUSION 13: OPDs

In the order of effectiveness, phasing out of Quad bikes and replacing with well-designed SSVs is likely to be superior to reliance on fitment of OPDs for risk mitigation. In the interim, for low speed workplace environments OPDs may be beneficial overall, but may also prove hazardous in some crash circumstances. However, any Australian real world case demonstrating an OPD has been causal to an injury has yet to be identified. Moreover, fitment of these devices needs careful monitoring and evaluation by regulators to ensure that any possible adverse outcomes of OPDs are promptly identified and publicised. This is not to suggest that significant improvements to the rollover crashworthiness effectiveness cannot be achieved for both Quad bikes with OPDs and SSVs in the future.

⁴ See US CPSC (2014) for examples of seat belt interlock systems offered by some SSV manufacturers.

⁵ Sometimes also less generically referred to as Crush Protection Devices (CPDs).

CONCLUSION 14: Quad bike designs can be improved for increased stability and dynamic handling. Quad bike track width can be increased and their driveline and suspension systems modified to significantly improve rollover resistance and handling. Such changes are realistic and practical, as demonstrated, for example, in the testing of the prototype Quad bike and by the US CPSC regarding the Yamaha Rhino repair program.³

CONCLUSION 15: Data collection and recording, and access to data of Quad bike and SSV vehicle incidents at all levels (including fatalities) in the agricultural sector and workplace generally is inadequate, and has been a key obstacle to date in advancing the safety of such vehicles in workplace and agricultural settings.

CONCLUSION 16: The handling characteristics and operating environment of Quad bikes and SSVs are sufficiently different from other licensed motor vehicles such as motorbikes, cars or trucks, that vehicle specific basic training and instruction is required for these vehicle types by specialist accredited instructors. This type of training and instruction is equivalent to what is required when first beginning to operate any type of mobile plant. It is not to be confused with advanced driver training. Other specialist training already occurs in other aspects of farming, such as accreditation for chemical and pesticide use.

CONCLUSION 17: The fatal incidents involving children operating adult Quad bikes and the inability of children to properly handle adult Quad bikes, identifies that children under 16 should not operate adult-sized Quad bikes.

CONCLUSION 18: Incidents involving child fatalities and serious injuries indicate that Quad bikes are not an appropriate vehicle for the transportation of children on farms or recreationally. SSVs (with appropriate child restraints fitted) could be considered as an alternative vehicle. Guidelines for age appropriate standard-compliant child restraint or similar to be used in SSVs needs to be developed.

CONCLUSION 19: Active Riding and rider separation are not considered reliable rollover risk reduction strategies for Quad bikes in the work/ farm setting.

RECOMMENDATIONS

The Authors recommend that the following strategies should be considered, developed, and implemented as soon as practicable.

The use of a Star Rating system to inform consumers has been widely used and accepted by the general public, stakeholders and much of Industry. Examples include star ratings for white goods product energy efficiency, water efficiency (dishwashers, washing machines, etc.), consumer financial products, and, for vehicles, the very successful Australasian New Car Assessment Program (ANCAP), e.g. stars on cars for vehicle safety. Indeed, ANCAP has been a catalyst for and helped promote large technological safety advances that have delivered major safety benefits in terms of reduced community trauma in the case of road vehicles.

It is hoped that ATVAP, if adopted, would provide similar benefits for consumers and workplace plant managers and plant controllers. The objective would be to introduce a robust, test based rating system, in order to provide workplace and consumer based incentives for informed, safer and appropriate vehicle purchase (highlighting ‘Fit For Purpose’ criteria), and at the same time generate corresponding incentives and competition amongst the Quad bike and SSV Industry for improved, safer designs and models.

Ideally the ATVAP Rating system would sit within ANCAP to provide consumers with the maximum benefits when considering Quad bikes and SSVs for the workplace and elsewhere.

Experience from NCAP has shown that it cannot not be taken as a given that farmers will recognise safety assessment and ratings for their equipment and even if they do will make an informed purchasing decision. Therefore there will be a strong requirement for an effective implementation strategy for ATVAP as well as learning from ANCAP of how this can be done successfully.

The Authors recommend that the following strategies should be considered, developed, and implemented as soon as practicable:

Recommendation:	Actioned by			
	Regulator	Industry	Work- place	Research Groups
1. Require all Quad bike riders and SSV drivers in the workplace or otherwise to receive vehicle specific basic training and instruction by specialist accredited instructors.	✓	✓	✓	
2. Mandate wearing a suitable standard-compliant helmet, that is comfortable for workplace use, yet offers protection against head impact and thermal loading. Industry should encourage the increase of helmet use.	✓	✓	✓	
3. No child under the age of 16 should be allowed to operate an adult Quad-bike. A separate study should be undertaken in regards to safety performance and requirements of Quad bikes marketed for use by children under 16. Industry should provide this advice.	✓	✓	✓	✓
4. Where children are carried as passengers in SSVs, an age appropriate standard-compliant child restraint or similar to that used for passenger vehicles is likely to be required, for the same reasons that current adult three point restraints in road vehicles are not appropriate for children. This requirement needs to be investigated. Guidelines for age appropriate standard-compliant child restraint or similar to be used in SSVs needs to be developed.	✓	✓	✓	✓

Recommendation:	Regulator	Industry	Work-place	Research Groups
<p>5. Farmers and the general community should be informed through media and education programs that carrying a pillion (including a child) and elevated loads (e.g. spray tanks) on single rider Quad bikes can be particularly hazardous in terms of considerably reducing the Quad bike's rollover resistance to dangerously unstable levels as well as negatively impacting the rider's control of the vehicle. Similarly, farmers and the general community should be informed that carrying of relatively small loads adversely affects the Quad bikes stability more that of the SSVs. In addition, a targeted program through rural schools and preschools similar to pool safety and general road safety program could be adopted.</p>	✓	✓	✓	✓
<p>6. Suppliers of aftermarket attachments for Quad bikes and SSVs should assess the effect of their products on the static stability, dynamic handling and crashworthiness of these vehicles and make this information available to prospective purchasers, possibly via a sticker attached to the product.</p>		✓		
<p>7. Industry recognise that the majority of farmers killed over the past decade are older riders who in all likelihood will not ride Quad bikes as an Active Rider as recommended by manufacturers and therefore the industry recommend alternate vehicles for older riders. However, it is noted that the Authors do not accept Active Riding as an effective and reliable risk control measure.</p>		✓	✓	
<p>8. Recognise that the current configuration Quad bikes are promoted by Industry as Active Riding machines and that riders should not use them if they are not trained, or the task does not allow active riding, etc. The Authors therefore recommend a new safety warning label on Quad bikes with a continuous specific communication campaign to support this:</p> <div data-bbox="225 1402 896 1608" style="border: 1px solid black; padding: 10px; margin: 10px auto; width: fit-content;"> <p style="text-align: center; color: red; font-weight: bold;">WARNING for QUAD Bike Riders</p> <p style="text-align: center; font-size: small;">THIS VEHICLE IS DESIGNED AND REQUIRES THE RIDER TO USE ACTIVE RIDING - IF YOU HAVE NOT BEEN TRAINED IN ACTIVE RIDING, DO NOT HAVE THE PHYSICAL CAPACITY OR CAN NOT APPLY ACTIVE RIDING WHEN YOU ARE RIDING, THEN DO NOT USE THIS VEHICLE. IT IS UNSAFE FOR YOU.</p> </div> <p>However, again it is noted that the Authors do not accept Active Riding as an effective and reliable risk control measure.</p>		✓	✓	
<p>9. Considering that farmers often work alone in the field, development of a suitable Personal Locator Beacon (PLB), which ideally would activate automatically should a Quad bike roll over, should be developed or resourced from existing technology (e.g. from other industries such as mining) such that this would facilitate assistance as early as possible to a rider in distress.</p>		✓	✓	✓

Recommendation:	Regulator	Industry	Work- place	Research Groups
10. Promote, implement and support the 'Australian Terrain Vehicle Assessment Program (ATVAP)' as a consumer guide for Quad bike and SSV buyers, that provides independent information about these new vehicles on the Australian market concerning their rollover resistance and rollover crashworthiness. The Authors recommend that the ATVAP rating should be listed at point of sale, a rating sticker on the vehicle, and ratings presented online as with the ANCAP Ratings. All relevant rating tables and graphs for static stability, dynamic handling and rollover crashworthiness should be included in any ATVAP rating literature or presentation.	✓	✓	✓	
11. Any SSV should not be sold in Australia unless it complies with the ANSI/ ROHVA 1-2011 Industry voluntary standard as a minimum, and upgraded as per the recommendations of this, the supporting Part 1 to Part 3 reports, and the US CPSC latest September 2014 recommendations for improved stability, handling and crashworthiness performance requirements.		✓	✓	
12. Any Quad bike should not be sold in Australia unless it complies with the ANSI/SVIA 1-2010 Industry voluntary standard as a minimum, and upgraded as per the recommendations of this, and the supporting Part 1 and Part 2 reports for improved stability and handling performance requirements.		✓	✓	
13. Evaluation. The Authors strongly recommend a thorough evaluation program be developed and implemented that examines and reviews the safety performance of Quads bikes which comply with ANSI/SVIA 1-2010 and the safety performance of SSVs which comply with the ANSI/ROHVA 1-2011 and ascertain what further safety improvements to these Industry voluntary standards are required, e.g. rollover crashworthiness. These results should be published.	✓			✓
14. Hold workshops in capital cities, major regional centres and agricultural shows to disseminate this project's findings and safety improvement strategies.	✓	✓	✓	✓
15. Industry consider the standard against which occupant containment and protection are evaluated against, and upgrade the ANSI/ROHVA 1-2011 to include a dynamic rollover crashworthiness test for Side by Side Vehicles for occupant containment and protection.		✓		✓
16. A self-assessment be carried out by farms/workplaces with sloped and/or rugged terrain access roads on farms and terrain to aid in the selection of a vehicle best suited to the task and workplace. Access roads on farms and terrain over which Quad bikes travel should be speed limited taking into consideration the vehicle's TTR and dynamic handling characteristics. Vehicle distributors should consider this information in making recommendations to prospective purchasers. A template should be developed that assists farmers with such assessments.		✓	✓	✓

Recommendation:	Regulator	Industry	Work- place	Research Groups
17. Identify, mark out and sign post using reliable low cost methods, workplace areas inappropriate or hazardous for Quad bikes to travel over. All users should be informed of no-go areas. A template should be developed that assists farmers with such assessments.			✓	
18. A co-ordinated Australia wide comprehensive data collection and reporting, of mobile farm equipment injury and fatal incidents, including explicit details of make, model, year (MMY) to enable on-going evaluation of safety performance be established.	✓	✓		✓
19. Carry out Australia wide exposure surveys to better identify exposure variables for Quad bikes and SSVs to enable risk and Star safety ratings to be further developed for these vehicle types. Such exposure surveys would include MMY data, hours and time of use, kilometres travelled, terrain type, loads carried and attachment types, etc.	✓	✓		✓
20. Engage with insurers, industry, suppliers, government and the community regarding economic factors that currently encourage or discourage (e.g. price) the purchase and operation of vehicles 'Fit For Purpose', and identify mechanisms to facilitate safer vehicle selection.	✓	✓	✓	✓
21. OPDs. A minimum of 4 stars rated vehicles should be considered in the first instance when purchasing new vehicles for the workplace. In the circumstances where Quad bikes have been assessed as acceptable in the workplace, new Quad bike purchases should be fitted with OPDs prior to sale, noting they are likely to offer a net safety benefit in slow speed crashes typical of most farm use.		✓		
22. OPDs. Wherever possible and practical, the replacement of existing Quad bikes with four star rated vehicles should be considered. Where it has been assessed that existing Quad bikes are still acceptable or cannot be replaced, then OPDs be retrofitted to existing on-farm Quad bikes noting they are likely to offer a net safety benefit in slow speed crashes typical of most farm use.		✓	✓	
23. OPDs. In order to provide the ongoing monitoring of the effectiveness and safety of OPDs in a workplace application, a field based monitoring program should be established. Also there is a need to develop a more effective rollover crashworthiness test protocol for evaluation of OPD's for Quad bikes.	✓		✓	✓
24. Quad bikes. Retrofit programs be considered that improve Quad bike stability and dynamic handling characteristics to achieve at least a three star rating.	✓	✓	✓	

2. THE QUAD BIKE PERFORMANCE PROJECT

2.1 Background

This Project arose from the *Heads of Workplace Safety Authorities (HWSA)* identifying Quad bike fatalities as being a major workplace health and safety issue. They state that “*In Australia, more than 64 per cent of quad bike deaths occur on farms and in the last 10 years there have been 130 quad bike fatalities across the country. In New Zealand, five people (on average) are killed on farms and over 845 injuries reported each year.*”

The Authors also note that Quad bikes and SSVs are classified as mobile plant in the Work Health and Safety legislation. The hierarchy of controls for managing risks within that legislation specifies that engineering controls which design out the hazard are considered more effective control measures than administrative controls such as training courses which seek to change human behaviour and personal protection measures (e.g. helmets).

The Star Rating System developed and presented in this report is capable of informing both consumers and workplace plant managers and controllers which Quad bikes and SSVs provide improved rollover resistance and rollover crashworthiness protection in the event of a rollover crash.

The Quad Bike Performance Project (QBPP) is aimed at improving the safety of Quad bikes in the workplace and farm environment by critically evaluating, conducting research, and carrying out testing, to identify the engineering and design features required for improved vehicle Static Stability, Dynamic Handling and Rollover Crashworthiness including operator protective devices and accessories.

It is recommended that this best be done through the application of a Quad bike and Side by Side Vehicle Star Rating system (ATVAP: Australian Terrain Vehicle Assessment Program). It is also recommended that ATVAP be located within ANCAP. Such a program would inform consumers purchasing vehicles or accessories for use in the workplace. The Star Rating system is intended to provide ‘a safety rating’ in that Quad bike and SSVs with higher star ratings will represent a lower risk of rollover and subsequent potential injury in the event of a rollover incident, in the workplace environment, based on the best currently available information.

HWSA and the Quad bike Industry supported Working Group developed a strategy aimed at reducing fatalities and injuries from Quad bike use on farms in a work setting. Part 7 of that Strategy document was ‘Design’. This related to the aim to ‘critically consider engineering and design features’ for improved vehicle static stability, and improved crashworthiness including rollover protective devices (including retrofit of safety accessories). The work of this Project is intended to address that strategy.

In Australia, it is estimated (Mitchell, 2014) that there were approximately 270,000 Quad bikes and SSVs in use in 2010 (Australian ATV Distributors, 2010). This compares to an estimated 80,000 Quad bikes and SSVs in use in New Zealand agriculture in 2010 (Carman et al., 2010) and an estimated 10 million Quad bikes and SSVs in use by 16 million individuals in 2008 in the United States (US) (Helmkamp et al., 2011).

This Project's focus on Quad bike rollover and the need for improving vehicle stability and rollover crashworthiness was firstly based on data presented by Lower et al. (2012) which identified the high incidence of rollovers. Of the 127 Quad bike deaths in Australia between 2001 and 2010, they identified that *"65% of fatalities occurred on-farm, with 45% of incidents being work-related and 46% involving rollovers of the quad bike."* They further found: *"Analysis of the nature of the crash event highlights the leading mechanisms of injury as: collision with stationary object (34), rollover with no load or attachments (33), collision with other vehicle (10) and rollover with spray tank (9). Rollover of the quad bike [was] attributed to 46% of all deaths where the mechanism of injury was known. Additionally, where the work status and mechanism were known, rollovers accounted for 58% of deaths."*

The findings of this Project support and extend the analysis by Lower et al. (2012). Detailed analysis of the coronial case files from 2000 to 2012, identified that of the 109 included fatal cases studied in detail: approximately 75% occurred on farms; a rollover occurred in 71% of all cases and of these 85% of the work related fatal cases involved a rollover compared to 56% of recreational cases; 28% involved mechanical asphyxia; 50% were 'pinned' by the Quad bike and for the 53 farm cases 68% were 'pinned'. Regarding Quad bike & SSV injuries, based on hospital and other injury databases, it is estimated that there are approximately 1,400 presentations per annum at hospitals in Australia, from minor to severe injuries.

In response to the incidence of fatal and serious injury rollovers involving Quad bikes, and the Quad bike Industry response that provision of rollover protection systems on these vehicles is hazardous⁶, it has been proposed by some authorities and other safety stakeholders that, as a minimum, OPDs such as the devices shown in Figure 3, be installed on all workplace Quad bikes. That proposal is based mainly on the observation that a two post Rollover Protection System (ROPS) fitted to old and new tractors has resulted in a marked reduction of tractor fatalities (Day & Rechnitzer, 1999; Scott et al, 2002; Franklin et al, 2005) and hence, by analogy, might be effective in reducing Quad bike rollover harm.

While in principle it appears that such systems may have a protective benefit in some rollovers, it is also clear that fitment of OPDs will not prevent rollovers from occurring in the first instance and OPDs may not be effective in all rollover situations (Grzebieta and Achilles, 2007), as active separation or ejection still occurs and impact or crush by stiff areas on the Quad bike or the OPD itself may result. Other than the reports by the Authors, Australian research on the effectiveness of OPDs based on fatality and hospital data has yet to be done. Some USA research has been done and published based predominantly on computer simulations and some limited field rollover tests on full ROPS designs (Van Auken and Zellner, 1997 & 1998; Grzebieta et al, 2005; Zellner et al., 2004, 2006, & 2013; Van Ee et al., 2012), but similarly no US cohort studies have been carried out to assess the effectiveness of OPDs in the field or laboratory tests of Quad bikes fitted with an OPD.

⁶ <http://safetyatworkblog.com/2011/05/19/quad-bike-manufacturers-walk-out-of-safety-working-group/>

Thus, there has been little agreement on the way forward in improving Quad bike safety in regard to rollover⁷. The Industry position for Quad bikes is that while some design and safety performance measures have been standardised and introduced (mandatory under US law), Industry remains focused on rider training, administrative controls and personal protection equipment (PPE) such as helmets.

The Authors of this report support administrative controls⁸, as one of the components of a larger holistic Safe System Approach (Grzebieta et al., 2013) based on the Swedish 'Vision Zero' criteria (i.e., deaths or serious injuries in the workplace injury that results in a permanent disability are not acceptable). Any control should include increasing rollover resistance and enhancing rollover crashworthiness design, while still maintaining the operational capabilities of the vehicles. Hence, increasing rollover resistance and enhancing rollover crashworthiness design, should be one of the first components in the hierarchy of controls for managing risks within such a Safe System Approach in the workplace.

For this reason, users of Quad bikes, farm Industry groups, safety regulators, farm safety stakeholders and safety researchers, see from the history of safety advances in road vehicle transport that design countermeasures are possible, and that fitment of OPDs to Quad bikes is seen as a means of harm minimisation. In contrast, the Quad bike Industry continues to negate promotion of or indeed adequately research any design solutions concerning fitment of OPDs. The Quad bike Industry's resistance to fitment of OPDs (in their view) is that there is no scientifically valid research indicating that fitment of OPDs would be effective, not harmful and not compromising the capabilities of the vehicle.

Hence, there exists a decades-long impasse on advancing Quad bike rollover crashworthiness safety and the need for a new approach, as a way ahead to reduce Quad bike trauma (Rechnitzer et al., 2013).

Whilst the Authors agree with the Quad bike Industry that further in-depth injury data relating the characteristics of Quad bike and SSV rollover crashes to vehicle stability, handling and crashworthiness design would be of benefit, the Authors disagree that vehicle

⁷ FCAI, (2012). ATV Industry opposes rollover devices on safety grounds.

<http://www.fcai.com.au/news/news/all/all/311/atv-industry-opposes-rollover-devices-on-safety-grounds>.

⁸ Administrative controls are generally accepted as the lesser effective form of control in a Vision Zero Safe System Approach (death or serious injury that results in a permanent disability in the workplace are not acceptable), in the hierarchy of safety controls. Nevertheless, the FCAI have advised the Authors that:

"In the USA, where since 1991 the only increases in control have been in administrative controls (i.e., increasing passage of state laws regarding Quad bike usage, increasing to 47 out of 50 states as of 2013), during 1999 – 2006 Quad bike fatality rates (per 10,000 vehicles in use) decreased by 29%, and during 2001-2010, Quad bike emergency department rates (per 10,000 vehicles in use) decreased by 56% (Garland (2011, Tables 4 and 7), demonstrating the effectiveness of administrative controls."

However, the Authors note that in the hierarchy of control measures for managing risks, engineering controls which design out the hazard are considered more effective control measures than training courses which seek to change human behaviour. The Authors note from regulations covering mobile plant and structures, that persons with management or control of plant at a workplace are required to prevent mobile plant from overturning or the operator from being ejected from the plant. This person must ensure, so far as is reasonably practicable, that a suitable combination of operator protective devices (OPD) for the plant is provided, maintained and used.

design safety advances cannot proceed until such data is fully obtained and analysed. This argument should not be used to hinder safety design advancement for Quad bikes and SSVs. The Authors consider that until such data can be obtained, the principles established over the past 50 years in mobility safety for all vehicle types can be usefully and appropriately applied to Quad bike and SSV safety design.⁹ What is clear is that rollover is a major contributor to fatal and serious injury outcomes involving Quad bikes, and therefore measures aimed at reducing both the incidence and severity of rollover are obvious injury prevention countermeasures that should be strongly advanced. The Authors do not agree that Quad bikes and SSVs are exempt from such fundamental safety principles which apply to all mobile vehicles that transport people (e.g., cars, trucks, trains, trams, buses, etc.). A pro-active approach should be taken rather than waiting another decade until such data may become available, with many additional casualties occurring as a consequence of such delays. We are reminded here of the wise aphorism “*Do not let the best be the enemy of the good*”, with regard to progressing Quad bike and SSV safety.

On this basis, this Project is aimed at addressing Part 7 of the HWSA and Quad Bike Industry Working Group's Strategy (Design) to assist consumers and workplace plant managers and to address the current technical challenges in improving vehicle-centred safety of Quad bikes and SSVs, in the farm environment. This will be done through the development of a Quad bike and SSV *Star Rating System - Australian Terrain Vehicle Assessment Program – ATVAP*.

While clearly we make no claim that the ‘newly-born’ ATVAP can draw on a long and well validated history, as can the NCAP (worldwide New Car Assessment Programs), with its now 36 years history of development, innovation and robust validation (NCAP, started in the USA in 1978), it is apparent that such a testing based star rating system for consumer information has been a major catalyst for and helped promote large technological safety advances in automobile safety, with ‘star ratings’ used in many other arenas.

⁹ The Industry perspective advice to the Authors regarding Quad bike Safety is that:

“The principles established over the past 50 years in ‘rider active’ mobility safety (e.g., for motorcycles) can be usefully and appropriately applied to Quad bike safety design. Principally this is the research of Dr. Peter Bothwell (1973) in a series of studies for the US NHTSA, who found and recommended that motorcycle safety design could be improved by incorporating ‘smooth outer contours’, removing ‘sharp lacerating protrusions’, and “clearing the separation path” of the rider from the motorcycle during accidents.”

However the Authors, while acknowledging that some of the principles for motorcycles may also apply to Quad bikes, note in particular that what is not apparently being acknowledged by the Industry are the significant differences in vehicle characteristics, injury mechanisms and operational environment. One of the obvious differences are that Quad bikes are four wheeled vehicles (not two), typically much higher weight (about 250kg to 400kg), with rollover being the most frequent fatal crash mechanism. In particular, as noted from the Coronal data, rollover, being pinned and asphyxia are major fatal injury mechanisms for Quad bikes – however, these are not typical injury mechanisms associated with motorcycles. Thus the necessary safety countermeasures are quite different for motorcycles and Quad bikes. These major differences in the safety paradigm for motorcycles and Quad bikes needs to be recognised by Industry and to date has not been, in the Author's opinion.

The project objective is to introduce a robust, test based rating system, in order to provide workplace and consumer based incentives for informed, safer and appropriate vehicle purchase (highlighting 'Fit For Purpose' criteria), and at the same time generate corresponding incentives and competition amongst the Quad bike Industry for improved designs and models for the workplace environment. The premise is that Quad bikes and SSVs with a higher resistance to rollover and improved rollover crashworthiness will result in reduced rollover related fatalities and serious injuries. This opinion takes its basis from the Coronial data, which indicates overwhelmingly that rollover, pinned entrapment and asphyxiation are the major casual factors involved in farm place deaths related to Quad bikes. The star rating system can be evaluated progressively over the years based on real world field injury and fatality data.

It is hoped that ATVAP will be implemented in Australia (and internationally), and also provide safety gains for Quad bikes, SSVs and similar type vehicles for farm, workplace and indeed eventually in recreation use, over the years as it matures and accumulates further real world data to provide appropriate development, validation and refinement.

This report further sets out a series of recommendations for improving farm workplace use of Quad bikes and SSVs, through appropriate vehicle selection based on 'fitness for purpose' criteria¹⁰, improved vehicle design for rollover resistance, dynamic handling and crashworthiness, fitment of OPDs, driver training and use of personal protective equipment (PPE).

2.2 Project Structure and Methods

The project commenced in September 2012, with completion in August/September 2014.

The project consisted of six research and testing Tasks of which three essential testing related Parts have been reported on, namely: Part 1 Static Stability Tests, Part 2 Dynamic Handling Tests; and Part 3 Rollover Crashworthiness Tests. Two supplementary Tasks, namely: Collection of Coroner fatality data from all States and Territories and a detailed analysis of the cases and NSW workcover and hospitalisation injury data; and development of a Finite Element Computer model of a Honda 500cc Quad bike and rollover crash simulations (Mongiardini et al., 2014). The sixth and last task is the Final Project Summary Report (this report), namely, Quad Bike Performance Project Test Results, Conclusions and Recommendations. Each of the tasks are detailed as follows in the order they were presented to NSW Workcover:

Task 1: Part 1 - Static Stability Tests. This task was comprised of 318 tilt table tests for rollover resistance in lateral roll, forward and rearward pitch. The tests used a 95th percentile Hybrid III Anthropomorphic Crash Test Dummy (ATD) as a surrogate rider with

¹⁰ 'Fitness for Purpose' vehicle selection. This involves matching the vehicle's stability and crashworthiness requirements to a risk assessment which assesses the workplace operating environment, task environment, and user's capability. From such an assessment the selection of the most suitable vehicle type can be made and one which would provide a lower risk of a rollover incident occurring and a lower risk of injury.

a test mass of 103kg. The test matrix included the vehicle on its own with a rider; and with combinations of maximum cargo loads on the front and rear. The effects of a selected sample of operator protection type devices (OPDs) on static stability were also tested to assess their effect on stability.

Task 2: Part 2 - Dynamic Handling Tests. This task was comprised of 680 dynamic handling tests which included the ISO 4138: 2012 Passenger Cars - Steady State Circular Driving test method and the ISO 7401: 2011 Road Vehicles - Lateral Transient Response – open loop test method. Both these test methods were modified for a Quad bike and a SSV. An obstacle perturbation test (simulating riding one side over a rock like object) was also included. Components of these tests complemented the static stability evaluation.

Task 3: In Depth Case Study of Fatal Australian Quad Bike and SSV Incidents and Retrospective Review of NSW Workcover and Hospitalisation Injury Data. This was presented as a supplementary report detailing and summarising two sub tasks and was completed prior to establishing the rollover crashworthiness assessment method. The intention was to have this task completed prior to the completion of Task 1 (Static Stability Tests). All Coroners in five States (Victoria, NSW, Queensland, Tasmania, South Australia) and the ACT were extremely helpful and provided full access to all the data, including witness statements and photographs. However, there were major delays in accessing data in Western Australia and the Northern Territory, which had carry over effects to the whole Project. A Supplemental Report was submitted to NSW Workcover summarising outcomes from the fatality data collected and analysed by Dr. McIntosh and Dr. Patton (2014a) and the NSW injury data collected and analysed by Dr. Rebecca Mitchell (2014).

Task 4: Part 3 - Rollover Crashworthiness Tests. This task was comprised of over 65 tests that focussed on SSVs rollover crashworthiness. Quad bikes were assessed for lateral rollover and front and rear pitch rollover, with and without OPDs, to determine serious injury risk. The tests considered the outcomes from the injury analysis of National Coroners Information System (NCIS) and CPSC data carried out by McIntosh and Patton (2014a), the NSW injury data carried out by Mitchell (2014), and additional analysis of the Coroner case files by the Authors identifying the rollover related injury mechanisms that were causal to the 53 farm workplace fatalities;

Task 5: Finite Element Computer Modelling and Simulation. The objective of this research was to develop a Finite Element (FE) model of a typical ATV (the 2012 Honda TRX500FM) used in a farming environment. The FE model has allowed the Authors to simulate the vehicle kinematics that leads to a rollover as well as the interaction between a surrogate Hybrid III ATD rider and the vehicle in typical tilt table rollover crash tests. The developed model, which reproduced in detail the geometry and inertial properties of a real ATV, was validated through comparison with tilt table tests and bump test (Mongiardini et al., 2014).

While computer modelling and simulation have been developed and used in this project to assist in refining some of the crashworthiness test protocols, the project is not based

on virtual modelling, but rather based on the comprehensive physical test program at Crashlab, involving over 1,000 physical tests. Nevertheless, the model proved to be a powerful tool for investigating the risk level of potentially hazardous scenarios ranging from simple turns occurring on level terrain to more complex situations involving holes or obstacles, on level terrain or slopes. A copy of the Journal paper detailing how the model was developed can be provided on request.

Task 6. Final Report - Star Rating. This report (current report) details the development of the ATVAP Star Rating system that combines the assessments of all three tests series, namely Part 1 (Rollover Static Stability), Part 2 (Dynamic Handling) and Part 3 (Rollover Crashworthiness), into a 5 Star Rating System. The Star Rating System is intended to provide 'a safety rating' in that vehicles with higher star ratings will represent a lower risk of rollover and subsequent potential injury, in the workplace environment, based on the best currently available information.

2.3 The Project Reports

This Final Project Summary Report is supported by a series of detailed reports, as set out in [Table 1](#). The Crashlab reports provide details of the test methods and results. The report for the prototype Quad bike was provided to the Authors as a separate report and is not included in any of the report Attachments in order to conceal the identity of the manufacturer. The main reason for this is that the prototype Quad bike is not a production vehicle. Final versions of the TARS Report (this report) and all Supporting Reports have now been finalised. First Draft dates of the reports that were supplied to the NSW Workcover Authority and Industry for review and comment are provided in [Table 1](#).

Publications

The following papers have been published to date:

1. McIntosh A.S, Patton D.A, Rechnitzer G. and Grzebieta R.H., (2015). ***An in-depth case series analysis of Australian quad bike and side-by-side vehicle fatalities***, (Submitted to Injury journal for Peer-Review).
2. Mitchell R.J., Grzebieta R. and Rechnitzer G., (2015). ***Capture and surveillance of quad bike (ATV)-related injuries in administrative data collections***, International Journal of Injury Control and Safety Promotion, Published on-line 7th Jan 2015, <http://dx.doi.org/10.1080/17457300.2014.992353>.
3. Grzebieta R.H., Rechnitzer G.R., McIntosh A.S., Mitchell R. and Patton D., (2014). ***Road Related Quad Bike and Side by Side Vehicle Casualties***, Proceedings of the 2014 Australasian Road Safety Research, Policing & Education Conference 12-14 November.
4. Mongiardini M., Hicks D.C.E., Grzebieta R.H., Rechnitzer G.R., (2014). ***Modelling a Quad Bike for Simulating Rollover Events***, Transportation Research Record (TRR), Journal of the Transportation Research Board (TRB), Vol. No. 2425, Transportation Research Board of the National Academies, Washington, D.C., 2014, pp. 50–60, DOI: 10.3141/2425-07 (also presented at TRB Annual Meeting 2014 Paper No. 14-3603).

5. Renfroe, D., Roberts, A., Grzebieta, R., Rechnitzer, G. and Simmons J.K., ***Reconciliation of ATV/UTV Handling Characteristics and the Operator***, SAE Technical Paper 2014-01-0095, 2014, doi:10.4271/2014-01-0095.
6. Rechnitzer G., Grzebieta R.H., McIntosh A.S., Simons K., (2013). ***Reducing All -Terrain Vehicles (ATVs) Injuries and Deaths - A Way Ahead***, Proc. 23rd Int. Technical Conference on the Enhanced Safety of Vehicles, Seoul, Korea, Pap. Num. 13-0213-W, May, 2013.

Following WorkCover's official release of the Project reports, the authors intend to present further papers for publication and presentations at national and international forums.

Table 1: Details of the Final Report's supporting documentation.

TARS Report	TARS Supporting Reports	Other Supporting Reports
<p>QBPP: Report 4</p> <p><i>Final Project Summary Report: Quad Bike Performance Test Results, Conclusions and Recommendations</i></p>	<p>QBPP: Report 1</p> <p><i>Part 1: Static Stability Test Results</i></p>	<p>CrashLab Special Report SR2013/003</p> <p><i>Quad Bike Performance Project Quasi-Static Tilt Testing, including Appendix A to F (Test specification, Test matrix, Instrument response data, Test specimen details, Test photographs, Instrument details)</i></p>
	<p>QBPP: Report 2</p> <p><i>Part 2: Dynamic Handling Test Results</i></p>	<p>CrashLab Special Report SR2013/004</p> <p><i>Quad Bike Performance Project Dynamic Vehicle Performance Testing</i></p> <p><i>Appendix A to G (Test specification, Test matrix, Result summary data, Instrument response data, Test specimen details, Test photographs, Instrument details)</i></p>
	<p>QBPP: Report 3</p> <p><i>Part 3: Rollover Crashworthiness Tests Results</i></p>	<p>CrashLab Special Report SR2014/003</p> <p><i>Quad Bike Performance Project Crashworthiness Testing</i></p> <p><i>Appendix A to E (Test matrix, Instrument response data, Test specimen details, Test photographs, Instrument details)</i></p>
	<p>QBPP Report Supplemental Report</p> <p><i>Examination and Analysis of Quad Bike and Side By Side (SSV) Fatalities and Injuries.</i></p>	<p>Supplemental Report: Attachment 1 <i>Quad Bike Fatalities In Australia: Examination Of NCIS Case Data - Crash Circumstances And Injury Patterns.</i></p> <p>Supplemental Report: Attachment 3 <i>Report On United States Consumer Product Safety Commission (CPSC) Fatal ATV (Quad bike) Crashes: Circumstances And Injury Patterns.</i></p> <p>Supplemental Report: Attachment 4 <i>Quad Bike Injuries And Fatalities: A Literature Review.</i></p> <p>Supplemental Report: Attachment 5 <i>Quad Bike And SSV Crashworthiness Test Protocol.</i></p> <p><i>AUTHORS: Attachments 1 and 3 to 5: Dr. Andrew McIntosh and Declan Patton.</i></p> <p>Supplemental Report: Attachment 2 <i>Quad Bike-Related Fatal And Non-Fatal Injuries: Examination Of Injury Patterns And Crash Circumstances.</i></p> <p><i>AUTHOR: Dr. Rebecca Mitchell.</i></p>

3. FATALITY AND INJURY DATA

The following section summarises the findings from the examination and analysis of Australian and US fatality and serious injury data relating to Quad bikes and SSVs.

These data were used to inform the static stability, dynamic handling and crashworthiness test methods. The findings identified that rollover was the main associated mechanism in fatalities investigated.

3.1 Fatality Data

In regards to Australian fatal crashes, 141 fatalities were identified from the NCIS dataset of fatalities that occurred over a period of thirteen years (2000 to 2012). The vehicles involved were almost all Quad bikes. Only five cases involving some form of SSV were found in the data. Full documentation of the closed cases was retrieved from State Coroners around Australia, investigated and key information noted and analysed. It is unclear whether the dominance of the Quad bikes in the data is because of exposure (higher number of Quad bikes and their usage) or other factors.

The rate of fatalities per 10,000 vehicles for both Quad bikes and SSVs needs to be established and monitored. Presently, the fatality rate for Quad bikes appears to be around 0.6 per 10,000 vehicles, higher than for road vehicles which is presently around 0.47 per 10,000 vehicles. It is not possible to establish the rate of fatalities per 10,000 vehicles for SSVs. This is because data on the number of SSVs in Australia has not been available from the Federal Chamber of Automotive Industries (FCAI) or elsewhere.

Of the 141 cases identified and detailed case files obtained, 32 cases were excluded in this analysis as they involved public road crashes and other vehicle types such as sand dune 'buggies'. There were 106 Quad bikes, two SSVs and one six wheel straddle type vehicle in the remaining sample of 109 cases

Key findings from the NCIS data analysis were that rollover (70.6%) and being pinned (50.5%) by the Quad bike were key factors in these 109 fatal cases; Almost half the farm work fatalities (n=26) were caused by asphyxia or a related condition:

- Farms were the location for approximately three quarters (82) of all the 109 incidents. Approximately half (n =54: 53 farm and 1 forestry) of the 109 fatalities were related to farming activity and half (55) to 'recreational' (non-work) activity. 86% of deaths were male.
- In work related fatal cases, a higher percentage of these were older riders, namely: 78% were 50 or older; 50% were 60 years or older; 42% were 65 years or older; and 33% were 70 or older. In comparison, for all fatal cases, 43% were 50 years or older, and only 9% of recreational riders killed were 50 years or older.
- Rollover was the predominant crash type. The vehicle rolled in 77 of the 109 cases (70.6%). Forty six (46) of the 54 (85.2%) work related crashes involved a rollover compared to 31 of the 55 (56.4%) recreational crashes.

- Where the roll direction was noted, there were 11 (10.1%) forward rolls, 32 (29.4%) lateral rolls, 5 (4.6%) rearward rolls (remainder unknown). In 29 (26.6%) cases rollover was noted but the roll direction was unknown.
- Where the initiator of the crash was known, 31 (57.4%) farm vehicles and 18 (32.7%) recreational vehicles lost control on a slope and/or driving over an object.
- It was identified from the 37 pinned fatality cases analysed (out of 54 workplace fatalities - 53 farm place and 1 forestry) that riders were predominantly pinned on the left (13) or right (7) side, i.e. a total of 20 cases or around 37% ($\approx 1/3$). Ten (10) were pinned with the vehicle upside down and 2 with the vehicle upright.
- The main cause of death for farm workers was chest injury (59%) compared to head injury for recreational riders (49%). Only 13% of farm workers died as a result of head injury.
- A helmet was found to be worn in 24 of the 109 cases. Of these, head injury was the cause of death and in nine cases multi-body injury was the cause of death.

Rollover accompanied by crush and asphyxiation was identified by McIntosh and Patton (2014a) as one of the major injury causal mechanisms occurring in farming related crashes. Around 62% of farm workers had crush injuries under the vehicle without extensive impact related injuries, e.g. received a flail chest. Moreover, fifty-five (50.5%) of the 109 deceased riders were pinned by the Quad bike, i.e. the person was restrained under the vehicle until they were found. A higher proportion of farm workers ($n=37$, 69.8%) were pinned under the Quad bike than recreational riders ($n=18$, 32.7%). This was the dominant injury mechanism for farm workers.

From the available information, albeit limited, the Authors estimate that the majority of pinned cases occurred at low speeds, likely approximately 20km/h or less. Almost half the farm work fatalities ($n=26$) were caused by asphyxia or a related condition. In these cases the worker was pinned under the Quad bike and typically suffered no injury to a body region other than the thorax and injuries to the thorax were not otherwise fatal. The data suggest strongly that approximately twenty (20) of the farm workers who died of asphyxia would have survived the crash if the vehicle did not pin them with a force sufficient in terms of magnitude and duration to cause asphyxia. In most cases the vehicles in this situation were on their side and lesser number were upside down (ratio of approximately 2 to 1).

In addition to other approaches described in detail in this report, considering that farmers often work alone in the field, development of a suitable Personal Locator Beacon (PLB), which ideally would activate automatically should a Quad bike roll over and would facilitate assistance as early as possible to a rider in distress.

3.2 Injury Data

In regards to injury data, information on the injury patterns and causal circumstances of fatal and non-fatal Quad bike related injuries was obtained from the following data collections: Safe Work Australia's National Dataset for Compensation-based Statistics (NDS),

WorkCover NSW's workers' compensation scheme claims, WorkCover NSW's incident reports, Transport for NSW's Road Crash Analysis System (RCAS), the NSW Admitted Patient Data Collection (APDC), and the NSW Public Health Real-time Emergency Department Surveillance System (PHREDSS).

The data collections examined (Table 2 below) have different inclusion criteria and were examined across different time periods. The NDS (excluding NSW and Tasmania) contained 208 claims related to Quad bike incidents during 1 July 2006 to 30 June 2011. WorkCover NSW's workers' compensation scheme contained 232 claims during 1 September 2003 to 1 July 2011 and WorkCover NSW's incident reports contained 80 incidents during 1 September 2003 to 3 November 2012 for Quad bike incidents. The RCAS identified 12 Quad-related fatalities during 1 January 2006 to 16 October 2012. There were 1,515 'special all terrain-related vehicles' identified in the NSW APDC during 1 July 2000 to 30 June 2011 and there were 3,300 Quad bikes, 40 electric Quad bikes, and 11 SSVs identified in the PHREDSS during 1 January 2006 to 31 December 2012.

The results from the analysis of the different databases are summarised in Table 2 below. For those databases where the characteristics of the quad-bike incident were known, the table shows that rollover is a major casual factor in incidents and that the thorax is one of the most common body areas injured.

While information was readily available to describe the demographic characteristics of the injured individual, the information contained within the data collections was not ideal to describe the model of Quad bike (or SSV) and any attachments, the purpose for which the Quad/ SSV was being used and the circumstances of the crash, including the geographic typology. Details of the mechanisms of how riders/ drivers/ passengers are injured and vehicle make/ model/ year (MMY) are sketchy at best albeit rollover is the major mechanism. This fundamental deficiency with data collection for Quad bikes (and SSVs) is still an impediment to advancing Quad bike safety and needs to be corrected in terms of hospital admissions and work related investigations.

Finally, it should be noted that the data indicate that over a seven year period there were around 3,307 records of Quad/SSV related Emergency Department Presentations (EDP) for NSW (around 472 per year). NSW has a population of around 7.3 million and is around 32% of Australia's total population. Extrapolating the injury count for Quad bikes/SSVs one could expect a total of around 1400 EDP for Australia each year currently.

Data collection	Timeframe	Number of quad bike incidents	Most common injuries	Most common body location of injury	quad bike incident	Other comments
SafeWork Australia National Dataset for Compensation-based statistics	1 July 2006 - 30 June 2011 (data provided for different timeframes from each jurisdiction)	n=208 claims, including 2 fatalities	<ul style="list-style-type: none"> • Sprains & strains (35.6%) • Fractures (29.8%) 	<ul style="list-style-type: none"> • Trunk (29.3%) • Upper limbs (27.4%) • Lower limbs (25.0%) 	-	<ul style="list-style-type: none"> • Workers' compensation claims only • Excludes NSW and Tasmania • Not all injured workers make claims
WorkCover NSW Workers' Compensation Scheme Claims	1 Sept 2003 - 1 July 2011	n=232 claims, including 3 fatalities	<ul style="list-style-type: none"> • Sprains & strains (41.8%) • Fractures (22.4%) 	<ul style="list-style-type: none"> • Upper limbs (27.2%) • Trunk (24.1%) • Lower limbs (19.4%) 	<ul style="list-style-type: none"> • Fell off quad bike (25.0%) • Quad bike rollover (22.0%) 	<ul style="list-style-type: none"> • Workers' compensation claims only • Not all injured workers make claims • Identification of cases by quad bike classification and text descriptions
WorkCover NSW Incident Data	1 Sept 2003 - 3 Nov 2012	n=80, including 17 fatalities	-	-	<ul style="list-style-type: none"> • Quad bike rollover (40.0%) • Hit object (23.8%) • Fell off quad bike (13.8%) 	<ul style="list-style-type: none"> • Not all quad bike incidents notified • Identification by searching text descriptions
Road Crash Analysis System	1 Jan 2006 - 16 Oct 2012	N=12 fatalities	-	-	<ul style="list-style-type: none"> • Quad bike rollover (58.3%) 	<ul style="list-style-type: none"> • Not all quad bike incidents captured.
NSW Admitted Patient Data Collection	1 July 2000 - 30 June 2011	n=1,515, including 4 fatalities	<ul style="list-style-type: none"> • Fractures (47.6%) • Open wounds (13.3%) • Internal organs (8.7%) 	<ul style="list-style-type: none"> • Head (19.5%) • Knee & lower leg (15.1%) • Thorax (13.2%) 	-	<ul style="list-style-type: none"> • Data quality issues with identification, likely under enumeration
NSW Near Real-time Emergency Department Data Collection	1 Jan 2006 - 31 Dec 2012	n=3,300 quad bikes, n=40 electric quads, and 11 side by side vehicles	<ul style="list-style-type: none"> • Fractures • Lacerations • Open wounds 	-	-	<ul style="list-style-type: none"> • Possible not all quad bike incidents identified • Identification by searching text descriptions

Table 2: Summary of Quad bike/SSV vehicle-related incidents for the six data collections examined.

4. THE TEST QUAD BIKES AND SIDE BY SIDE VEHICLES

4.1 The Test Vehicles

A total of seventeen vehicles were included in the test and rating program. These comprised the 16 production vehicles and a prototype Quad bike set out in Figure 2. Details of the test vehicle specification are provided in 'Part 1: Static Stability Test Results' report and Attachment 2 in that report, i.e. the Crashlab QBPP Quasi-Static Tilt Testing report, Appendix D.

The prototype Quad bike was provided by Dr. David Renfroe¹¹ from EI Consultants, LLC (formerly known as The Engineering Institute, LLC) for testing, late in the program. The prototype was modified in accord with specialist consultancy provided by Dr. David Renfroe to the manufacturer regarding improving Quad bike stability and handling. This vehicle incorporated increased track width (around 150mm either side compared to the Honda TRX700XX, for example), an open and lockable rear differential, and modified suspension design (independent suspension and tuned shock absorber for spring and damping) aimed at significantly improving stability and dynamic handling. Because the vehicle was a prototype the manufacturer's identity is not revealed in this report. However, the intention of testing this vehicle was to demonstrate that the rollover resistance and dynamic handling of Quad bikes can be significantly improved for the work environment. The results for the prototype Quad bike are compared to the other vehicles but were not included into the final Star Rating table presented later in this report. Only production vehicles are listed in the Star Rating table.

Regarding Quad bike and SSV selection, the intent was to obtain examples of new Quad bikes and SSVs typically sold in Australia in late 2012 (i.e. purchased) and in use, subject to the limitations of the project budget. The selection criteria for the Quad bikes included: highest sales by manufacturer and common or popular models for these manufactures; sales data and models as suggested by major Quad bike distributors in NSW and Victoria; representation by imported higher sales of Taiwanese and Chinese models; Australian Quad bike fatality data from the Coronial case files by Quad bike manufacturer examined by the Authors; and Quad bike engine size by fatality (350cc and 500cc identified; although data is very limited).

For the three sports/ recreational models, these were selected by the Australian Consumer and Competition Commission (ACCC) in consultation with Quad bike distributors. One of the models included a youth model.

¹¹ Dr. David Renfore is on the Project Reference Group and is also an advisor to the Project Team and Crashlab on this project particularly in regards to the Dynamic Handling Tests.

No.	Model		No.	Model	
1	Honda TRX250; Quad bike (\$6k)*		9	Can-am DS90X; Sports/ Rec Quad bike (youth) (\$5k)	
2	Honda TRX500FM; Quad bike (\$12k)		10	Yamaha YFM250R Raptor; Sports/ Rec Quad bike (\$8k)	
3	Yamaha YFM450FAP Grizzly Quad bike (\$12k)		11	Honda TRX700XX; Sports Rec Quad bike (\$13k)	
4	Polaris Sportsman 450HO; Quad bike (\$8k)		12	Yamaha YXR Rhino; SSV (\$17k)	
5	Suzuki Kingquad 400ASI; Quad bike (\$9k)		13	Kubota RTV500; SSV (\$14k)	
6	Kawasaki KVF300; Quad bike (\$6k)		14	John Deere XUV825i; SSV (\$18k)	
7	Kymco MXU300; Quad bike (\$6k)		15	Honda MUV700 Big Red; SSV (\$18k)	
8	CF Moto; CF500 Quad bike (\$6.5k)		16	Tomcar TM2; SSV (\$25k)	
			17	Prototype wide track Quad bike	

*Approximate bulk purchase cost for the project in Australian dollars, 1k=\$1,000 (purchased November 2012 including 10% GST). Note: prices will vary depending on where the vehicle is purchased and under what terms

Figure 2: The 17 test vehicles.

In regard to the SSV selection, the criteria were based on obtaining vehicles from a retail price ranging from lower cost to higher cost (e.g. Kubota to Honda MUV700), and different model designs which are in more common use (Yamaha Rhino, John Deere; Honda and Kubota). The fifth SSV selected was the Tomcar made by an Australian manufacturer in that the model was just coming onto the market in Australia for farm use, but had a pedigree of being a high mobility vehicle based on an Israeli army 'all-terrain' model. It was included in the test series as providing a potential benchmark for good stability, handling and crashworthiness. It should be noted that the vehicles tested in the study were purchased in 2012. Clearly later models would require testing to be able to rate them. The 17 vehicles selected and tested represent the beginning of such evaluations, and as with other rating programs, hopefully, more vehicles will be tested in the coming years.

Why Were SSVs Included for Testing and Rating and Not Just Quad bikes?

In the original Project plan, the vehicles to be tested were to be restricted to Quad bikes only (12 vehicles). However it became apparent early in the project that this would have been far too limiting in scope, and that Side by Side vehicles (SSVs) should also be included as they were increasingly being used on farms and as possible alternatives to Quad bikes. This was a fundamental (yet still controversial to some) decision made early in the Project to expand the mix of 'workplace' and 'recreational' Quad bikes and SSVs.

This was also the first time that such a comparison of vehicle stability, handling and crashworthiness has been made across such a diverse range of terrain vehicle types. This decision has proven to be valid and invaluable. It has enabled the focus of the study to broaden from being constrained to consider OPDs as being the 'panacea' or not and what improvements to Quad bikes could be made. The study now includes a much more fundamental approach to risk reduction/management options involving, in principle, appropriate vehicle selection and 'fitness for purpose' criteria, and provision of previously unavailable comparison of Star Rating information for Quad bikes and SSVs for consumers.

4.2 Operator Protection Devices (OPDs)

To measure the effects on Quad bike static stability, handling and crashworthiness when OPDs are attached, three different model OPDs (see Figure 3) were fitted to three workplace Quad bikes chosen as representative of good, average and poor performance, in terms of static stability. The OPDs were not able to be fitted to the Sports/ Rec Quad bikes, as none of these units had any suitable mounting points nor was there any practical location for mounting the OPD units. As an integral part of the vehicle's design the SSVs are already fitted with ROPS and restraints at the point of manufacture.




Quadbar	Lifeguard	Quick-fix OPD
QB Industries	Ag TECH industries	Quick-fix
8.5kg	14.8kg	30.0kg
		

Figure 3: The three OPD units used in the static stability tilt-table tests with the workplace Quad bikes. Only the Quadbar and Lifeguard were included in the dynamic handling and crashworthiness test as the Quick-fix was found to be unsuitable from static stability tests.

5. STATIC STABILITY TESTS AND RESULTS

5.1 Background and Method

The Static Stability test program provides the first arm of the assessment and rating of the Quad bikes and SSVs for rollover propensity. Over 340 tilt table tests were carried out at Crashlab to measure the rollover resistance of the 17 vehicles in lateral roll, forward and rearward pitch, with various combinations of rider, loads and OPD devices fitted (Figure 4).

Tilt Table Ratio (TTR)

The rollover resistance was measured in terms of the fundamental physical stability characteristic for four-wheel vehicles: the point at which “static stability” is lost and at which overturn commences. This can be measured in terms of the parameter *Tilt-Table Ratio* (TTR) on a tilt table from the measured tilt-table angle (α) at which ‘2-wheel lift’ occurs.

$$TTR = \tan \alpha$$

The TTR is the tangent of the angle at tilt, and is very closely related to a vehicle’s Static Stability Factor, which is defined as the ratio of the track width (T) to the centre of gravity height (H):

$$SSF = \frac{T}{2H}$$

and for small suspension movement with stiff tyres $TTR = SSF$:

$$TTR = \tan \alpha = \frac{T}{2H} = SSF$$

While the TTR is a so called ‘static stability’ parameter it is a fundamental determinant of a vehicle’s resistance to rollover whether it is travelling on a slope, or changing direction in a steering manoeuvre, traveling around a curve, braking or accelerating or travelling over rough uneven terrain. The lower the TTR number the lower the vehicle’s resistance to rollover in the test direction (lateral roll, rear or forward pitch).

Although other variables such as Active Riding for Quad bikes, suspension design, and handling¹² can affect a vehicle’s rollover resistance (i.e. increase or decrease the lateral acceleration at 2-wheel lift), the principal stability characteristics for a vehicle are limited¹³ by the vehicle’s fundamental geometric properties of Centre of Gravity (CoG) height (and how this varies with any load), wheel base and track width. Note that the testing was conducted with a 95th percentile adult male¹⁴. The larger mass ATD was thus used as a

¹² The Dynamic Handling tests for this Project are analysed in Part 2.

¹³ It is noted that with modern vehicles electronic Stability Control Systems (ESC) have been installed to prevent loss of control leading to rollover crashes. Such ESC systems may possibly become relevant for Quad bikes and SSVs to help reduce the incidence of rollover.

¹⁴ Workplace risk assessments for plant safety typically require catering for not just a 50th % adult male person but also for the majority of the working population which includes the higher mass 95th % adult male.

surrogate rider for the Quad bikes, and driver for SSVs. The suspension was ‘unlocked’ in the TTR tests, with suspension and tyre movement allowed.

Active Riding – not included in these tests

‘Active Riding’ is promoted as a key part of Quad bike dynamics, training and risk mitigation for rollover and handling by the Quad bike Industry. It involves the rider actively moving and shifting his body position on the Quad bike to increase stability and rollover resistance as well as mobility visibility and other performance attributes. While Active Riding is promoted as playing a part in all Quad bike riding, the limited and significant variability of its effectiveness depending on rider age, weight, physical capabilities, training, experience, and work tasks while riding, means that it is not a reliable risk mitigation strategy in the workplace, and therefore has not been included in the Static Stability test program per se, but is examined in part in the Dynamic Handling tests.¹⁵



Figure 4: Photographs from the tilt table tests, showing Quad bike with ATD and OPD for a lateral roll tests, and the John Deere SSV for lateral roll, rear and forward pitch tests.

¹⁵ Active riding may increase the performance envelope of a vehicle in many circumstances. The proposed rating system is a relative rating system between vehicles and not a measure of ultimate performance. Each vehicle has been advantaged / disadvantaged equally and hence the comparative rankings would be the same even if active riding were applied.

5.2 TTR Results for the Static Stability Tests

Table 3 summarises the TTR results for lateral roll and rearward and forward pitch, including maximum load combinations and OPDs. Figure 5 shows in bar chart form the TTR results.

The SSVs generally have a notably higher TTR in all directions than the workplace Quad bikes. For lateral roll the TTR is up to 50% higher with an operator (e.g. TTR = 0.96 vs 0.60).

For all of the vehicles forward pitch stability (TTR) is significantly higher than lateral TTR, particularly for the SSVs. This is largely a function of vehicle wheel base and CoG position. The SSVs' wheelbase range from 1.8m to 2.05m, compared with the much shorter wheelbase for the workplace Quad bikes of 1.13m to 1.28m (see Part 1: Static Stability Test Results). For forward pitch (with an operator) the TTR for SSVs is up to 75% higher than for Quad bikes (e.g. 1.08 vs 1.88).

Similarly, for all of the vehicles, rear pitch static stability is higher than lateral static stability when unloaded, particularly for the SSVs. Furthermore, rear pitch static stability is lower than forward pitch static stability, particularly when fully loaded. This is largely a function of the rear loading. With full rear load, as would be expected, rear stability reduces significantly by up to 40%.

For the SSVs the rear pitch TTR values compared to forward pitch stability, vary significantly between various SSV models, and are much lower, by almost half from 1.81-1.95 down to 0.77-1.01, when fully loaded. As the SSVs only carry rear load, and have a relatively high rated loaded capacity (181kg to 454kg; see Part 1: Static Stability Test Results, Attachment 2 Crashlab Report, Appendix D), rear pitch static stability is significantly reduced by up to 39% from baseline, down to the range 0.77 to 1.01.

Vehicle type	Test	TTR and Load Condition					TTR Max. Reduction from base line %
		Baseline	Operator only	Operator plus rear load	Operator plus front load	Operator & front & rear load	
Work Quad	Lateral roll	0.72 to 0.82	0.46 to 0.60	0.44 to 0.56	0.43 to 0.57	0.41 to 0.55	43%
	Rear Pitch	1.13 to 1.31	0.78 to 0.95	0.62 to 0.79	0.81 to 1.01	0.68 to 0.82	40%
	F'ward Pitch	1.12 to 1.34	0.94 to 1.08	0.97 to 1.10	0.82 to 0.94	0.89 to 1.02	30%
SSV	Lateral roll	0.85 to 1.01	0.65 to 0.96	0.64 to 0.83	na	na	25%
	Rear Pitch	1.08 to 1.66	1.04 to 1.49	0.77 to 1.01	na	na	39%
	F'ward Pitch	1.89 to 2.18	1.70 to 1.88	1.81 to 1.95	na	na	14%
Prototype Quad bike	Lateral roll	0.99	0.81	0.76	0.79	0.75	24%
	Rear Pitch	1.19	0.94	0.85	0.97	0.85	28%
	F'ward Pitch	1.18	1.01	1.06	0.94	0.96	11%
Sports/ Rec Quad bike	Lateral roll	0.93 to 1.10	0.56 to 0.78	na	na	na	40%
	Rear Pitch	1.17 to 1.32	0.73 to 0.90	na	na	na	37%
	F'ward Pitch	1.31 to 1.39	0.97 to 1.10	na	na	na	26%

Table 3: Tilt Table TTR Summary of Results. Comparison by vehicle type category and change in TTR with maximum loading. 95th % adult male ATD used except for Can-am DS90X youth model where 5th % adult female ATD used.

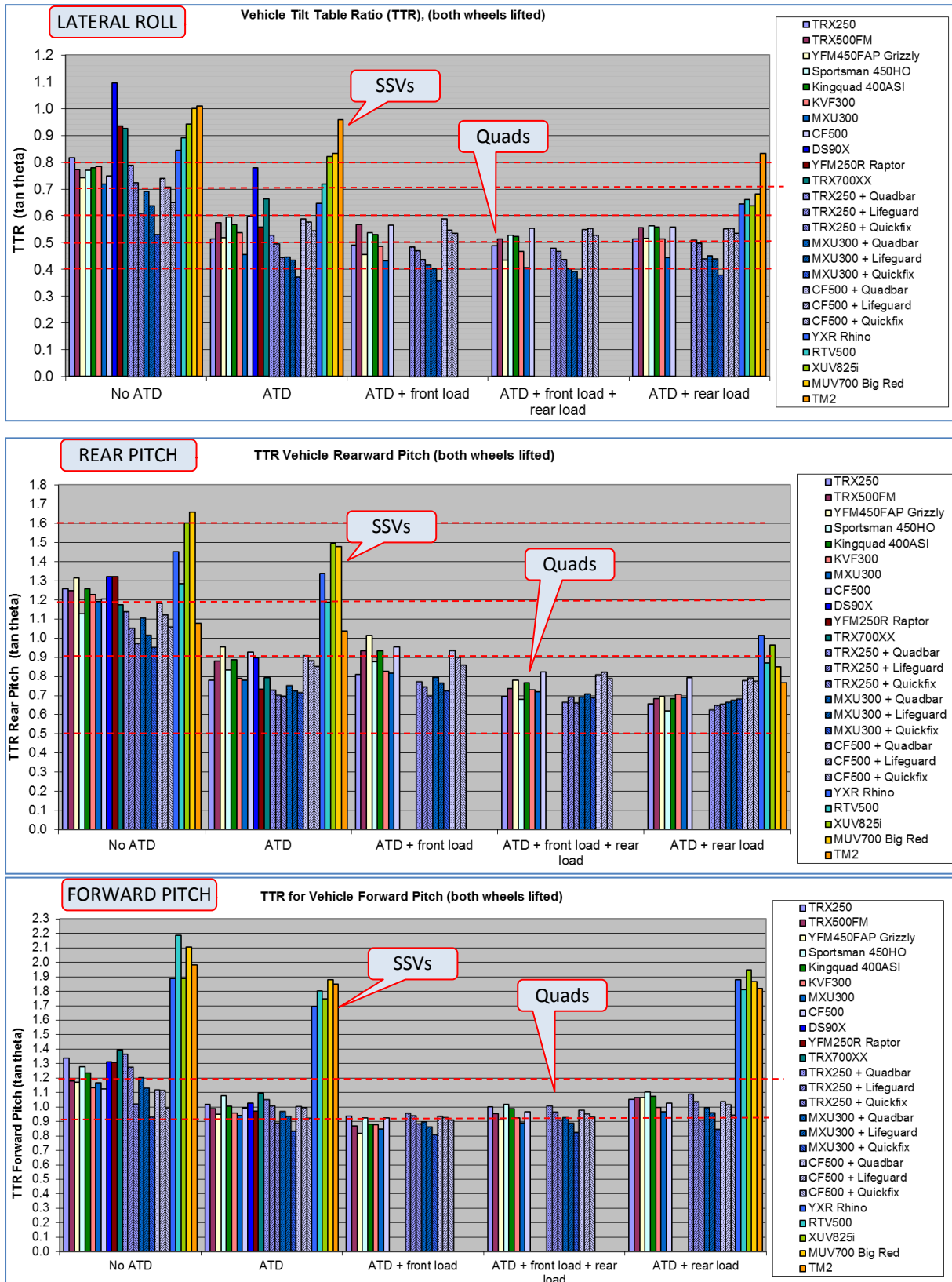


Figure 5: TTR results for Lateral Roll, Rearward Pitch and Forward Pitch. All 16 vehicles, all tests including OPDs. 95th % adult male ATD used except for Can-am DS90X youth model where 5th % adult female ATD used. Prototype Quad bike not shown.

The relatively low TTRs for Quad bikes highlight the effect of the weight of the rider and full load on reducing Quad bike rollover resistance, and highlight the low stability margins these vehicles may have on steeper slopes and hilly or uneven terrain, which leads to an increased risk of rollover.

In regard to discrimination in TTR values between Quad bikes, this is much less marked than the difference between the Quad bikes and SSVs, with SSVs being substantially higher. For the production vehicles, the Quad bike with the highest TTR was less than the SSV with the lowest TTR in almost all situations. It should also be recognised that the rear load capacities (as tested), are much higher for the SSVs than the Quad bikes.

The effect of OPDs was varied. Both the lightweight Quadbar (about 8.5kg) and heavier Lifeguard (about 14.8kg) have a small and not significant effect on the stability of the Quad bikes, of less than 4%. However the Quickfix (full 4 post canopy, 30kg) reduced the SSF by about 13% with a rider, and about 8% fully loaded together with a large rider. All of this mass is applied well above the CoG of the Quad bike, and is considered by the Authors as too top heavy. Moreover, the Quickfix canopy restricts riders from correctly riding actively on the machines. For these reasons the Quickfix OPD was not used in any further testing (Dynamic Handling and Rollover Crashworthiness) and is not recommended for use with Quad bikes.

In general, the sports/ recreational Quad bikes have higher TTRs than the workplace Quad bikes with a large rider, as a result of a combination of their having a lower CoG height and/or wider track width.

5.3 Performance of the prototype Quad bike

The wider track prototype Quad bike has much higher lateral TTR (on average 50% higher) than all the Quad bikes and comparable with some of the SSVs, as shown in Table 4 compared with extracted values from Table 3. For example with an operator, the prototype Quad bike's TTR was 0.81, compared with a TTR of 0.46 to 0.6 for the other Quad bikes, and 0.65 to 0.96 for the SSVs. As mentioned earlier, the prototype has a widened track width to make the vehicle considerably more stable, an open (lockable) rear differential to allow more responsive and simpler steering on firm terrain, and an understeer characteristic to allow a more intuitive rider response to steering demand in most circumstances.

Vehicle type	Test	TTR and Load Condition					TTR Max Reduction from base line %
		Baseline	Operator only	Operator plus rear load	Operator plus front load	Operator plus front and rear load	
Work Quad bike	Lateral roll	0.72 to 0.82	0.46 to 0.60	0.44 to 0.56	0.43 to 0.57	0.41 to 0.55	43%
SSV	Lateral roll	0.85 to 1.01	0.65 to 0.96	0.64 to 0.83	na	na	25%
Prototype Quad bike	Lateral roll	0.99	0.81	0.76	0.79	0.75	24%

Table 4: Comparison of the Tilt Table TTR results for the prototype Quad bike and the other Quad bikes for Lateral Roll. 95th % adult male ATD used.

6. DYNAMIC HANDLING TESTS AND RESULTS

6.1 Background and Method

The Dynamic Handling test program provides the second arm of the assessment and rating of the Quad bikes and SSVs for rollover propensity (Figure 7, Figure 8 and Figure 9).

Improvements in Quad bike and SSV handling has been highlighted by authors such as Roberts (2009) and others as being a practical means to reduce crash and rollover risk. However, the Industry (through FCAI) claim that there is currently no incident statistical data available or collected to enable determining the correlation (if any) between a vehicle's handling characteristics and collision and injury risk. The Authors strongly disagree with this proposition. For example, the United States of America (USA) Consumer Product Safety Commission (CPSC) most recent September 2014 report (CPSC, 2014) proposing a Safety Standard for Recreational Off-Highway Vehicles (ROVs), Notice of Proposed Rulemaking, 16 CFR Part 1422 states that: *"the Commission believes that improving lateral stability (by increasing rollover resistance) and improving vehicle handling (by correcting oversteer to understeer) are the most effective approaches to reducing the occurrence of ROV rollover incidents"*. The CPSC also highlighted in that report the Yamaha Rhino repair program as evidence that improvements to lateral stability and dynamic handling will reduce incidents.

Moreover, correlations have been established for Static Stability Factor and risk of a rollover for a diverse range of other vehicle types such as passenger cars, SUVs, pickups, four wheel drives and heavy trucks, e.g. Mengert (1989) and New Zealand government (DIER, 2006). This is discussed in more detail in Section 3.3.2 in the Part 1: Static Stability Test Results report. It is obvious from the graphs presented in the Part 1: Static Stability Test Results report (Figures 2 and 3) that the higher the vehicle's lateral stability is, the less likely the vehicle will roll over because more lateral force is necessary to cause rollover than a vehicle with lower lateral stability, i.e. it has a higher resistance to rollover.

In order to show a perspective regarding the stability of Quad bikes and SSVs, Figure 6 provides a comparison of the Author's postulated crash rate versus Static Stability Factor (SSF) for Quad Bikes and SSVs compared to NHTSA's Mengert (1989) crash rates for cars and SUVs, and New Zealand's (DIER, 2006) crash rates for trucks. Figure 6 is essentially a composite (see Figures 2 and 3 in Part 1 report) with the addition of the Author's postulated curve¹⁶, showing the relationship between the TTRs measured for Quad bikes and SSVs versus relative rollover crash rate. Furthermore, Figure 6 shows that the stability of Quad bike's TTR (SSF) is in the lower range and not dissimilar to trucks; whereas the TTR (SSF) for higher stability SSVs overlaps with a four wheel drive/ Sports Utility Vehicles (SUVs). The Authors postulate that the likely rollover risk for lower stability Quad bikes could be as much as four times (or higher) as the highest stability SSVs.

¹⁶ This curve is postulated as the actual real world rollover crash rate versus static stability factor data required has not been collected to date. The data required is the make, model and year (MMY) of the Quad bike or SSV and the actual incidence of rollover (and not just rollover injury events) and exposure data.

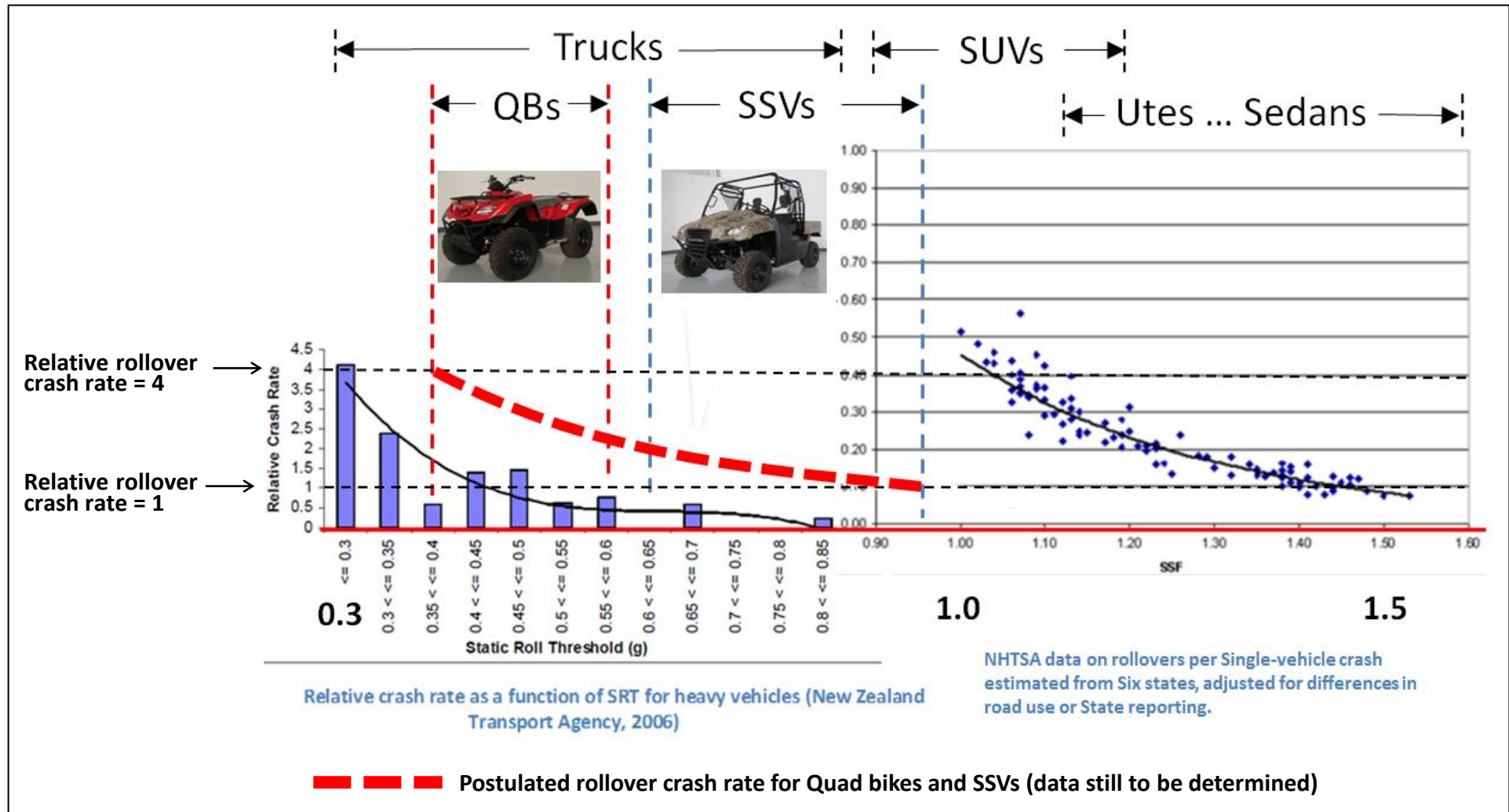


Figure 6: Postulated crash rate versus Static Stability Factor for Quad Bikes/SSVs with rider/driver (with 95th % ATD) compared to NHTSA's Mengert for cars, SUVs & trucks.

Hence, we the Authors are strongly of the opinion that history has clearly demonstrated that advances in safety for all types of land mobile vehicles are correlated with improvements in stability, handling and crashworthiness. There is no reason why Quad bikes and SSVs should be any different and not obey the same laws of physics and vehicle dynamics.¹⁷

The dynamic test program consisted of 546 tests, in three different dynamic tests series all relating to vehicle control and handling characteristics which improve a driver/ rider's vehicle path control and resistance to rollover.

These dynamic tests were also innovative in that they showed that Quad bikes could be subject to scientifically reliable, reproducible, and meaningful Dynamic Handling testing. The tests were also innovative in terms of introducing a bump test to ascertain possible loss of control mechanism leading to rollover. This finding was contrary to claims by some in Industry that such testing was not feasible or meaningful.

The overall conclusion from these dynamic tests, was that in contrast to the Quad bikes, SSVs had more forgiving handling and higher stability characteristics (i.e. higher resistance to rollover), and are less reliant on operator vehicle handling skills. The following tests were carried out:

- 1. Steady-state circular driving behaviour dynamic tests** to determine each vehicle's limit of lateral acceleration and the understeer/ oversteer characteristics. The steady-state circular driving behaviour test consisted of slowly accelerating each vehicle from rest whilst tracking around a circle of 7.6m radius. The vehicle was accelerated until it either lifted (Figure 7) the two inside tyres off the ground and tipped up, drove out of the circle, spun into the circle, or could not travel any faster.
- 2. Lateral transient response dynamic tests** to determine each vehicle's time taken to respond to steering manoeuvres. The test consisted of driving the vehicle in a straight line at a velocity of 20km/h and then rapidly inputting a steering response to generate a lateral acceleration of 0.4g. The steering response time was recorded.
- 3. Bump obstacle perturbation tests** to determine each vehicle's ability to ride over bumps with minimal change in steering direction or displacement of the rider/ driver. The test consisted of towing the vehicle in a straight line towards a 150mm high semi-circular 'bump' object lined up with either the right or left vehicle track. Each vehicle 'free-wheeled' over the obstacle without being under the effect of the tow system. A 95th % adult male ATD was positioned on the vehicle with the resultant lateral and vertical pelvis acceleration recorded. The steady-state circular driving behaviour and lateral transient response tests were conducted at Sydney Dragway, Eastern Creek, NSW, Australia. The bump obstacle perturbation tests were conducted at Crashlab, Huntingwood, NSW, Australia.

¹⁷ This has been discussed in more detail in the Part 1 and Part2 reports and the US CPSC (2014) report.



Figure 7: Typical quad circular driving behaviour test (G130449) – both wheels lifted.



Figure 8: Typical Side by Side Vehicle setup – no load case.



Figure 9: Quad bike vehicle setup – with OPDs (Quadbar and Lifeguard).

- 4. Asphalt surface.** While most testing was conducted on an asphalt surface (for reproducibility of test results), to identify the effects of different surfaces on handling, some testing was conducted on dry grass as well.
- 5. Repeatability.** Each test configuration was tested three times to establish result repeatability. Full results tables are contained in 'Part 2: Dynamic Handling Test Results' Attachment 1, Crashlab Report (Section 3 and Appendix C). These results show good repeatability and confirm that Quad bikes can be reliably tested and rated for dynamic handling characteristics, and thus also improvements in dynamic handling can be demonstrated.

6.2 Test Results - Steady-State Circular Driving Behaviour: Limit of Lateral Acceleration:

The dynamic test results are summarised in Figure 10. They show for each vehicle the limit of lateral acceleration (in 'g') for when two wheel lift occurs (i.e. tip up) or when the vehicle slides out or broke traction (no tip up). Also shown as a comparison is the measured 'static' lateral stability in terms of the Tilt Table Ratio (TTR), from the Static Stability Test Results Report. The observations from these test results are:

1. For the production Quad bikes the measured minimum limit of lateral acceleration at tip up was in the range of 0.55g to 0.36g, and for each Quad bike was less than the TTR. The circle tests validated that the tilt-table static stability TTR value provide valid measures of the lateral stability (i.e. level of rollover resistance) of Quad bikes.
2. For the production Quad bikes the limit of lateral acceleration occurs by tipping up onto two wheels, which unless able to be counteracted by the rider, is a precursor to rollover or loss of control – that is, a loss of stability.
3. For the SSVs, those that had an open differential did not tip but either simply broke traction on the rear inside wheel and reduced speed or slid out. The Yamaha Rhino had a locked differential and reached its limit of lateral acceleration by tipping up. These results are consistent with the static stability tilt-table tests, which showed higher stability metrics for the SSVs.

Effect of Different surfaces

4. The three Quad bikes that were tested on asphalt and grass displayed very similar handling characteristics and tipped up at similar lateral acceleration values on both surfaces. Testing of Quad bikes on an asphalt surface did provide relevant, performance characteristics.
5. The Honda TRX250 Quad bike¹⁸ was used as a representative Quad bike for comparing the effects of surface type, load combinations and Active Riding on lateral stability. With Active Riding (asphalt), the dynamic stability values increased by approximately 13%, from 0.46g up to 0.52g. These values were very similar to the tilt table TTRs (without Active Riding) of 0.51.

Effect of the Quadbar and Lifeguard

6. The example Quad bike (Honda TRX250) when tested with the Quadbar and Lifeguard OPDs, showed only a minor change in limit of lateral acceleration (0.46g down to 0.45g).

¹⁸ A 'representative' Quad bike was selected for these comparison tests. It was beyond the scope and budget of this dynamic test program to be able to test all of the 16 vehicles in all load and surface combinations. As noted well in excess of 546 tests were conducted in this dynamic test program alone.

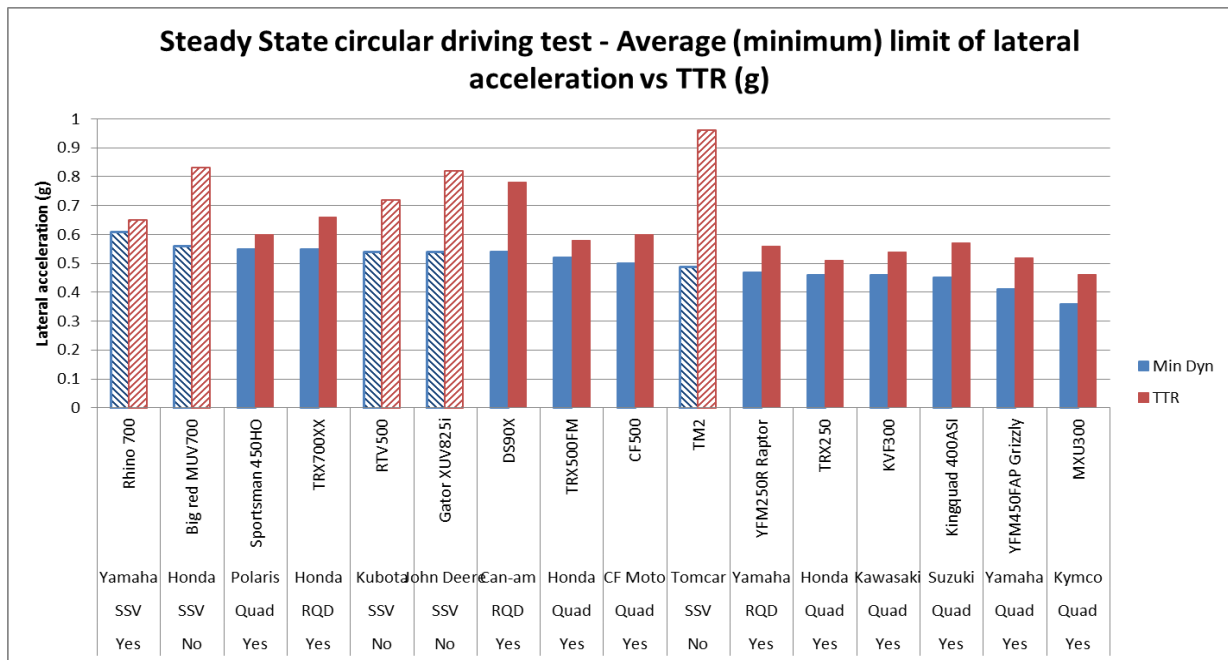


Figure 10: Steady State circular driving test - Average (minimum) limit of lateral acceleration vs TTR (g). The category ‘Yes’ is for two wheel lift occurring (i.e. tip up), and ‘No’ is for no tip up. Asphalt surface, rider/driver only. Hashed columns are for SSVs.

6.3 Test Results - Steady-State Circular Driving Behaviour: Understeer/Oversteer Characteristics

In order to handle well (consistently and safely) and reduce the risk of a loss of control crash occurring, a Quad bike or Side by Side, like any other self-propelled vehicle, should have a slight understeer characteristic when excited between 0.1 and 0.5 g lateral acceleration.

1. The results overall obtained show that most Quad bikes tested had an oversteer characteristic, which is not a favourable characteristics for most workplace riding situations.¹⁹ Notably, the Honda TRX700 recreational Quad bike, showed a light understeer characteristic of around 2 degrees per g through to above 0.5 g. This is considered by the Authors to be a very good steering characteristic and demonstrates that it is quite possible to design the steering system of a Quad bike to produce the recommended handling results for a work place environment.
2. Most Quad bikes had a fixed rear differential, which meant that the rear wheels rotated in unison, even when on a curve. Most SSVs that had an open differential (or the option to switch from an open to fixed differential and vice versa), all exhibited light understeer handling characteristics. When the rear differential was locked, the vehicle demonstrated oversteer characteristics.

¹⁹ As set out in Part 2: Dynamic Handling Test Results

6.4 Test Results - Lateral Transient Response Time

All vehicles tested unloaded on asphalt had steering response times of less than 0.3 seconds, with a significant number of the vehicles displaying steering response times of less than 0.2 seconds (see Figure 11), which is generally considered to be satisfactory.

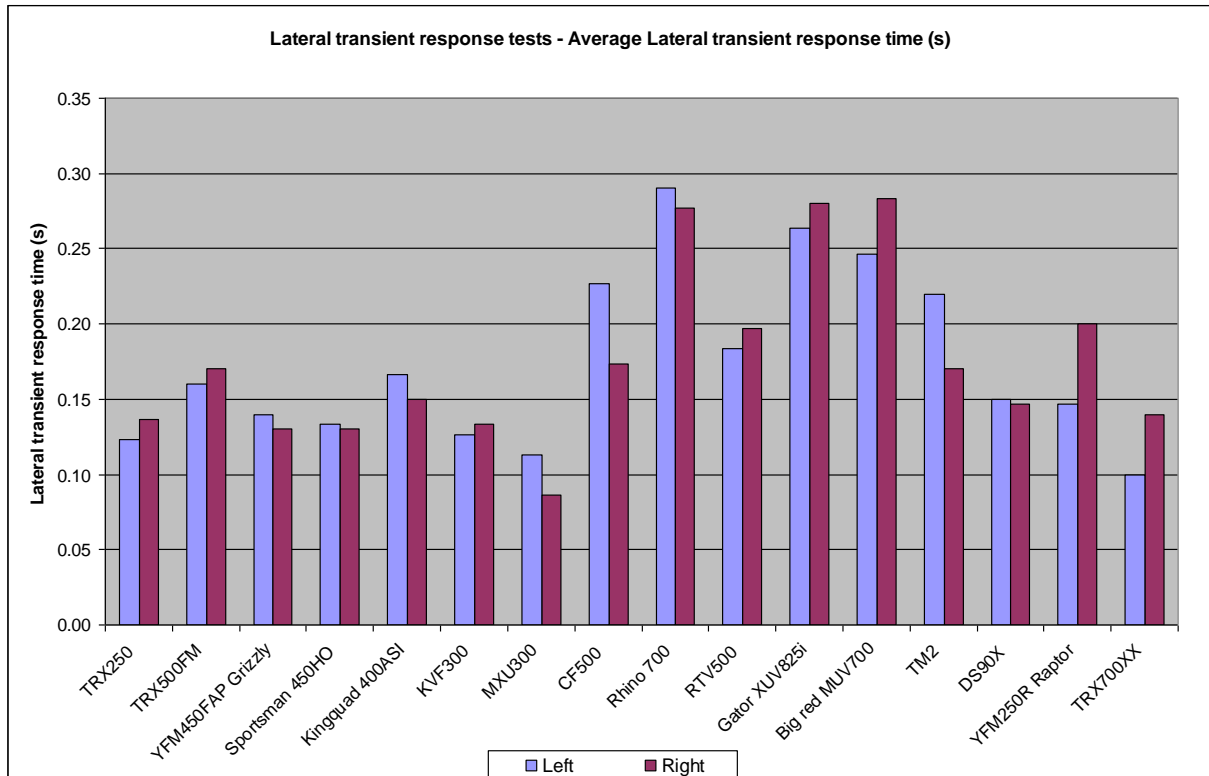


Figure 11: Average steering response time - unladen vehicles on asphalt.

6.5 Test Results - Bump Obstacle Test

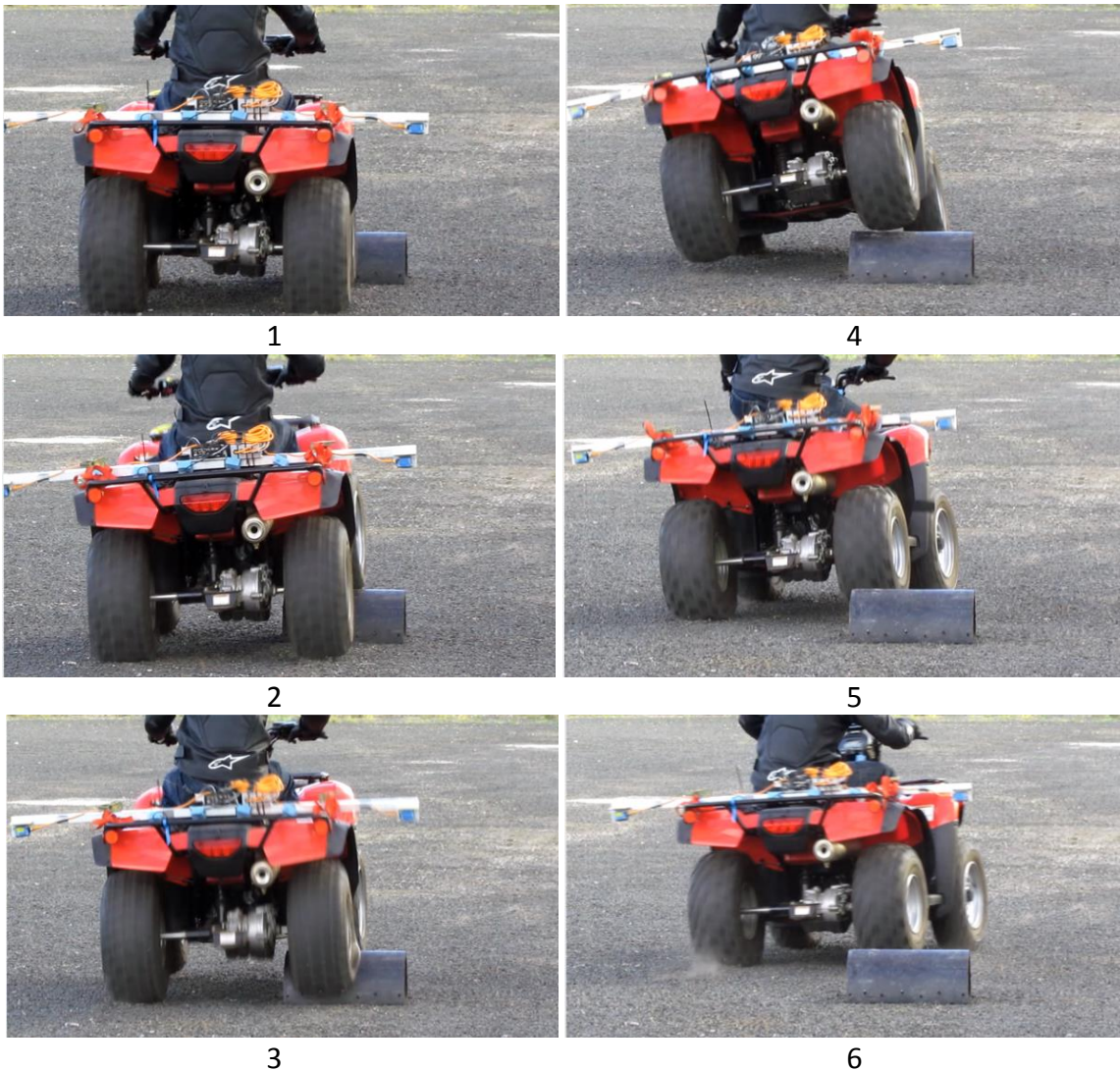
Twelve Quad bikes were subjected to the bump obstacle test (Figure 12) using the 95th % adult male Hybrid III ATD as well as subjective comparison tests with riders.

The vehicles exhibited ATD pelvis lateral/vertical resultant acceleration values of between 1.47g and 3.66g. Quad bikes that exhibited lower resultant ATD pelvis acceleration typically showed little ATD movement relative to the seat of the Quad bike. Quad bikes that exhibited higher resultant ATD pelvis acceleration typically showed significant ATD movement relative to the seat of the Quad bike.

The 'bump tests' identified, possibly for the first time, a significant mechanism in which Quad bike riders could potentially lose control in what appear to be low risk scenarios, going over moderate bumps (such as logs, small mounds, ruts, etc.) at the relatively low speed of 25 km/h. Where the rider who is not Actively Riding and remains sitting on the seat, and the Quad bike is displaced excessively laterally whilst traversing a 'bump', the rider could pull on the handle bar (to keep themselves on the quad bike) further exacerbating the turn of the Quad bike leading to rollover. All of the SSVs traversed the bump satisfactorily, with a low level of rider or vehicle perturbation.



Left side perturbation



Right side perturbation

Figure 12: Bump obstacle test, showing the lateral displacement of the Quad bike and rider/ ATD. Note in top frame rear left wheel is airborne as the Quad bike is turning left and if not arrested by the bungee cord, the Quad bike would have rolled over in the test.

7. CRASHWORTHINESS TESTS AND RESULTS

7.1 Background and Method

The Part 3 Rollover Crashworthiness test program provides the third arm of the assessment and rating of these Quad bikes and SSVs for rollover stability, handling and crashworthiness. It complements the Static Stability tests and the Dynamic Handling tests for the 17 vehicles.

The findings from Section 3 is that rollover, and subsequently being pinned and asphyxiated, often without injury, are the predominant injury mechanisms for Quad bike related fatalities on farms. These findings determined that the crashworthiness test program needed to be focussed on rollover of the Quad bikes and SSVs, with testing and ratings developed as presented below.

The Rollover Crashworthiness test program consisted of 65 tests and SSV inspections focussing in three different areas, all relating to vehicle crashworthiness characteristics. A selection of the different tests carried out is shown in Figure 13. Crashworthiness is the ability of a vehicle to provide injury protection to its occupant(s) in a collision or rollover event. Details of the tests are provided in Part 3: Rollover Crashworthiness Test Results. Four different test series were carried out, namely:

1. Measurements of ground contact force for the Honda TRX500 with and without an OPD on its left and right side and when inverted The mass difference between different Quad bike models tested was considered by the Authors to be not sufficient to provide significant discrimination in terms of asphyxia potential;
2. Inspection and measurements of SSV occupant retention in accordance with the US National Standard for Recreational Off-Highway Vehicles ANSI/ROHVA 1-2011 with additional requirements applied;
3. Vehicle and rider/driver rollover tests consisting of positioning a Motorcycle Anthropomorphic Test Device (MATD) crash test dummy in the operator's position of a Quad bike (Honda TRX500) or SSV (Tomcar and Yamaha Rhino), tilting the vehicle to an angle at which rollover would occur and releasing the vehicle to rollover to observe survival space and functionality of the OPD and in the case of the two SSVs the ROPS and restraints.
4. Side by Side Vehicle ROPS structure load tests consisting of applying a lateral load followed by a vertical load then a longitudinal load to the vehicle ROPS whilst recording the deflection and noting the structural integrity, in accordance with the United States (US) National Standard for Recreational Off-Highway Vehicles ANSI/ROHVA 1-2011 requirements for the ISO option.

The characteristics determined from these tests, namely occupant survival space, contact loads, occupant containment, ROPS and seatbelts, can potentially reduce a driver's/ rider's

risk of harm in a rollover crash within the workplace environment for the higher rated vehicles.

The crashworthiness ratings were then used together with the ratings detailed in reports 'Part 1: Static Stability Test Results' and 'Part 2: Dynamic Handling Test Results' to provide an overall Star Rating of the 16 production vehicles.

7.2 Rollover Crashworthiness of Quad Bikes

1. At the start of this project, the project team considered that it would be possible - though challenging - to conduct testing which would distinguish between the rollover crashworthiness of different Quad bike models and SSVs. Through the exploratory rollover crashworthiness tests using the MATD as a surrogate vehicle operator, it became apparent (based on assumed test variability and the similarity of most Quad bikes) that it was currently unrealistic to discriminate the rollover crashworthiness between different Quad bike models, based on such rollover testing – however discrimination between these vehicle types (Quad bikes and SSVs) was realistic. In considering this, it was also recognised that there was little that differentiated the Quad bike models in terms of ground plane clearance in a rollover, and vehicle mass might be the only substantial difference among Quad bikes. The exploratory tests did highlight the potential hazards that an operator would be exposed to when a Quad bike rolled, which were consistent with the review of fatal cases.
2. Further, it was also evident from such rollover testing that for a rider of Quad bikes, due to the stochastic ('hit and miss') nature of severe injury risk and the large range of possible rollover permutations, it was unrealistic to continue with such tests for each Quad bike model for rating purposes.
3. Indeed, it was concluded by the Authors that the term "Crashworthy Quad bike" was essentially a contradiction in terms. For this reason the Quad bike types were all rated equally for rollover crashworthiness, and all were assigned the 5 point baseline rating when assessing Rollover Crashworthiness protection. There are numerous instances where a rider has survived a rollover crash without any serious injury as illustrated by Van Ee et al. (2012). Fundamentally, Quad bikes where the rider straddles the vehicle and steers in the same way as a motorcycle via handle bars, do not and cannot satisfy the well-known principles of occupant protection in rollover - good containment, restraint of the occupant, impact management and crush prevention.

The manufacturers' and industries' safety paradigm for Quad bikes is 'separation' and Personal Protection Equipment (PPE), as with motorcycles. This strategy appears to work in a large number of instances albeit not in all the circumstances as evidence from the Coronial fatalities and hospitalisations data clearly demonstrate.⁸ Industries' 'separation' safety paradigm for Quad bikes is not capable of meeting the 'Vision Zero' criteria required/ legislated in the workplace, i.e. death or serious injury that results in a permanent disability in the workplace are not acceptable. Note however that death or

serious injury that results in a permanent disability currently continues to occur with virtually all vehicles used in the workplace (i.e., trucks, tractors, machinery, passenger cars, motorcycles, etc.). However, as has been well established that the rate of fatalities for these other vehicle types (including tractors) has decreased greatly due to advances in vehicle design, crash avoidance technology and crashworthiness amongst other factors.

4. Nor was it possible to discriminate Quad bike crashworthiness performance based on current real world crash information (in contrast to passenger vehicles, for example). This is due to the absence of make/model/year (MMY) crash involvement injury data and exposure data for Quad bikes and SSVs. This fundamental deficiency with data collection for Quad bikes (and SSVs) is still an impediment to advancing Quad bike safety. For Quad bikes, this leaves rollover crash prevention as the primary control mechanism to prevent injury in rollover, with the fitment of OPDs seen by safety stakeholders as a secondary measure that could reduce injury risk in the workplace.

As with motorcycles, the safety crashworthiness basis for Quad bikes promoted by Industry is separation. It needs to be recognised that Quad bike riders are in this same category of 'unprotected vulnerable road users' where the risk of injury is substantially higher than when contained in a vehicle with appropriate rollover and restraint protection. Similarly if increased crash protection is a key performance requirement then, as with motorcycles, different vehicle types which offer such protection as part of their design need to be considered and substituted instead (e.g. SSVs).

7.3 Rollover Crashworthiness of SSVs

1. In contrast to Quad bikes, the SSVs do adhere in general to rollover crashworthiness principles, in that they are fitted with ROPS, seatbelts and various degrees of containment measures. As the effectiveness of such designs in terms of severe injury prevention can vary widely, it is possible to discriminate and rate SSVs, as a first step.
2. The SSVs were rated for rollover crashworthiness against the containment, occupant retention and ROPS requirements of the ANSI/ROHVA 1-2011 Industry voluntary standard for SSVs (which becomes relevant in the USA for 2014 models).
3. SSVs with a well-designed rollover protection system provide greater potential rollover crashworthiness in comparison to Quad bikes even when the Quad bikes are fitted with an OPD. This is on the condition that SSV drivers and passengers are restrained with an appropriate seat belt, namely a 3 point lap sash belt or a 4 or 5 point harness, and wear an approved helmet.
4. The SSV ROPS for three vehicles met the US ANSI/ROHVA 1-2011 Industry voluntary standard. The Honda Big Red, while not meeting all the ROPS load requirements of the standard, did meet the lateral load requirement and 88% of the vertical load before the ROPS could no longer sustain any increase in load. It was subsequently discovered that

the Honda Big Red met the US OSHA standard (Code of Federal Regulations) which requires a ROPS Strength to Weight Ratio (SWR) of only 1.5, which has been found by the Authors and others to be totally inadequate for occupant protection in rollover in regards to passenger vehicles (Young and Grzebieta, 2010; Brumbelow et al, 2009; Brumbelow and Teoh, 2009).

5. All five SSVs had seat belts fitted. The Tomcar offered 4 point harness seat belts whereas the Kubota only offered 2 point seat belts. The John Deere offered a seat belt warning light which extinguished when the seat belt was engaged, but only on the driver side. The Yamaha Rhino also offered a seat belt warning light but did not switch off when the seat belt was engaged. None of the SSVs offered an audible seat belt warning system or a seat belt interlock system.

7.4 Effectiveness of Operator Protective Devices (OPDs)

1. Retrofitting an OPD has been encouraged by a number of Quad bike safety stakeholders and is currently being considered by regulators. The rollover crash tests with the Honda TRX500 indicate that such devices do increase survivability and 'crawl out' space (clearance) and change crush loads applied to the operator under certain rollover circumstances. The baseline rollover crash tests demonstrated how the full weight of the Quad bike without an OPD could rest on top of the rider in lateral, rearward and forward pitch rolls, whereas when the vehicle was fitted with an OPD the vehicle's full weight did not load or rest on the rider. The OPD may offer the conscious operator or rescuer an opportunity to self-extract (crawl out) or extract the pinned operator by increasing survival space when the vehicle is in an inverted position.
2. The performance of the Quadbar in terms of rollover crash harm minimisation appeared better in some aspects to the Lifeguard in a low velocity, low height, rearward pitch roll. When the Quad bike was pitched rearward from a higher height of 1,500 mm (measured from the lower edge of the tilt table) the Quadbar deformed such that it reduced the CoG rising and thus to some extent alleviated the situation presented by Van Ee et al. (2012) (see *Figure 6* in 'Part 3: Rollover Crashworthiness Test Results'), while at the same time providing survival/ crawl out space and maintaining the rear of the vehicle above the rider.
3. In the Quad bike tests, the rider was at risk of neck and head injuries in the lateral and forward pitch direction rollover tests. The Coronial data has revealed that seven farm workers received cervical spine fractures or dislocations and three farmers had cervical spinal cord injury. There were two thoraco-lumbar vertebral fractures. There were no lumbar or thoracic spinal cord injuries.
4. There is a concern that the Quadbar may impart a load to the head, neck, or back similar to the scenario hypothesised by Van Ee et al. (2012) and depicted in *Figure 4* 'Part 3: Rollover Crashworthiness Test Results'. *Figure 14* top right frame shows the Quad bar was close to the ATD's head and neck in its final rest position. There was also

a concern with the Lifeguard OPD in a rearward pitch roll, where it was identified that the rider's posterior could move backwards into the hollow part of the OPD entrapping them during the pitch over. This is demonstrated in *Figure 11 a)* in the 'Part 3: Rollover Crashworthiness Test Results' report.

5. For the Quad bikes, the contact ground load tests for the Quad bike on its side or up-side-down, showed that point loads on a person under the Quad bike, would exceed the mechanical asphyxia load criterion of 50kg (McIntosh and Patton, 2014c), with and without OPDs. However, OPDs would likely reduce the risk due to increasing survival space underneath the Quad bike for the inverted position, but not for a Quad bike on its side.
6. Overall, the Authors consider that the addition of an OPD will likely result in a net benefit in terms of reducing harm to workplace Quad bike riders involved in a rollover crash. This is based on the assumptions that (i) Quad bike overturns in the workplace environment typically occur at low speeds; (ii) based on the limited testing presented in the Part 3 report, and (iii) the Authors are currently unaware of any injuries from OPDs that have occurred in the field.

The important qualifiers here are:

- a. A 'fitness for purpose assessment' be carried out first and the opportunity to substitute a well-designed SSV, for example, for a Quad bike should be considered. If an SSV is not 'Fit For Purpose', then an OPD is an engineering control that may improve Quad bike safety in the workplace.
- b. In some crash events such OPDs could result in injury – rather than prevent it;
- c. It is essential that close monitoring and ongoing evaluation of the field performance of OPDs is required.
- d. Improved, more in-depth and uniform Quad bike and SSV accident data collection forms and procedures be put in place at state and federal levels, to enable monitoring of the relevant details of Quad bike and SSV incidents, including OPD and ROPS/ seat belt effects (both positive and negative).

7.5 The Rollover Crashworthiness Ratings

These provide a points rating out of a maximum of 25 points, of the Author's assessment of the rollover crashworthiness of the tested vehicles for the workplace environment, based on the rollover tests, evaluation against the ANSI/ROHVA standard and fundamental crashworthiness principles of rider/occupant protection in rollovers.

1. The SSVs all have notably higher overall rating (see Table 9 and Figure 18) with points from 15 to 21, with the Tomcar and John Deere receiving the highest rating, compared with 5 points for both the 'workplace' Quad bikes and 'recreational' Quad bikes.

2. In regards to the Quad bikes, the maximum rating these vehicles can potentially receive is an index of 5 if the straddle position is maintained in regards to the design of the vehicle and no rider protection is fitted to the vehicles, i.e. a ROPS. The work Quad bikes were all indexed at 5 points.
3. In contrast to the Quad bikes, well designed SSVs offer superior rollover crash protection in a typical farming environment, i.e. they are fitted with ROPS, seatbelts and various degrees of containment measures which combine to keep the occupants within a protected space. This is provided that three point (or harness) seatbelts and helmets are worn and other occupant lateral restraints are fitted and are in place.
4. The results from the rollover crashworthiness tests provide sufficient discrimination in the range of vehicles tested (Quad bikes and SSVs) to use as a basis for the rollover safety rating system.
5. The real-world validation and ongoing improvement and refinement of such ratings and Quad bike and SSV safety design, will further depend on the ongoing, proper, systematic collection of real world crash data involving Quad bikes and SSVs, including MMY and exposure data.

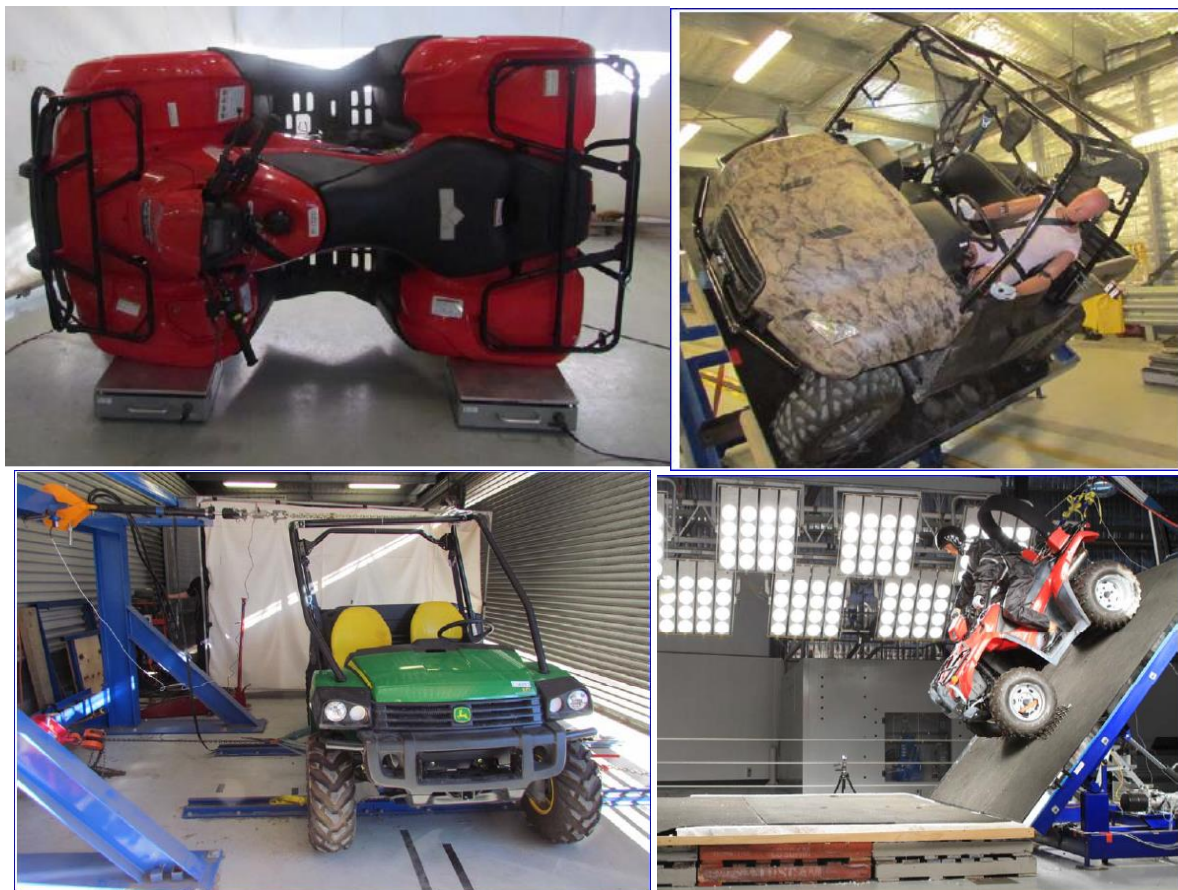


Figure 13: Examples of: 1. (top left) Quad bike contact force tests using load scales; 2. (top right) Side-by-Side Vehicle occupant retention; 3. (bottom left) SSV Roll-Over Protective Structure (ROPS) lateral pull test; and 4. (bottom right) Rollover test with occupant and Lifeguard OPD.

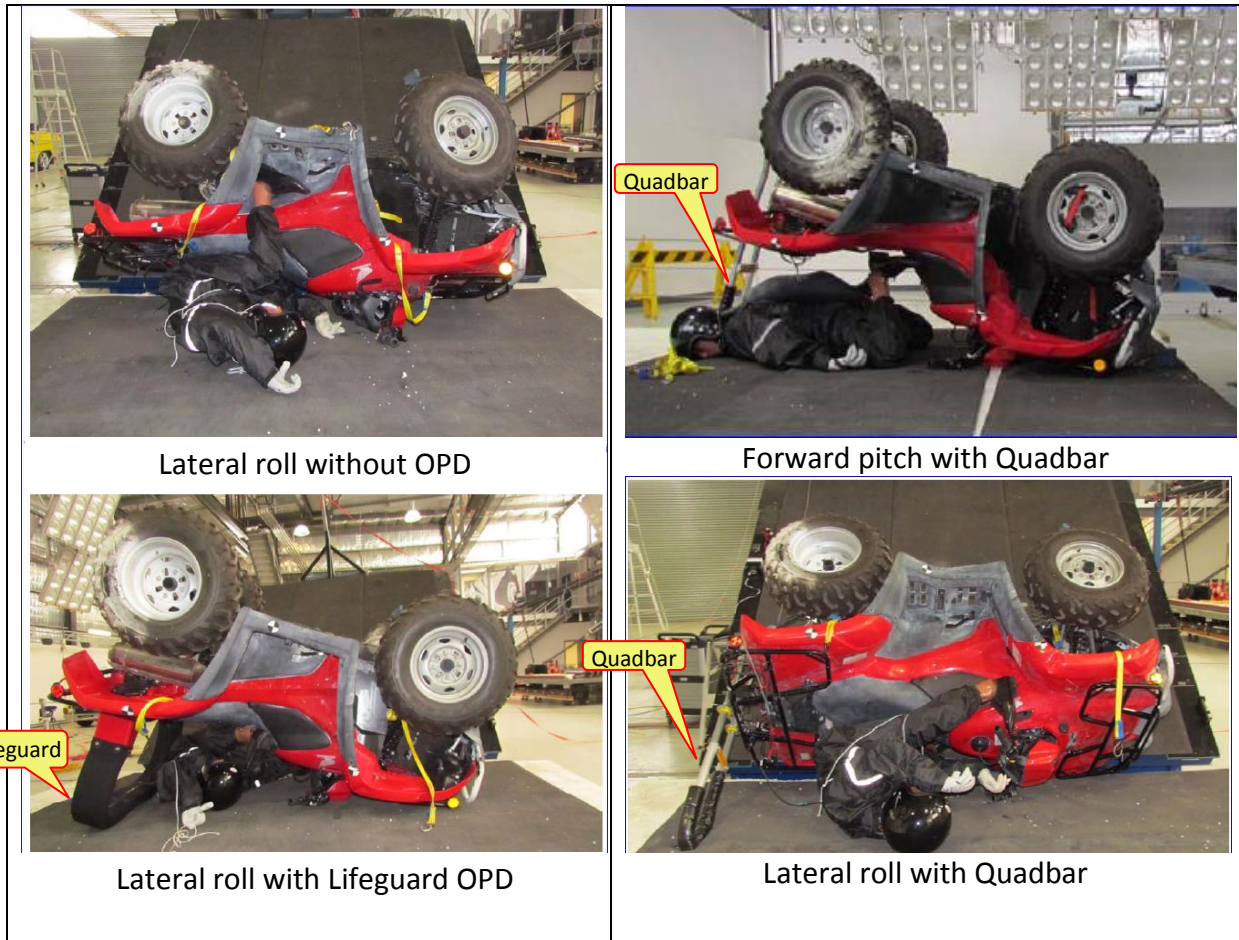


Figure 14: Examples of Quad bike lateral rollover and forward pitch tests with and without OPDs. For more details see 'Part 3: Rollover Crashworthiness Test Results' report.

8. ATVAP: THE AUSTRALIAN TERRAIN VEHICLE ASSESSMENT PROGRAM AND STAR RATINGS

The following sections summarise the rating method and rating points for each of the three test categories, followed by the final Australian Terrain Vehicle Assessment Program (ATVAP) Star Rating for the 16 production test vehicles.

The Star Rating is the sum of the points for the three tests, with 25 points each, and maximum of 75 points, plus up to 10 bonus points, giving a total of 85 points, as follows:

Static Stability	= 25 points
Dynamic Handling	= 25 points
<u>Crashworthiness</u>	<u>= 25 points</u>
<u>Total Points</u>	<u>= 75 Points</u>

Plus Bonus Points: (improved dynamic handling for Quad bikes and SSVs, and restraint assurance for SSVs)

Open differential (OD):	3pts.
Open differential (OD) on Start up:	5pts
Seat belt interlock (SBI):	5pts.

The Star Rating is based on five equal divisions of the 85 points:

One STAR	= ≤ 17pts;
Two STARS	= 18 to 34pts
Three STARS	= 35 to 51pts;
Four STARS	= 52 to 68 pts
Five STARS	= 60 to 85pts

8.1 Static Stability Overall Rating Index for the 17 Test Vehicles

8.1.1 Basis of the Static Stability Overall Rating Index

It is important to highlight that the Static Stability Overall Rating Index is a relative index which compares one vehicle with another. As such no one vehicle is being disadvantaged against another as the same criteria and weighting is applied to all vehicles. Preliminary parametric analyses of the effect of any weighting variations indicate that the relative Static Stability Overall Rating Index (of one vehicle compared with another) is relatively insensitive to such variations.

The stability indices are firstly based on the TTR values for each of three tilt test directions, by summing and then averaging the TTR values for each loading combination within those test directions:

1. Lateral Roll
2. Forward Pitch
3. Rear Pitch

The final Static Stability Overall Rating Index for each vehicle is then derived from weighted average TTR values for each of the three test directions, as will be described subsequently.

Two different final Static Stability Overall Rating Index systems are considered.

- i. **Static Stability Overall Rating Index - System 1:** For vehicles carrying loads as well as the operator(s).²⁰ This Index enables the 14 vehicles that can carry loads: the 8 workplace Quad bikes, 1 prototype Quad bike and 5 SSVs, to be compared. It uses the baseline TTR (i.e. unloaded and no rider) plus the TTR with the large rider or driver, plus the TTRs for all maximum load combinations.
- ii. **Static Stability Overall Rating Index - System 2:** For vehicles with rider/ driver only, no other loads being carried. This Index enables Static Stability Ratings to be compared for all the 17 vehicles if they are just being used to travel between locations (and not for load carrying). It uses the baseline TTR (i.e. unloaded and no rider) plus the TTR with the large rider or driver

8.1.1.1 Assumed risk exposure

It is important to note that the baseline TTR is also used in the Static Stability Overall Rating Index as its inclusion reflects for the Quad bikes, that the TTR with a rider will range somewhere between the baseline alone and baseline plus larger rider condition. This is because the tests were conducted for the heavier 95th % adult male rider weight, and with lighter riders the TTR will be higher in most cases. It also reflects some effect of Active Riding on Quad bikes in some situations, which through body weight shift in position, could move the TTR to some degree towards the higher baseline value. Furthermore, by also using all of the TTR maximum load combinations, with the base line TTR and the baseline plus operator TTR, this reflects a measure of exposure for the vehicle usage. That is, implicit in this method of analysis, i.e. the exposure for each vehicle type is assumed to be approximately:

Assumed Risk Exposure time for Static Stability Overall Rating Index - System 1:

Assumed risk exposure time for Work Quad bikes:

- 20% with lighter rider or some form of Active Riding;
- 20% with heavy rider;
- 20% with heavy rider plus full front load;
- 20% with heavy rider plus full rear load;
- 20% with heavy rider plus full front and rear load;

Risk exposure time for SSVs

- 33% of with lighter driver;
- 33% of with heavy driver;
- 33% of with heavy driver plus full rear load;

²⁰ All loads are maximum loads to the manufacturer's specification. For ATD the 95th PAM ATD was used for all vehicles except for the Can-am DS90X youth model where 5th PAF ATD used.

Assumed Risk Exposure time for Static Stability Overall Rating Index - System 2:

Assumed exposure time for Work Quad bikes and Sports/ Recreational Quad bikes:

- 50% with lighter rider or some form of Active Riding;
- 50% with heavy rider;

Risk exposure time for SSVs

- 50% of with lighter driver;
- 50% of with heavy driver;

Due to the very limited exposure data on Quad bikes and SSV usage in Australia, the Authors consider that the above usage distribution of weightings represents a reasonable allocation until such time that Australian exposure data becomes available. Moreover, variations of these weightings appear to not affect the relative rating of the Static Stability Overall Index.

8.1.1.2 Standardising the TTR values for the three test directions

To provide similar relative magnitudes for the indices for each of the three test directions, each TTR value was normalised against a relatively high TTR value as follows:

- Lateral Roll: Maximum Index for TTR =1.0. $\tan(45^\circ) = 1.0$
- Forward Pitch: Maximum Index for TTR =2.0. $\tan(63.4^\circ) = 2.0$
- Rearward Pitch: Maximum Index for TTR =1.75. $\tan(60.2^\circ) = 1.75$

Thus each TTR index value is adjusted by dividing by the relevant factor of 1.0, 2.0 and 1.75, respectively. These values are proposed by the Authors as benchmark reference values for lateral roll, forward pitch and rearward pitch respectively. These benchmark values were achieved (or nearly achieved) by those vehicles displaying the highest TTR stability measures, in some loading conditions. While these benchmark values could be argued as to basis, the Authors consider, based on all available information as discussed in this report and subject to further research and field evaluation, that they provide a reasonable starting point for desired stability value benchmarks.

8.1.1.3 Weighting of the Static Stability Overall Rating Index for roll direction incidence frequency

To take into account the different relative incidence of lateral roll, forward pitch and rear pitch rollovers, a relative weighting of 2:1:1 was assigned. As there is very limited data to date from the Quad bike rollover incident databases on rollover direction, this was considered by the Authors as to be not sufficiently reliable to base the weighting factors on so simple exposure based weightings were used.

The final Static Stability Overall Rating Index is determined by summing the normalised points for the three tilt-table test directions, but weighted in the ratio of 50% lateral roll, 25% forward pitch and 25% rear pitch. The Weighted Index has a maximum value²¹ of 20.

²¹ It is noted that where a test vehicle exceeds the normalising value of 1.0, 2.0 and 1.75 respectively, a slightly higher score than 20.0 can be achieved theoretically.

The weighting factors used at the most basic level are based on the geometric characteristics of the vehicles and reflect that lateral roll can occur in two directions (left and right) compared with one each for forward and rearward pitch. Hence, the relevant ratio of 2:1:1.

Thus the **Weighted Total Index** points are calculated as follows:

$$\text{Weighted Total Index} = 5 \times (2 \times \text{Roll Index Normalised} + \text{Rear Pitch Index Normalised} + \text{Forward Pitch Index Normalised})$$

e.g. from Table 5, for the Honda MUV700 Big Red:

$$\text{Weighted Total Index} = 5 \times (2 \times 0.84 + 0.76 + 0.98) = 17.1$$

8.1.2 The Static Stability Overall Rating Index for each vehicle

The **Static Stability Overall Rating Index - System 1** with loads, for the 8 workplace production Quad bikes and 5 SSVs is set out in Table 5 and Figure 15. The Sports/ Rec Quad bikes do not carry load and are included in System 2 (no loads).

The **Static Stability Overall Rating Index - System 2** no loads, for the 8 workplace production Quad bikes, 3 Sports/ Rec Quad bikes and the 5 SSVs is set out in Table 6 and Figure 16.

Note that for the Final ATVAP Star Rating (Section 8.4), the respective Index values in Table 5 and Table 6 used are multiplied by 1.25 to result in a maximum value of 25 points.

8.1.3 Observations from the two Static Stability Overall Rating Index systems

From these index results the following observations are made:

1. The Static Stability Overall Rating Index - System 1 (with loads)

This Static Stability Overall Index is intended for vehicle stability comparison in the work environment or other uses where the vehicles carry loads as part of their usage.

The SSVs all have notably higher Indices than the workplace Quad bikes, with Indices ranging from 15.3 to 17.1, compared with 9.7 to 11.3 for the workplace Quad bikes.

2. The Static Stability Overall Rating Index - System 2 (with rider but no loads)

This Static Stability Overall Rating Index is intended for vehicle stability comparison in environments or other uses where the vehicles do not carry loads, but are used for travel or mobility work tasks only, e.g. herding cattle or sheep or accessing farm areas.

The vehicle's Indices are higher than those determined for Static Stability Overall Rating Index - System 1, as without loads stability is increased.

The SSVs all have higher Indices than the workplace Quad bikes, with points ranging from 15.9 to 18.6, compared with 11.3 to 12.7 for the workplace Quad bikes.

The prototype Quad bike would have received 14.8 points with operator only and 14.1 with load. This would have placed this vehicle just below the lowest SSV. This demonstrates that it is possible to increase the rollover resistance of the Quad bikes.

Static Stability Overall Index- System 1 - all loads			Roll	Rear Pitch	Forward Pitch		
Type	Make	Model	Index Normalised	Index Normalised	Index Normalised	Total Index	Weighted Total Index
SSV	Honda	MUV700 big red	0.84	0.76	0.98	2.57	17.1
SSV	Tomcar	TM2	0.93	0.55	0.94	2.42	16.8
SSV	John Deere	XUV825i	0.80	0.77	0.93	2.50	16.5
SSV	Kubota	RTV500	0.76	0.64	0.97	2.36	15.6
SSV	Yamaha	Rhino	0.71	0.72	0.91	2.35	15.3
Quad	CF Moto	CF500	0.61	0.54	0.51	1.65	11.3
Quad	Polaris	Sportsman 450HO	0.60	0.47	0.54	1.62	11.1
Quad	Suzuki	Kingquad 400ASI	0.59	0.52	0.52	1.63	11.1
Quad	Honda	TRX500FM	0.60	0.51	0.51	1.62	11.1
Quad	Honda	TRX250	0.56	0.48	0.53	1.58	10.7
Quad	Yamaha	YFM450FAP Grizzly	0.53	0.54	0.49	1.57	10.5
Quad	Kawasaki	KVF300	0.56	0.49	0.49	1.53	10.5
Quad	Kymco	MXU300	0.49	0.48	0.48	1.45	9.7
							Max 20
Weighted Total Index = $5 \times (2 \times \text{Roll} + \text{Rear Pitch} + \text{Forward Pitch})$							

Table 5: Static Stability Overall Rating Index, System 1- with maximum loads, for the 8 production work Quad bikes and 5 SSVs.

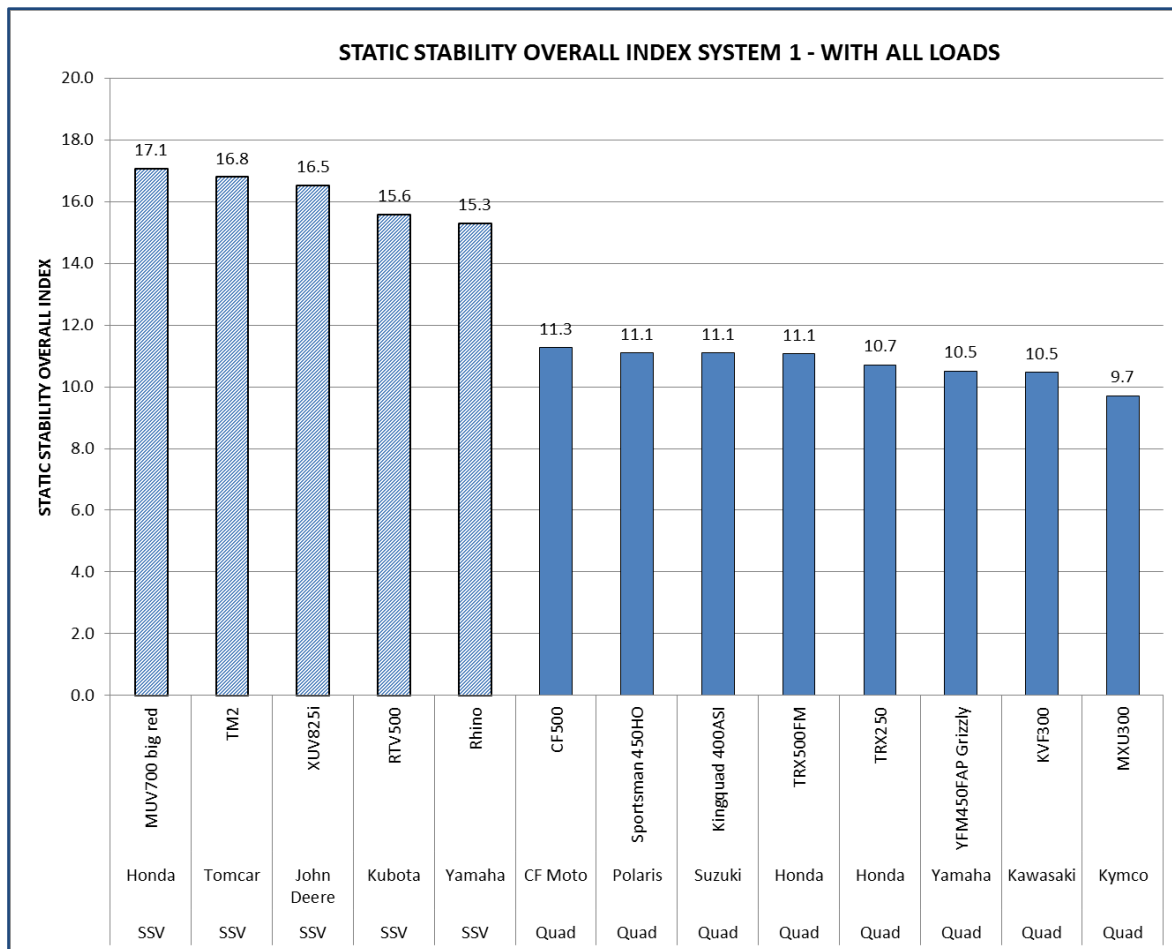


Figure 15: Bar chart showing the Static Stability Overall Rating Index, System 1- with maximum loads, for the 8 production work Quad bikes and 5 SSVs.

Static Stability Overall Index System 2-no loads			Roll	Rear Pitch	Forward Pitch	Total Index	Weighted Total Index
Type	Make	Model	Index Normalised	Index Normalised	Index Normalised		
SSV	Honda	MUV700 big red	0.92	0.90	1.00	2.81	18.6
SSV	John Deere	XUV825i	0.88	0.88	0.91	2.68	17.8
SSV	Tomcar	TM2	0.98	0.60	0.96	2.55	17.7
SSV	Kubota	RTV500	0.80	0.71	1.00	2.51	16.6
SSV	Yamaha	Rhino	0.75	0.80	0.90	2.44	15.9
Quad	Can-am	DS90X	0.94	0.63	0.58	2.16	15.5
Quad	Honda	TRX700XX	0.79	0.56	0.62	1.98	13.9
Quad	Yamaha	YFM250R Raptor	0.75	0.59	0.57	1.91	13.3
Quad	Polaris	Sportsman 450HO	0.69	0.56	0.59	1.84	12.7
Quad	Suzuki	Kingquad 400ASI	0.67	0.61	0.56	1.85	12.6
Quad	Honda	TRX250	0.67	0.58	0.59	1.84	12.5
Quad	Honda	TRX500FM	0.67	0.61	0.54	1.83	12.5
Quad	CF Moto	CF500	0.67	0.61	0.53	1.81	12.4
Quad	Yamaha	YFM450FAP Grizzly	0.63	0.65	0.53	1.81	12.2
Quad	Kawasaki	KVF300	0.66	0.58	0.52	1.76	12.1
Quad	Kymco	MXU300	0.59	0.56	0.53	1.68	11.3
							Max 20
Weighted Total Index =						5 x (2 x Roll + Rear Pitch + Forward Pitch)	

Table 6: Static Stability Overall Rating Index, System 2- no loads, for 16 production vehicles.

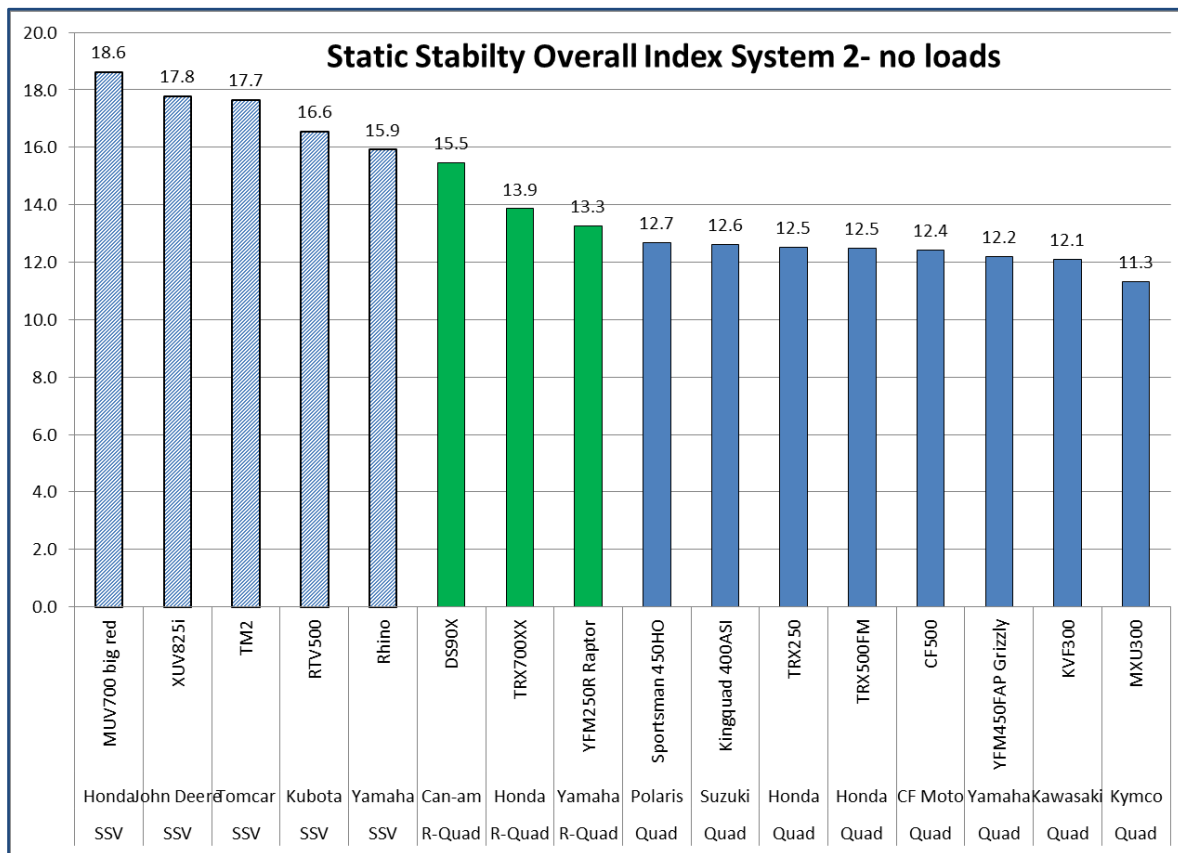


Figure 16: Bar chart - Static Stability Overall Rating Index, System 2- no loads, for the 16 production vehicles.

8.2 Dynamic Handling Overall Rating Index for the 17 Test Vehicles

The Dynamic Handling Overall Rating Index is the second of the three major test components of the ATVAP Star Rating system which takes into account the Static Stability Tests, Dynamic Handling Tests and Rollover Crashworthiness Tests. The proposed Dynamic Handling Overall Rating Index is based on the summation of the Index values from the following four dynamic test results with rider/ driver for each vehicle.

8.2.1 Points Ratings

Each test was rated out of 5 points, with a total of 25 points, as set out in Table 7.

1. **Steady-state circular driving behaviour dynamic tests** - the limit of lateral acceleration, A_y (g)
2. **Steady-state circular driving behaviour dynamic tests** - scores either the understeer or oversteer characteristic.²²
3. **Lateral transient response dynamic tests** - the steering response time.
4. **Bump obstacle perturbation tests** - the measured acceleration of the ATD pelvis.

The total points for the Dynamic Handling Overall Rating Index (25) are the same to those calculated from the Static Stability Overall Rating Index (25).

Criteria	Points rating				
	1	2	3	4	5
1. Lateral Stability A_y (g) at tip up (no tip up = 3 pts)	<0.4	0.4 to 0.59	0.6 to 0.79	0.8 to 0.99	>1.0
2. Steady State turning -Transition to oversteer (g)	0.1	0.2	0.3	0.4	0.5
3. Steady State turning -Understeer Gradient (degree/g)	≥8.0	8.0 to 6.0	5.9 to 4.0	3.9 to 3.0	0.49 to 3.0
4. Steady State turning - Oversteer Gradient (degree/g)	≥ -8.0 Oversteer	-7.9 to -4.0 Oversteer	-3.8 to -1.0 Oversteer	-0.99 to 0.5 Neutral	0.49 to 3.0 Understeer
5. Steering response time (s)	>0.5	0.4 to 0.5	0.3 to 0.4	0.2 to 0.3	<0.2
6. Bump Obstacle Response - Pelvis acceleration (g)	>3.0	2.0 to 3.0	1.5 to 2.0	1.0 to 1.5	<1.0

Table 7: Points allocation for the Dynamic Handling Overall Rating Index (Max. 25 points).

8.2.2 The Dynamic Handling Overall Rating Index

For the 17 vehicles, the Rating for each of the 5 test categories, and the Weighted Total Index²³ is given in Table 8 and in bar-chart form in Figure 17. The ‘Weighted total Index’ is the ‘weighted’ sum of the 5 individual Rating values, with the weighting equal to ‘1.0’ for each test. That is, each test is included with equal weighting, at this stage.

²² The point of transition between understeer and oversteer is also rated, with no transition - remains in understeer earning 5 points and no transition - remains in oversteer earning 1 point.

²³ Notes regarding Table 8 and Figure 17: For Test 5, for SSVs - the pelvic acceleration was not measured as testing identified that the bump test did not result in adverse perturbation of the SSV or driver, with a high positive Rating of ‘4’ being assigned to each of the SSVs, accordingly.

Dynamic Handling Overall Index Driver Only			1. Limit of Lateral Acceleration	2. & 3. Steady State Steering Characteristics					4. Lateral Transient Response		5. Bump Response		Weighted Index
Type	Make	Model	Ay (g)	1. Rating	Understeer Gradient (deg/g)	2. Rating	Transition Point (g)	3. Rating	Time (sec)	4. Rating	Pelvis Resultant Acceleration (g)	5. Rating	
SSV	Honda	MU700 Big Red	0.56 (no tip up)	3	3.6	4	n/a	5	0.27	4	1.5	4	20
SSV	Kubota	RTV500	0.54 (no tip up)	3	2.2	5	0.40	4	0.20	4	1.5	4	20
SSV	Tomcar	TM2	0.49 (no tip up)	3	5.3	3	n/a	5	0.20	4	1.5	4	19
SSV	John Deere	XUV825i	0.54 (no tip up)	3	6.5	2	n/a	5	0.27	4	1.5	4	18
SSV	Yamaha	Rhino	0.61	3	-8.7	1	0.19	2	0.28	4	1.5	4	14
Quad	Prototype		0.57 (no tip up)	3	7.8	2	n/a	5	0.12	5	2.1	2	17
Quad	Yamaha	YFM450F AP Grizzly	0.41	2	-4.4	2	0.18	2	0.14	5	1.9	3	14
Quad	Polaris	Sportsman 450HO	0.55	2	-8.3	1	0.15	2	0.13	5	1.7	3	13
Quad	CF Moto	CF500	0.50	2	-4.4	2	0.03	1	0.20	4	1.8	3	12
Quad	Honda	TRX500FM	0.52	2	-4.4	2	n/a	1	0.17	5	2.1	2	12
Quad	Kawasaki	KVF300	0.46	2	-4.2	2	n/a	1	0.13	5	3.0	2	12
Quad	Suzuki	KingQuad400ASi	0.45	2	-8.6	1	0.01	1	0.16	5	2.2	2	11
Quad	Honda	TRX250	0.46	2	-8.8	1	0.06	1	0.13	5	2.8	2	11
Quad	Kymco	MXU300	0.36	1	-9.0	1	0.12	2	0.10	5	2.1	2	11
RQuad	Honda	TRX700XX	0.55	2	4.1	3	0.33	3	0.14	5	2.0	3	16
RQuad	Can-Am	DS90X	0.54	2	-3.9	3	0.18	2	0.15	5	3.5	1	13
RQuad	Yamaha	YFM250R Raptor	0.47	2	-8.0	1	0.01	1	0.15	5	3.1	1	10

Max 25

Table 8: Dynamic Handling Overall Rating Index for the 17 vehicles, rider/ driver only (i.e. no added loads). Maximum rating =25 points.

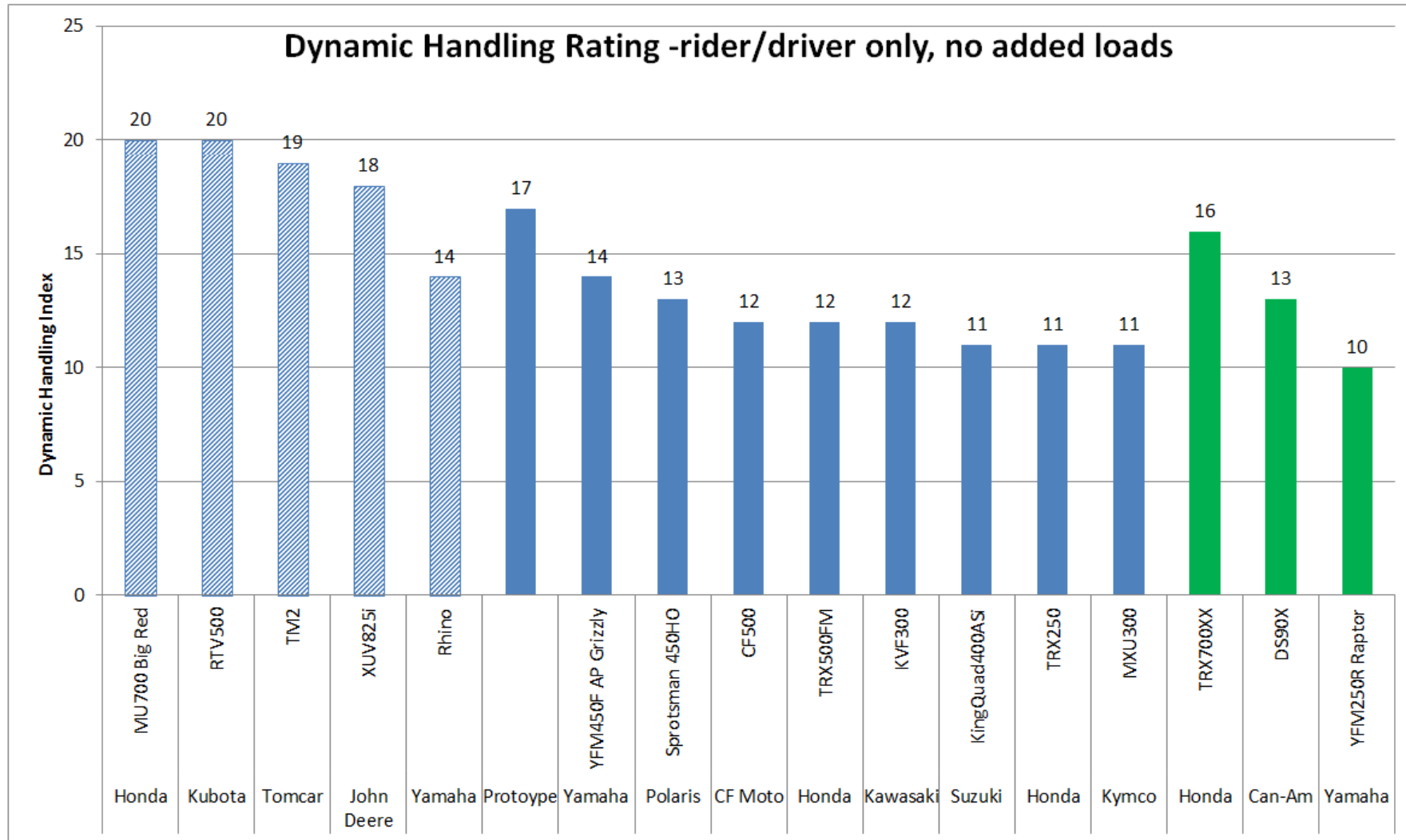


Figure 17: Bar chart showing the Dynamic Handling Overall Rating Index for the 16 production vehicles, rider/ driver only (i.e. no added loads).
 Maximum rating =25 points

8.2.3 Observations from the Dynamic Handling Overall Rating Index

The results from the dynamic handling tests provide sufficient discrimination in the range of vehicles tested (Quad bikes and SSVs) to use as a basis for the Star Rating system. The prototype Quad bike was included into Table 8 and Figure 17 for comparative purposes.

From these Index results given in Table 8 and Figure 17 the following observations are made:

1. The SSVs, except for one model (14 points) all have higher overall indices with points from 18 to 20, compared with 10 to 12 for the workplace Quad bikes. One of the recreation Quad bikes has a high rating of 16 points. The prototype Quad bike received a higher rating of 17. The maximum rating is 25 points.
2. These dynamic tests were also innovative and most significant as they showed that Quad bikes could be subject to a scientifically reliable, reproducible, and meaningful dynamic handling testing. This finding was contrary to claims by some in Industry that such testing was not feasible or meaningful.
3. The dynamic tests further showed how a Quad bike's suspension system and track width could be modified, e.g. the prototype, so that the vehicle's dynamic handling performance is comparable to SSVs.

8.3 Rollover Crashworthiness Overall Rating Index for the 16 Test Vehicles

The Rollover Crashworthiness Overall Rating Index is the third of the three major test components of the ATVAP Star rating system which takes into account the Static Stability Tests, Dynamic Handling Tests and Rollover Crashworthiness Tests. The basis of the proposed Rollover Crashworthiness Overall Rating Index for each vehicle is the summation of the Index values from the following five test categories. Details of the different tests performed can be found in 'Part 3: Rollover Crashworthiness Test Results'.

8.3.1 Points Ratings

Point scores for each test category are allocated as follows, with a total of 25 points:

1. **Five points (5 points) are allocated to all vehicles automatically.** This is regardless of whether they are a Quad bike or an SSV. The intent of this allocation is that people do survive rollover crashes using these vehicles, e.g. as per Van Ee et al. (2012).

For Quad bikes, these can only receive 5 points as noted. Fitment of OPDs is not rated in terms of points currently as it is not possible to rate their relative effectiveness.

2. **ROPS: For SSVs five points (5 points) are allocated to a vehicle that has a four post (minimum) ROPS.** This is regardless if the vehicle meets any of the US Industry voluntary standards.

3. **For SSVs up to five points (5 points) are allocated to ROPS that meet the US ANSI/ROHVA 1-2011 ejection criteria and Zone restraint** with the additional proposed requirement of no displacement outside the width of the vehicle. Any excursion of the head or torso/shoulder outside the width results in no points allocated. For a situation where the vehicle meets the requirement but does not meet the Zone 1 to 4 and warning label requirement, 1 point is deducted for every instance the requirement is not met.
4. **For SSVs up to five points (5 points) are allocated to ROPS that meets the US ANSI/ROHVA 1-2011 (ISO Option) load criterion** – if the minimum load is not reached within the energy constraints of the standard in any one of the three loading directions the vehicle scores 0 points.
5. **For SSVs five bonus points (5 points) are provided for SSVs that have met the requirements set out in 3 and 4 above, as follows:** 3 point or harness seat belt (1 point); a seat belt warning light which switches off when the seat belt is locked in (1 point); for a seat belt audible alarm that is maintained for at least 5 minutes when a person is seated in the vehicle (1 point); and for a seat belt interlock system that is ignition or speed interlock based (2 points).

The total points for the Rollover Crashworthiness Overall Rating Index is twenty five (25) and is similar to those calculated FROM the Static Stability Overall Rating Index (25)²⁴ and Dynamic Handling Overall Rating Index (25).

8.3.2 The Rollover Crashworthiness Overall Rating Index

For the 17 vehicles the weightings for each of the five categories and the Weighted Total Index for rollover crashworthiness is given in Table 9 and for the 16 production vehicles in bar chart form in Figure 18. The rating for the Prototype Quad bike is provided in Table 9.

The Rollover Crashworthiness Overall Rating Index has been calculated for a rider/ driver only, i.e. no loads were carried by any of the vehicles, and no OPD has been fitted to the work Quad bikes.

8.3.3 Observations from the Rollover Crashworthiness Overall Rating Index

All five SSVs with ROPS structures were assessed individually using the range of tests described above. Quad bikes were not assessed on an individual basis. Each Quad bike was awarded the baseline five points. From these Index results given in Table 9 and Figure 18, the following observations are made.

The SSVs, all have notably higher overall indices with points from 15 to 21 (the Tomcar and John Deere received the highest rating), compared with 5 points for both the work Quad bikes and recreational Quad bikes.

²⁴ Factored up from 20 points by 1.25.

Crashworthiness Overall Index driver/ rider only			Baseline rollover protection	ROPS fitted		Meets ANSI/ROHVA 1-2011 Ejection Criteria & Zone restraint	Meets ANSI/ROHVA 1-2011 ROPS Force Criteria		3 point or harness seat belt (1 pt), seat belt warning light (1 pt), seat belt 5 minute buzzer (1 pt), seat belt interlock (2 pts)			Total Index
Type	Make	Model	1. Rating		2. Rating		3. Rating		4. Rating		5. Rating	
SSV	Tomcar	TM2	5	Yes	5	Yes	5	Yes	5	Yes - Harness	1	21.0
SSV	Honda	MUV700 big red	5	Yes	5	Yes	5	No	0	Yes - 3 pt belts	1	16.0
SSV	John Deere	XUV825i	5	Yes	5	No - Zones 1, 2 & 4	2	Yes	5	Yes - belt and light	2	19.0
SSV	Yamaha	Rhino	5	Yes	5	No regarding excursion ² No - Zones 2 & 3	0	Yes	5	Yes - 3 pt belts	1	16.0
SSV	Kubota	RTV500	5	Yes	5	No regarding excursion ¹ No - Zone 1, 2 & 4 No helmet warning sticker	0	Yes	5	No - only 2 pt belt	0	15.0
Quad	CF Moto	CF500	5	No	0	No	0	No	0	No	0	5.0
Quad	Polaris	Sportsman 450HO	5	No	0	No	0	No	0	No	0	5.0
Quad	Suzuki	Kingquad 400ASI	5	No	0	No	0	No	0	No	0	5.0
Quad	Honda	TRX500FM	5	No	0	No	0	No	0	No	0	5.0
Quad	Honda	TRX250	5	No	0	No	0	No	0	No	0	5.0
Quad	Yamaha	YFM450FAP Grizzly	5	No	0	No	0	No	0	No	0	5.0
Quad	Kawasaki	KVF300	5	No	0	No	0	No	0	No	0	5.0
Quad	Kymco	MXU300	5	No	0	No	0	No	0	No	0	5.0
RQuad	Honda	TRX700XX	5	No	0	No	0	No	0	No	0	5.0
RQuad	Can-Am	DS90X	5	No	0	No	0	No	0	No	0	5.0
RQuad	Yamaha	YFM250R Raptor	5	No	0	No	0	No	0	No	0	5.0
Quad	Prototype		5	No	0	No	0	No	0	No	0	5.0
Max 25												

¹ Head outside vehicle width and pelvis slid on seat

² Head, torso, shoulder and elbow outside vehicle width

Table 9: Rollover Crashworthiness Overall Rating Index for the 17 vehicles, rider/driver only (i.e. no added loads).

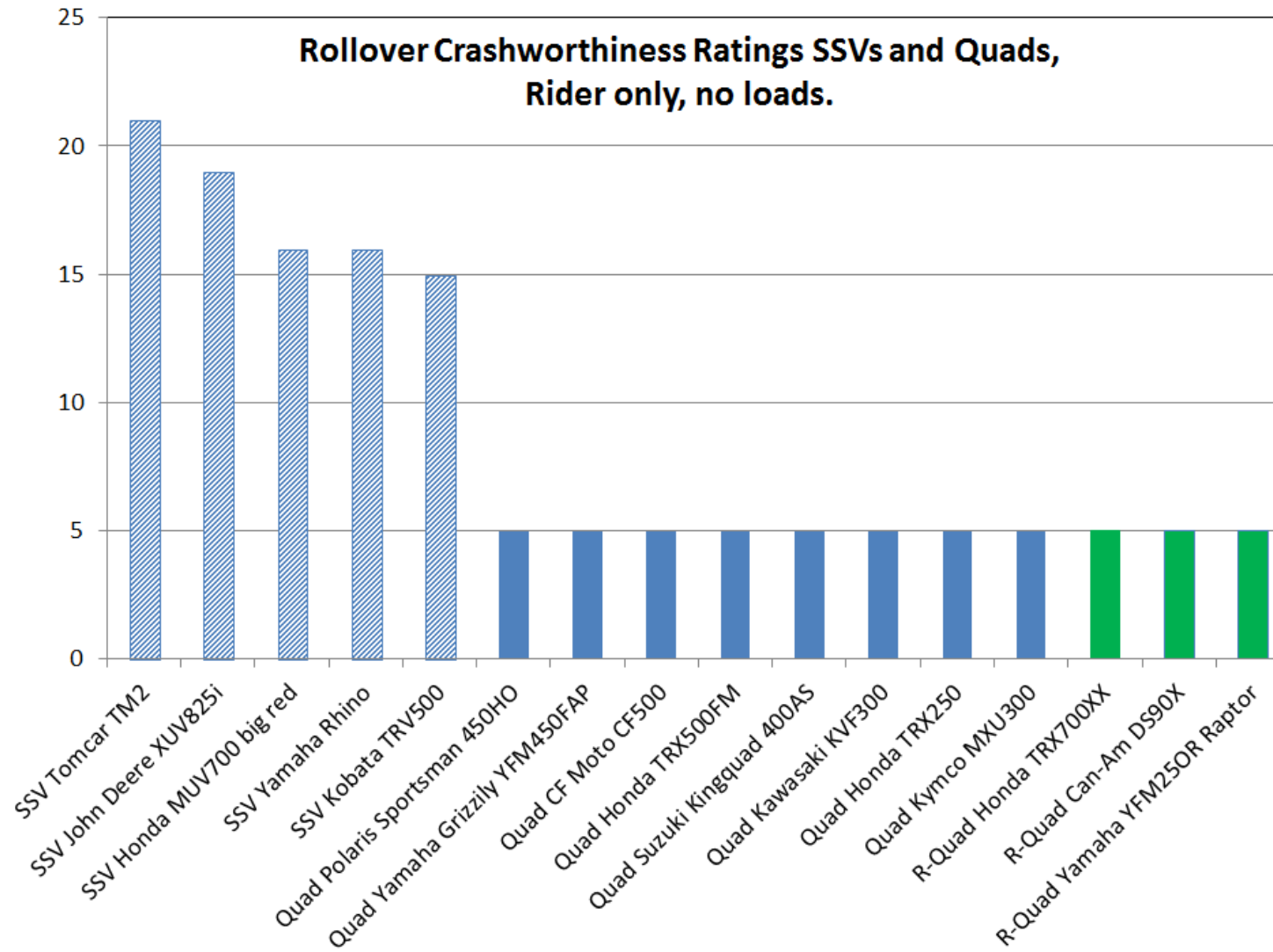


Figure 18: Rollover Crashworthiness Overall Rating Index for the 16 production vehicles, rider/ driver only.

The Honda Big Red's performance in the ROPS vertical load test in which it did not sustain the full specified load in the variant of the ANSI/ROHVA 1-2011 standard (ISO Option) used, resulted in zero points allocated in this category, and hence the vehicle's lower performance compared to the Tomcar and John Deer SSVs. It was later discovered that the Honda Big Red met the US OSHA method (Code of Federal Regulations) standard which requires a ROPS Strength to Weight Ratio (SWR) of only 1.5, which has been found by the Authors and others to be totally inadequate for occupant protection in rollover in regards to passenger vehicles (Young and Grzebieta, 2010; Brumbelow et al, 2009; Brumbelow and Teoh, 2009).

In regards to the Quad bikes, the maximum rating these vehicles can potentially receive is an index of 5 if the straddle position is maintained with respect to the vehicle's design and 'separation' is the crashworthiness criterion adopted by the manufacturer.

8.4 Final ATVAP Rollover Stability, Dynamic Handling and Crashworthiness Star Ratings for the 16 Production Tested Quad bikes and SSVs

The final ATVAP Star Rating for the 16 production vehicles tested is given in Figure 19, below. The maximum rating score is out of 85 points, and from one to five Stars.

Four Star ratings were achieved by four of the five SSVs in the following order: by the Tomcar TM2 (max 65pts), the John Deere XUV825i (62pts); the Honda MUV700 Big Red (62pts) and the Kubota RTV500 (59pts).

Three Star ratings were achieved by the Yamaha Rhino SSV (50pts), and two of the 'Recreational' Quad bikes: the Honda TRX700XX (38pts) and the Can-Am DS90X (37pts).

Two Star Ratings were achieved by all the other Quad bikes (28pts to 32pts).

The individual points rating from the three test categories plus bonus points are set out in Table 10 (points for rider/ driver only – no load) and Figure 19 (Quad bikes with rider only – no load; SSVs with driver only and also with driver and load).

The prototype Quad bike would have received around 37 points, placing within the best of the Quad bikes but still a much lower rating than the SSVs, mainly because of a low rating for Rollover Crashworthiness.

Star Rating Overall Index - driver/rider & loads			Static Stability	Dynamic Handling	Crashworthiness	Open differential (OD) = 3pts; OD default on startup = 5pts; & Seatbelt interlock = 5pts.		Star Rating	
Type	Make	Model	1. Rating	2. Rating	3. Rating		Bonus	Total Index	
SSV	Tomcar	TM2	21	19	21	OD - not default	3	64	4
SSV	Honda	MUV700 big red	21	20	16	OD - not default	3	60	4
SSV	John Deere	XUV825i	21	18	19	OD - not default	3	61	4
SSV	Yamaha	Rhino	19	14	16		0	49	3
SSV	Kubota ¹	RTV500	19	20	15	OD - not default	3	57	4
Quad	CF Moto	CF500	14	12	5		0	31	2
Quad	Polaris	Sportsman 450HO	14	13	5		0	32	2
Quad	Suzuki	Kingquad 400ASI	14	11	5		0	30	2
Quad	Honda	TRX500FM	14	12	5		0	31	2
Quad	Honda	TRX250	13	11	5		0	29	2
Quad	Yamaha	YFM450FAP Grizzly	13	14	5		0	32	2
Quad	Kawasaki	KVF300	13	12	5		0	30	2
Quad	Kymco	MXU300	12	11	5		0	28	2
Rquad ²	Honda	TRX700XX	17	16	5		0	38	3
Rquad ²	Can-Am	DS90X	19	13	5		0	37	3
Rquad ²	Yamaha	YFM250R Raptor	17	10	5		0	32	2
								Max 85	

¹ Head outside vehicle width and pelvis slid on seat

² Recreational quads - no provision to carry loads or attach OPD

Table 10: ATVAP: Final Points and Star Rating of the 16 production Quad bikes and SSVs tested with rider/ driver.

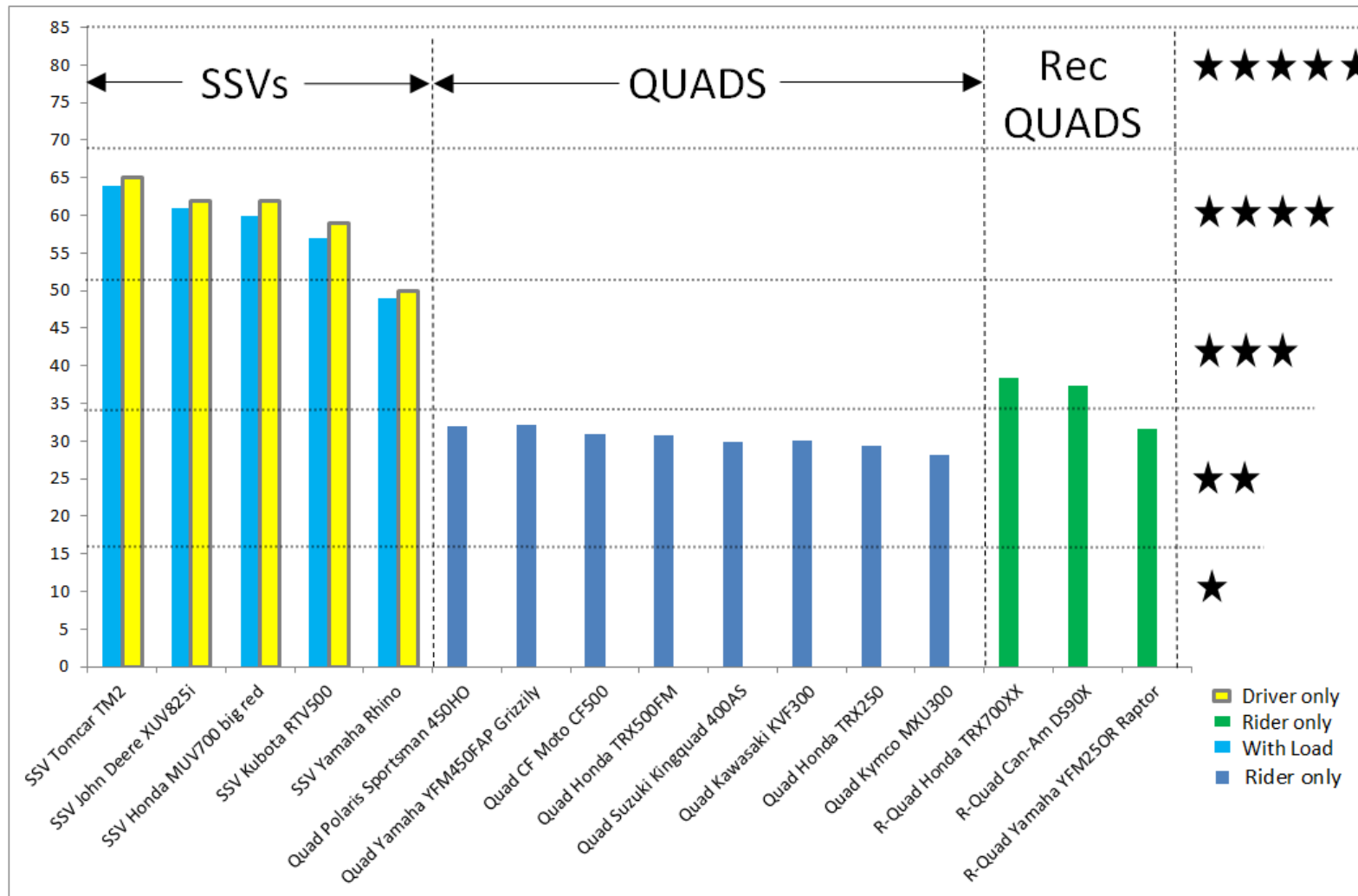


Figure 19: Final Points and Star Rating of the 16 production Quad bikes and SSVs tested.

9. CONCLUSIONS

The following conclusions have been drawn from the Quad bike Performance Project's review of Australian Quad bike & SSV fatality and injury, and the extensive test program that consisted of Static Stability, Dynamic Handling and Rollover Crashworthiness tests carried out on 17 vehicles.

The (more than) 18 months Project comprised a comprehensive research and physical test program involving over 1000 tests carried out at the Roads and Maritime Services, Crashlab laboratory facility at Huntingwood. This extensive project also involved the examination and analysis of 109 Coronial case files selected from 141 case files collected from all Australian States and Territories, and workplace and hospital admissions data from NSW and elsewhere, for the period 2000 to 2012. The focus of the test program on rollover prevention and injury mitigation were based on the findings from the fatality data which indicated that rollover was involved in over 71% of the fatalities (77 of 109).

The 16 production vehicles and prototype Quad bike tested are shown in Figure 2.

The aims of the project were to also introduce a robust, test based Star Rating system, similar to other product rating systems, in order to provide consumer based incentives (and assist workplace plant managers) for informed, safer and appropriate vehicle purchase (highlighting 'Fit For Purpose' criteria) that reduced the risk of being injured in a rollover in a workplace setting, and at the same time generate corresponding incentives and competition amongst the Quad bike and SSV Industry for improved designs and models.

The main conclusions from the study are listed below, together with brief explanatory notes.

CONCLUSION 1: Quad bike Fatalities and Injuries in Australia for the period 2000-2012. Rollover and being pinned were the most frequent injury mechanisms for Quad bike related fatalities on farms.

1. 141 fatalities were identified from the Australian National Coronial Information System (NCIS) dataset. Approximately 10 to 15 fatalities per annum.
2. 109 fatal cases were relevant, the other 32 cases involved public road crashes or other vehicle types.
3. The 109 cases constituted 106 Quad bikes, and 2 SSVs and one six wheel straddle vehicle.
4. 86% of deaths were male.
5. Approximately 50% of the 109 fatalities were related to workplace activity (n=54; 53 farms and 1 forestry) and 50% (n=55) to recreational activity. The majority of cases involved riders on their own and remote from immediate help.
6. Approximately 75% of the 109 fatalities occurred on Farms.

7. Rollover occurred in 71% of the 109 cases. Of the 109 cases 85% of the work related fatal cases involved a rollover compared to 56% of recreational cases.
8. Loss of control on a slope and/or driving over an object was a factor in 58% of the farm cases and 33% of recreational cases.
9. In work related fatal cases, a higher percentage of these were older riders, namely: 78% were 50 years or older; 50% were 60 years or older; 42% were 65 years or older; and 33% were 70 years or older. In comparison, for all fatal cases, 43% were 50 years or older, and only 9% of recreational riders killed were 50 years or older.
10. The main cause of death for farm workers was chest injury (59%) compared to head injury for recreational riders (49%).
11. Around 13% of farm workers died as a result of head injury. A helmet was found to be worn in 22% of the 109 cases.
12. The dominant injury mechanism for farm cases was rollover followed by being pinned by the vehicle resulting in crush injury and/or mechanical asphyxia. 70% were pinned under the Quad bike. Most of the pinned events were with the vehicle on its side not upside down, by a factor of approximately two to one (2:1).
13. Almost 50% the farm work fatalities were caused by mechanical asphyxia, with approximately 77% of these estimated to have been survivable incidents if the rider did not remain pinned.
14. For recreational riders, a smaller number were pinned under the Quad bike, about 33% of cases.
15. Regarding Quad bike & SSV injuries, based on hospital and other injury databases, it is estimated that there are approximately 1400 presentations per annum at hospitals in Australia, for minor to severe injuries.

In regards to Australian fatal crashes, 141 fatalities were identified from the Australian National Coronial Information System (NCIS) dataset of fatalities that occurred over a period of twelve years (2000 to 2012). The vehicles involved were almost all Quad bikes. Only five cases involving some form of SSV were found in the data.

After review of the 141 cases by McIntosh and Patton, 32 cases were identified as involving public road crashes and other vehicle types such as sand buggies. These were excluded in the analysis of the remaining 109 cases. There were 106 Quad bikes, two SSVs and one six wheel bike in the remaining sample of 109 cases.

86% of deaths were male where the mean height and body mass for all cases in the age group 15 to 74 years were 1.75 m and 81 kg, respectively.

As noted, rollover was the predominant crash type. Where the roll direction was noted, there were 11 (10.1%) forward rolls, 32 (29.4%) lateral rolls, 5 (4.6%) rearward rolls. In 29 (26.6%) cases rollover was noted but the roll direction was unknown.

The older age of fatal cases on farms, is particularly relevant in so far that older rider's motivation and capacity to ride a Quad bike actively would be significantly less than a

younger rider. In effect, it is assumed that older riders would most likely ride the vehicle passively, continuously seated, not actively leaning or standing on the Quad bike to influence its stability or control. This suggests a more appropriate vehicle for this older age group would be SSV style vehicles, which do not require an Active Riding style, and are also designed to carry loads and a passenger. Further development of the prototype quad bike may provide an alternate quad bike design that does not require Active Riding.

Rollover accompanied by crush and asphyxiation was identified by McIntosh and Patton (2014a) as one of the major injury causal mechanisms occurring in farming related crashes. Around 62% of farm workers had crush injuries under the vehicle without extensive impact related injuries, e.g. received a flail chest. Moreover, fifty-five (50.5%) of the 109 deceased riders were pinned by the Quad bike, i.e. the person was restrained under the vehicle until they were found. A higher proportion of farm workers (n=37, 69.8%) were pinned under the Quad bike than recreational riders (n=18, 32.7%). This was the dominant injury mechanism for farm workers.

Almost half the farm work fatalities (n=26) were caused by asphyxia or a related condition. In these cases the worker was pinned under the Quad bike and typically suffered no injury to a body region other than the thorax and injuries to the thorax were not otherwise fatal. The data suggest strongly that approximately one third (n=20) of the farm workers who died of asphyxia would have survived the crash if the vehicle did not pin them with a force sufficient in terms of magnitude and duration to cause asphyxia. The use of an alert system in some cases may have enabled assistance to have arrived in time to release the rider. In the other fatal farm work cases a large proportion of those not asphyxiated were injured when the Quad bike interacted with the operator during a rollover.

Fatal and non-fatal Quad-related injuries were obtained from various data collections including: Safe Work Australia's National Dataset for Compensation-based Statistics (NDS), WorkCover NSW's workers' compensation scheme claims, WorkCover NSW's incident reports, Transport for NSW's Road Crash Analysis System (RCAS), the NSW Admitted Patient Data Collection (APDC), and the NSW Public Health Real-time Emergency Department Surveillance System (PHREDSS). The data indicates that over a seven year period there were around 3,307 records of Quad/SSV related Emergency Department Presentations (EDP) for NSW (around 472 per year). NSW has a population of around 7.3 million and is around 32% of Australia's total population. Extrapolating the injury count for Quad bikes/SSVs one could expect currently a total of around 1,400 EDP for Australia each year.

Finally it should be noted that from the analysis of the Coronial data that in the context of a Vision Zero based Safe System Approach (deaths or serious injuries in the workplace that results in a permanent disability are not acceptable), for a four wheel vehicle, Quad bikes, do not have sufficient 'human error tolerance' and safety factors to limit rollover propensity and/or mitigate related rollover injury risks in everyday working conditions on a farm. Low rollover resistance, no effective crashworthiness provisions (ROPS, seatbelts, and

containment) and Coronial fatality data all indicate the margin for error is minimal, in comparison to, for example, well designed SSVs.

CONCLUSION 2: The performance tests and ATVAP Star Rating system developed in this project rated four of the five SSV vehicles significantly ahead of Quad bikes in terms of higher resistance to rollover, and likely³ reduced injury risk in a rollover. However, it also identified lower performance SSVs and Quad bikes.

The past few decades has also demonstrated that the most effective way to influence vehicle design and safety advances by manufacturers is to apply an appropriate performance test and Star Rating system for consumer information and market action.

There are highly successful clear examples with respect to road vehicles and consumer goods where performance of the product has been enhanced through informing consumers via a Star Rating system, and vehicles being recommended (or mandated) on the basis of higher Star Ratings which are based on demonstrable safety enhancements.

There are no standards or compliance requirements in Australia for Quad bikes or SSVs. However, three main United State of America (USA) Industry voluntary standards exist, one of which is relevant to Quad bikes and two of which are relevant to SSVs. They are, respectively for Quad bikes: ANSI /SVIA 1-2010: American National Standard for Four Wheel All-Terrain Vehicles and for SSVs: ANSI /ROHVA 1-2011: American National Standard for Recreational Off-Highway Vehicles and the ANSI/OPEI B71.9-2012: American National Standard for Multipurpose Off-Highway Utility Vehicles. All relevant vehicles were checked for compliance with the respective standard. The difference between ANSI /ROHVA 1-2011 and ANSI/OPEI B71.9-2012 in terms of which SSV vehicle any respective standard applies to appears vague.

The proposed consumer Star Rating system presented in this report provides a rapid means of applying a performance benchmark testing protocol that can significantly reduce rollover injury risk. Using the Star Rating system, manufacturers would be encouraged to compete with each other in order to make their products attractive to potential consumers and workplace plant managers wanting to purchase a safer workplace/farming vehicle and comply with workplace regulations.

Due to the inadequacies of the data collection for fatal Quad bike and SSV incidents in Australia, and especially the lack of detailed make, model and year (MMY) data, on-going validation of the proposed Star Rating system in regards to improved safety outcomes is required. Such validation has for example, been in done in the USA for New Car Assessment Program (NCAP) and for the Australasian New Car Assessment Program (ANCAP), and is part of the Used Car Safety Rating System (Newstead et al., 2014). Nevertheless the ratings do indicate that the Yamaha Rhino SSV received 3 Stars compared to the other SSVs which received 4 Stars. This confirms the US CPSC (2014) concerns regarding this vehicle's performance in real world reported rollover incidents.

CONCLUSION 3: There is a clear need to distinguish and treat differently, the safety requirements for Quad bikes used in the workplace/farms compared with those for recreational use due to different usage requirements. However, there is a common need for improved stability, dynamic handling and rollover crashworthiness safety for both workplace and recreational Quad bike usage.

It is important that there is a distinction made between Quad bikes used in the workplace and Quad bikes used for recreational purposes. The focus of the Quad Bike Performance Project test program and all reports generated is on the workplace environment. Hence, any recommendations for improvements to Quad bike safety are presented with that perspective.

It needs to be recognised that the use of Quad bikes is different in the workplace environment compared to recreational usage. The study of the Coronial files has revealed that farming related fatalities usually occur as a result of a low speed rollover where the dominant injury mechanism is a chest injury and/or asphyxiation resulting from being pinned by the vehicle. The recreational fatalities are more consistent with those commonly seen in motorcycle related fatalities where crashes occur at higher speeds and injury outcomes are usually to multiple body regions, i.e. head, chest and limbs.

Quad bikes are defined by the Industry as a high mobility vehicle, in the same class as motorcycles albeit the injury outcomes are different to the workplace.⁹ Such specialist vehicles require specialist rider training, and, compared with SSVs are significantly dependent on rider skill to avoid rollover and other incidents, and personal protective equipment (and separation from the vehicle) to reduce injury risk. This fundamental characteristic of Quad bikes has been under-recognised in their use in the workplace, and further increases rollover risk where rider attention becomes necessarily divided between work tasks and 'Active Riding' demands.

In many cases vehicles which are less demanding of rider/driver skill, and have larger safety margins in terms of rollover resistance, such as the higher Star Rated SSVs would be more appropriate for the workplace. In contrast, for Quad bikes in recreational use, rider's task demands are not divided and can remain focussed on the 'Active Riding' task.

It is also important to note that all stakeholders do not need to 'reinvent the wheel'. This report has called on and applies decades of understanding from road safety concerning vehicle stability, handling and crashworthiness advances, driver training, and appropriate environment in regards to compatibility between the vehicle used that is 'fit-for-purpose', the task demands, and the terrain it will be used to travel over.

The distinction between workplace use of Quad bikes and recreational use of Quad bikes, lies at the heart of the different approaches required for risk mitigation.⁹

Quad bikes used in the workplace should be treated similarly to other mobile plant and equipment in the workplace that is subject to appropriate risk assessment, Fitness For Purpose criteria, and driver training and validation of appropriate skill levels. However, it

needs to be emphasised that while the Authors of this report support administrative controls as one of the components of a larger holistic 'Vision Zero' criterion (deaths or serious injuries in the workplace that results in a permanent disability are not acceptable), increasing rollover resistance and enhancing rollover crashworthiness design, while still maintaining the operational capabilities of the vehicles, should be one of the first components considered in the hierarchy of controls for managing workplace risks.⁸

In contrast, use of high mobility vehicles in a recreational setting, leaves a large degree of discretion and risk taking to the user, as with motorcycles, bicycles, and other vehicle types. For Quad bikes this means that adult sized vehicles should only be used by properly trained 16 year or older rider, and with no passengers permitted, unless the Quad bike has been specifically designed and manufactured for such use.

Other vehicle types are becoming increasingly available on the market that may provide a safer alternative to Quad bikes style vehicles for recreation use, which incorporate a single bucket seat (rather than saddle style seating) full ROPS and seatbelts, and an alternative driving style (e.g. the Polaris Sportman Ace²⁵).

CONCLUSION 4: The findings support the view that multiple controls need to be applied, with a hierarchy based approach. Vehicles should first be selected on a 'Fit For Purpose' criterion, to ensure that the correct vehicle is chosen for the work task.

It is important that regulators and safety stakeholders maintain the perspective that preventing rollover injuries and fatalities is not simply about rollover protective systems (ROPS) or Operator Protective Devices (OPDs). They are only a component of the solution. Fitting a ROPS/OPD will not reduce the number of rollovers. On the contrary, if the ROPS or OPD is badly designed it could increase the vehicle's rollover propensity as was demonstrated in the case of the Quick-fix OPD (see Part 1: Static Stability Test Results) and possibly increase injuries. This is particularly so if ROPS are installed with seat belts and the riders do not fasten the seat belts.

Preventing the rollover occurring in the first place is critical. ROPS/OPDs should be viewed as a passive safety mitigation strategy for reducing rollover related injuries and fatalities. Thus static stability and dynamic handling (preventative) was rated on a 2 to 1 ratio compared to rollover crashworthiness (cure).

Workplace regulators and safety stakeholders need to encourage selection of vehicles that are on a 'Fit For Purpose' criterion, where the selection criterion is broadened over a uniform safety perspective for all vehicle types used in the farm environment, which may even include commercial road vehicles (utility and 4WD drive/ SUVs). It is the safety

²⁵ <http://www.polaris.com/en-au/atv-quad/sportsman/sportsman-ace/specifications>. This was not tested or rated under this project, as it only became available late in the project. It is recommended that such testing be undertaken.

performance for a given farming task that is important and thus was the focus of this study, not the vehicle type. The Star Rating system reflects that perspective.

Analysis of the Coronial fatality cases indicates that workplace related incidents tend to happen at low speed involving a rollover entrapment whereas recreational incidents appear to be happening at higher speeds with a greater involvement of ejection and impact events. Hence, any improvements to the vehicle that assists with reducing the propensity of a rollover occurring in the first place, and then providing rollover crashworthiness protection to the rider, will likely reduce the number of workplace fatalities and serious injuries.

CONCLUSION 5: Long term, effective improvement in Quad bike/ SSV safety requires a Vision Zero 'Safe System Approach' (safer vehicles, safer environment, safer people where deaths or serious injuries in the workplace that results in a permanent disability are not acceptable). That is – a multifaceted holistic approach to safety.

A Safe System Approach (safer vehicles, safer people, safer environment) as a Vision Zero based paradigm (deaths or serious injuries in the workplace injury that results in a permanent disability are not acceptable) underpins any proposed countermeasures to reduce serious injuries resulting from farming workplace rollovers. In other words, a holistic, multifaceted approach to safety needs to be implemented. Quad bikes are more susceptible to rollover than SSVs in low speed events typical of the workplace environment. The rollover resistance of Quad-bikes when loaded up to the manufacturer's recommended maximum load capacity, is low and leaves very little margin for error (safety factor) in terms of negotiating rough, uneven, bumpy, rocky, rutted, inclined terrain or when turning even at low speeds. This risk is compounded by the need for an Active Riding style requiring a high level of rider skill and attention.

The SSVs tested, in a range of driver and load configurations have, with some exceptions, a greater level of inherent stability and rollover resistance and more predictable handling and greater margins for error (safety factor). They also have rollover crashworthiness protection in the form of ROPS and seat belts. This places occupants generally at less risk of a rollover occurring, and less potential risk of injury in roll over and other crash events. This makes SSV's more compatible with use in farming workplaces. However, this only applies to well-designed SSV's that comply with the United States (US) ANSI/ROHVA 1-2011 (American National Standard for Recreational Off-Highway Vehicles) standard and provide good occupant containment in rollovers. US experience shows that at least three point seat belts (as opposed to inferior 2 point lap belts) must be worn in these vehicles (note the Tomcar has a 4 point harness which offers superior restraint compare to a 2 point seat belt).

The Star Rating in Figure 19 shows the SSVs rate at 4 Stars (Tomcar TM2, John Deer XUV825i, Honda Big Red MUV700 and Kubota RTV500) with the exception of the Yamaha Rhino which rated at 3 Stars. The Authors rated the SSVs at least 20% to 34 % better (depending which SSV) than Quad bikes on overall performance in terms of their capability

of reducing potential rollover injury in a farming workplace environment given the same typical conditions of operation. The prototype Quad bike, which had its suspension and driveline system modified, was just short of four stars, indicating Quad bikes can be modified to provide improved rollover resistance and dynamic handling equivalent to SSVs. Importantly, the prototype quad bike does not require an Active Riding style to operate it safely, although Active Riding will improve the vehicle's safe operating envelope.

CONCLUSION 6: The rollover resistance of Quad bikes is typically low, and provides low margins of safety against rollover, particularly when compared with SSVs. Similarly the carrying of relatively small loads adversely affects the Quad bike's stability more than that of the SSVs.

CONCLUSION 7: Well-designed SSVs are likely to have higher rollover resistance, better handling and lower severe injury risk than Quad bikes when drivers and passengers wear (three point or harness) seat belts, helmets and use the other restraint systems (head and shoulder barriers) included on the vehicles. SSVs should also have a seat belt interlock system, i.e. the vehicle should be disabled or only travel at 10 km/h or less if seat belts are not locked in.⁴ This would similarly apply to a Quad bike should a design with a ROPS and seat belt become available in the future.

Lateral rollover appears to be the predominant rollover direction for Quad bikes based on the limited injury data available to date, and thus lateral stability is a relevant parameter for reduction of Quad bike rollover.

The rollover resistance of a vehicle as measured by the Tilt Table Ratios (TTRs), identified Quad bikes as having a low value, with TTRs of 0.46 to 0.6 with a rider (and lower still when loaded), and low compared to SSVs where the TTRs range from 0.65 to 0.96. Carrying a passenger on an adult Quad bike designed for a single user would reduce the TTR to very low, particularly hazardous, levels. These results indicated that if the Quad bikes tested were to be used to carry various loads such as hay bales, animals, liquids in tanks for spraying purposes or any loads, these should only operate on flat smooth terrain and low turning and operational speeds in comparison to any of the SSVs tested.

This suggests that such low lateral TTR values are likely to be, in many cases, incompatible with the working environment, e.g. steeper sloped terrains, in which such vehicles are being used on some types of farms, particularly for larger riders and full loads. That is, low lateral TTR values means these vehicles should be restricted for use on flat smooth terrains and possibly speed limited for safer operation.

In comparison, SSVs have a higher lateral TTR than work Quad bikes, some by up to 40% to 60%. In either the fully loaded or unloaded condition, the least stable SSV is more stable (i.e. has a higher TTR) than the highest stability work Quad bike.

Both forward and rear pitch stability is also higher for SSVs than Quad bikes.

CONCLUSION 8: Dynamic Handling. The dynamic handling tests were innovative and showed that, contrary to industry opinion, Quad bikes could be subjected to scientifically reliable, repeatable, and meaningful dynamic handling tests.

CONCLUSION 9: Dynamic Handling. In contrast to Quad bikes, SSVs generally had more forgiving handling and higher stability characteristics (i.e. higher resistance to rollover), and were less reliant on the operator's vehicle handling skills. The performance of the prototype vehicle indicates Quad bikes can reach the same level of forgiving handling and higher stability characteristics as SSVs.

For the Quad bikes the measured minimum limit of lateral acceleration at tip up was in the range of 0.36g to 0.55g, and was less than each Quad bike's TTR value. The circle tests validated that the tilt-table static stability TTR value provides a valid measure of the lateral stability (i.e. level of rollover resistance) of Quad bikes.

All the Quad bikes' limit of lateral acceleration occurs by tipping up onto two wheels, which unless able to be counteracted by the rider, is a precursor to rollover or loss of control – that is a loss of stability.

For the SSVs these showed higher lateral stability than the Quad bikes, and those with an open rear differential did not tip up in these tests, i.e. when the inside rear wheel lifted, drive would transfer to the free wheel and it would spin up, causing a slight loss of vehicle speed and then the wheel would return to the ground.

The results overall obtained show that most Quad bikes tested for this program have an oversteer characteristic, which is not a favourable characteristics for most rider situations.

In order to handle well (consistently and safely) and reduce the risk of a loss of control crash occurring, a Quad bike or Side by Side, like any other self-propelled vehicle, should have a slight understeer characteristic when excited between 0.1 and 0.5 g lateral acceleration.

The 'bump tests' identified, possibly for the first time, a significant mechanism where riders on some Quad bikes may have lost control while traversing moderately sized bumps (similar to half-buried logs, drainage or irrigation pipes, small mounds, furrows, rocks, rabbit holes, etc.), which could have led to a rollover and resulted in their being pinned by the Quad bike as was observed in a large number of fatality cases analysed by the Authors. Where the rider and Quad bike is displaced excessively laterally whilst traversing a 'bump', the rider can pull on the handle bar, further exacerbating the turn of the Quad bike leading to rollover. All of the SSVs traversed the bump satisfactorily, with low level of rider or vehicle perturbation.

It was also noted in the Coronial farm related fatalities, where riders were pinned by the vehicle as a result of a rollover, that double the number of vehicle's laterally rolled left (anticlockwise looking forward while seated on the vehicle) as opposed to laterally rolling to the right side. The vehicle throttle is located on the right side and it appears that this may be influencing which side the vehicle rolls over when it becomes unstable. It is postulated that the rollover is precipitated further as a result of the rider not only pulling on the handle bar

but also at the same time inadvertently applying more throttle with their thumb. This increased throttle again further exacerbates the turn of the Quad bike leading to rollover onto its left side, i.e. in some cases the rider could have inadvertently pressed the thumb accelerator while trying to pull themselves back onto the Quad bike and accelerated the vehicle during this mechanism. This potential loss of control mechanism as observed in the bump tests is currently being explored by a postgraduate, David Hicks, as part of his PhD studies at TARS, UNSW.

Finally, it is worth noting that Industry based training courses and Quad bike owner's manuals recommend standing up with the rider's knees flexed while riding the machine over obstacles similar to that shown in Figure 12. By standing, balancing and centering over the vehicle seat can be maintained. Riding over an obstacle while seated on an Active Riding vehicle such as a Quad bike is a warned against behavior by Industry. However, this requirement by Industry further demonstrates the vulnerability of particular Quad bikes to such perturbations in terrain becoming unstable and rolling over. Moreover, from a human factors and ergonomics perspective, to require a rider to be continuously vigilant for such obstacles that may be camouflaged (e.g. long grass, water, etc.) within the terrain is an unrealistic expectation and unsafe requirement.

The Authors are strongly of the view that Quad bikes need to be designed to be more human error tolerant such that they can traverse terrain with moderate obstacles without requiring Active Riding and continual vigilance (which is from an ergonomics perspective unrealistic and hence unsafe). This is a much safer option than placing blame on riders for performing 'warned against behaviour'.

Hence, the introduction of the bump test to highlight the vehicle's low rider 'warned against behaviour' tolerance and the need to improve Quad bikes' stability.

CONCLUSION 10: Crashworthiness. Quad bikes without a Rollover Protection System (ROPS) have a limited ability to prevent severe injury risk in either low or high speed rollovers, although this also applies to poorly designed SSVs with substandard ROPS and inadequate seatbelts and interlocks, and poor containment to prevent partial ejection.

In regard to severe or fatal injury risk in Quad bikes, it needs to be recognised that, from anecdotal evidence, while many rollovers occur in Quad bike usage, in a high percentage of these cases no injury or only minor injury occurs. This is partly a result of Quad bike design, but also a matter of 'luck' in how the vehicle rolls, and where the occupant is positioned and also a function of the fitness and reflexes of the rider. However, the end result becomes a high number of fatalities, on average about 15 per annum in Australia²⁶, and an estimated 1,400 hospital presentations (from minor to serious injury) per annum.

²⁶ Though on an exposure basis this is equivalent to around 0.6 fatalities per 10,000 Quad bikes. This is greater than the equivalent rate for motor vehicles of around 0.47 per 10,000 vehicles in Australia (BITRE, 2014).

From the testing undertaken, it became obvious to the Authors that the term “*Crashworthy Quad bike*” was essentially an “*oxymoron*”²⁷. At this point in time it appears that it is not practical to design a Quad-bike where a rider can actively ride and at the same time be fully protected by a ROPS and restraint system. However, there is a long history of established evidence of how to protect an occupant seated in a vehicle that is subjected to a rollover crash. Crush protection and effective containment is at the heart of a good design. Improved protection in high speed rollovers for Quad bikes requires further investigation but was not part of the project scope.

Good containment requires that a person or head or limbs cannot be fully or partially ejected²⁸ (preventing ground contact or crushing), and that contacts within the vehicle as the vehicle rolls are non-injurious.

For Quad bikes, OPDs do not satisfy the fundamental crashworthiness criteria for rollover, i.e. containment and crush protection. OPDs may improve rollover crash survivability - as has been demonstrated in the two post ROPS program in the case of tractors (Day & Rechnitzer, 1999; Scott et al, 2002; Franklin et al, 2005), but not comprehensively. A well designed SSV with a ROPS and appropriate seatbelt restraint (3 point or harness) and lateral restraint (containment) can provide good protection in the rollover crashes that typify farm rollover crashes as identified in Coronial data.

Critical to occupant protection for SSVs is the wearing of the restraint to prevent ejection during the crash. Hence, emphasis is placed in the Star Rating process by means of awarding points (along with additional bonus points) to vehicles that had as a minimum a 3 point or harness (4 point or 5 point) seat belt and warned or ensured (interlock) drivers/riders/occupants wear a seat belt.

In regard to mechanical asphyxia risk, McIntosh and Patton (2014c) identified that around a 50 kg load applied for 10 minutes to the chest will asphyxiate a person. Measurements of ground contact forces were carried out to determine the load distribution for a typical work farm Quad bike, in this instance the Honda TRX500, and what potential load could be expected to transfer to the rider if it rolled onto and stayed on them.

When the Quad bike was rolled 90°, only in one of the four contact points (left front plastic wheel guard) was the load less than 50 kg. The contact loads were typically around 30 to 40 kg heavier on the other contact points. The Quad bike pinning a rider on either the left or right side is the dominant mechanism that traps the rider (20 (37%) from 54 cases).

²⁷ *Oxymoron* - a phrase in which two words of contradictory meaning are used together. Encarta English dictionary.

²⁸ Containment usually requires a strong roof structure (or ROPS), side doors or side bolsters, security safety side glazing or a restraining mesh. The AINSI/ROHVA 1-2011 standard for SSVs provides containment and ROPS criteria and tests.

When inverted the vehicle had ground contact points at the front of the vehicle, typically the handlebars or headlight shroud, and a single point at the rear of the vehicle, either the OPD if fitted or the rear load rack when the OPD was not fitted. Typically a large portion of the vehicle mass was applied through the ground contact points at the front of the vehicle. Without an OPD fitted 75% of the vehicle mass was applied to the ground through the two handlebars with only 25% applied through the rear load rack. However none of the loads were less than 50 kg. The Quad bike pinning a rider while in the inverted position was noted in 10 (19%) out of 54 workplace fatalities analysed by the Authors.

With an OPD fitted and the vehicle inverted the proportion of load applied through the rear vehicle contact point reduced further. The Lifeguard applied 16% of the load (47.5 kg) with the handlebars and front load rack applying the remaining load. The Quadbar applied less than 10% of the load (27 kg) with the headlight shroud at the front of the Quad bike applying more than 90% of the load at a single contact point (i.e. 274kg). However, when the vehicle (with an OPD fitted) was tilted to one side and it settled in a stable position, the load applied by the OPD contact point at the rear of the vehicle accounted for approximately one third of the vehicle's total mass for both OPDs (i.e., 114kg for the Lifeguard and 90kg for the Quadbar). In this configuration all of the contact loads were over the 50 kg limit criterion for mechanical asphyxia if the McIntosh and Patton (2014c) criterion is used.

CONCLUSION 11: Operator Protection Devices (OPDs). The static stability and dynamic handling tests identified that the Quadbar and Lifeguard (Figure 3) were not detrimental while a third (Quickfix) was found to be detrimental to the stability or handling of the Quad bikes.

CONCLUSION 12: OPDs. In regard to injury prevention in rollovers for the workplace environment, the two OPDs (Quadbar and Lifeguard) are likely to be beneficial in terms of severe injury and pinned prevention in some low speed rollovers typical of farm incidents. They do not reduce the incidents of rollover. In some specific cases injury risk could be increased although there is currently no real world recorded evidence of this. The findings support the view that multiple controls need to be applied. Of course there is scope for improvements to OPD designs in future.

Fitting an OPD will not reduce the number of rollover incidents. In approximately 67% of workplaces fatalities the rider was pinned, and in the majority of these the Quad bike pinned the rider under its side. The Authors estimate in approximately half of the pinned fatality cases an OPD would not have been effective.

For Quad bikes, OPDs do not satisfy the fundamental crashworthiness criteria for rollover, i.e. containment and crush protection. Nevertheless, OPDs can improve rollover crash survivability in some cases, as has been demonstrated in the two-post ROPS program in the case of tractors, but not comprehensively. A well designed SSV with a ROPS and appropriate

seatbelts (3 point or harness) with good occupant containment can provide good protection in the rollover crashes that typify farm rollover crashes as identified in Coronial data.

The Authors have received questions from Industry regarding why Quad bikes and SSVs are being assessed together and why they have not been assessed as separate vehicle groups, i.e. present a Star Rating for the Quad bikes separate to a rating for the SSVs. The Authors view this argument as fallacious. The purpose of completing a farming task in a safe manner should be the governing criterion for designing and indeed Star Rating which vehicle provides safe mobility in a farming work environment. This is in agreement with the Work Health and Safety Regulations that increasing rollover resistance and enhancing rollover crashworthiness design should be one of the first components within the hierarchy of controls for managing risks within a Safe System Approach in the workplace.⁸

The vehicle needs to be chosen from a 'Fitness For Purpose' perspective, i.e. which vehicle provides the greatest rollover resistance and also offers the best protection to a farm worker in the event the vehicle rolls over, i.e. the vehicle with the best rollover crashworthiness. This being the case, categorising and rating Quad bikes separately to SSVs would have provided little contrast and thus information to consumers regarding which vehicle is 'Fit For Purpose' for safe farm work. It is clear from the numerous tests carried out that a Quad bike, even with an OPD fitted, is greatly inferior in terms of rollover prevention and crashworthiness to the better designed SSV as rated here.

FCAI's concerns and resistance to fitting OPDs have some potential validity, for example regarding forward pitch re the Quadbar could potentially strike the rider in the head, back of the neck or spine, and re the Lifeguard in the rear pitch test entrapping the rider within the hoop.²⁹ Improvements to the design of these OPDs are still required.

The Quickfix unit being heavier (30kg) and higher, has a more pronounced effect on stability, reducing it, for example by about 11% laterally and 14% in forward pitch. Moreover the Quickfix unit restricts Active Riding. Because of the stability and functionality shortcomings, the Quickfix unit is not recommended for fitment to any Quad bike.

For recreational use, OPDs may not be effective compared with the workplace environment due to the generally higher speed of these incidents, and the fact they may inhibit separation, the main method used in motorcycling to minimise injury risk in a crash. Grzebieta and Achilles (2007) have indicated that in high speed crashes the Quadbar was found to be ineffective based on computer simulations of selected fatality cases reported in the United Kingdom and elsewhere.

It is clear that systematic evaluation and monitoring of the performance of OPDs in the field is required to identify both benefits and hazards. The rollover testing carried out for this project with OPDs, highlighted the stochastic 'hit and miss' nature of severe injury risk and

²⁹ See Part 3: Rollover Crashworthiness Test Results, *Figure 9* bottom row frames and *Figure 11 a*).

the large range of possible rollover permutations with Quad bikes and OPDs, and therefore the inherent inadequacy of such evaluation through testing or indeed computer simulation.

CONCLUSION 13: OPDs

In the order of effectiveness phasing out of Quad bikes and replacing with well-designed SSVs is likely to be superior to reliance on fitment of OPDs for risk mitigation. In the interim, for low speed workplace environments OPDs may be beneficial overall, but may also prove hazardous in some crash circumstances. However, any Australian real world case demonstrating that an OPD has been causal to an injury has yet to be identified. Moreover, fitment of these devices needs careful monitoring and evaluation by regulators to ensure that any possible adverse outcomes of OPDs are promptly identified and publicised. This is not to suggest that significant improvements to the rollover crashworthiness effectiveness cannot be achieved for both Quad bikes with OPDs and SSVs in the future.

In terms of the existing fleet, the Authors recommend regulators and safety stakeholders encourage current Quad bike users in the workplace to upgrade their vehicles to a well-designed, higher rated SSV.

From a rollover risk viewpoint in a workplace environment, particularly if loads are also being carried, based on the test results, SSVs in general provide a higher rollover resistance than Quad bikes. Loaded Quad bikes have a relatively low TTR and have a higher rollover risk when overloaded, i.e. carrying an additional passenger or spray tanks that elevate the vehicles centre of gravity.

Retrofitting an OPD has been encouraged by a number of Quad bike safety stakeholders and is currently being considered by regulators. The rollover crash tests with the Honda TRX500 indicate that such devices do provide some relief in terms of survivability (crawl out) space under certain rollover circumstances. The baseline rollover crash tests clearly showed how the full weight of the Quad bike could rest on top of the rider in lateral, rearward and forward pitch rolls whereas when the vehicle was fitted with an OPD the vehicle's full weight did not load or rest on the rider.

However, manufacturers have highlighted that in some scenarios (see Part 3: Rollover Crashworthiness Test Results) the OPD could exacerbate the injury. The rollover crashworthiness tests did highlight a potential issue with the Quadbar in a forward pitch roll and for the Lifeguard in a rearward pitch roll.²⁹ Moreover, based on computer simulations by Munoz, et al. (2007 and 2012) where they stated "*for the population of overturns, the Quadbar would cause approximately as many injuries and fatalities as it would prevent*", i.e. Industry's hypothesis that OPDs are likely to do as much harm as good thus simply substituting one injury mechanism for another, and therefore continue to oppose OPDs.

To date there have not been any reports of a Quadbar or a Lifeguard having caused an injury whereas there have been anecdotal reports indicating the OPD likely saved a rider from

injury. The Authors after reviewing the 37 cases (from 54 workplace deaths: 53 farming and 1 forestry) where a rider has been pinned, identified that fitment of an OPD could have potentially assisted in reducing the rider's injuries or being asphyxiated in around half of these incidents. There were a number of rollover crashes where the OPD would not have assisted the rider. What is not currently knowable from the available data or analyses is how many, if any, non-serious injury Quad bike rollovers would have become injurious had an OPD been fitted.

Taking into consideration

- the observation that Quad bike overturns in the workplace environment typically occur at low speeds,
- the 'survivability space' (crawl out space or clearance) observational results from the limited testing described in Part 3 Rollover Crashworthiness report,
- that fitment of the Quadbar or Lifeguard OPD does not adversely affect static stability or dynamic handling,
- the anecdotal positive evidence of the Quadbar's performance in the field concerning real world rollover incidents with no incidents reported of adverse effects,
- the evidence from the tractor two post ROPS program which has been beneficial to date in reducing tractor rollover related fatalities,

the Authors have concluded, on balance, that the addition of an OPD will likely result in a net benefit in terms of reducing harm to workplace Quad bike riders involved in a rollover crash.

This is on the condition that improved, more in-depth and uniform Quad bike and SSV accident data collection forms and procedures be put in place at state and federal levels, to enable monitoring of the relevant details of Quad bike and SSV incidents, including OPD and ROPS/ seat belt effects (both positive and negative).

In terms of higher speed activity commonly encountered in recreational activities, one of the Authors has shown through computer modelling that fitment of an OPD would likely not provide any benefit (Grzebieta and Achilles, 2007). To date around 3,000 Quadbars have been fitted to Quad bikes. This is only around 1% of vehicles currently in service and thus any injury incident data may not yield any statistical significance if assessed.

CONCLUSION 14: Quad bike designs can be improved for increased stability and dynamic handling. Quad bike track width can be increased and their driveline and suspension systems modified to significantly improve rollover resistance and handling. Such changes are realistic and practical, as demonstrated, for example, in the testing of the prototype Quad bike and by the US CPSC regarding the Yamaha Rhino repair program.³

In order to assess if Quad bike stability and dynamic handling could be improved, the Authors suggested Dr. David Renfroe from Engineering Institute Consultants design a

prototype Quad bike vehicle which incorporated all of the his recommended design features that he indicated would improve a Quad bike's static stability and dynamic handling. The main reason for testing this prototype Quad bike was to assess if indeed the static stability and dynamic handling characteristics could be modified so that they provide increased rollover resistance and improved dynamic handling and thus require less rider skill, and are more human error tolerant for the farm environment.

Track width is a critical parameter that affects the stability of the Quad bikes. The prototype Quad bike's track width was thus increased (around 150mm either side compared to the Honda TRX700XX, for example). The suspension was of an independent type and the shock absorber damping and springs were tuned so as to result in an understeer characteristic when the differential was switched to an open status.

These modifications to the prototype resulted in it having higher rollover resistance (high lateral TTR values) and very good dynamic handling. Importantly, the prototype Quad bike offered similar operating characteristics to the SSVs without Active Riding, however Active Riding can be used to extend the vehicle's safe performance envelope. Moreover, in regards to retrofitting of suspension systems, the results of the prototype³⁰ vehicle demonstrates that existing vehicles in the field could potentially be significantly improved in terms of reducing their propensity to rollover. The issue that arises is whether retrofitting vehicles to improve stability and dynamic handling is feasible and cost effective. In regards to SSVs, the US CPSC (2014) report discusses the Yamaha Rhino repair program presenting evidence of how, after improvements to lateral stability and dynamic handling, reported incidents reduced.

CONCLUSION 15: Data collection and recording, and access to data of Quad bike and SSV vehicle incidents at all levels (including fatalities) in the agricultural sector and workplace generally is inadequate, and has been a key obstacle to date in advancing safety of such vehicles in workplace and agricultural settings.

While the Project team has been most appreciative of the support it has received from various Coroners offices around Australia, the NCIS and from hospitals and other data sources, it is also apparent that such data collection is quite inadequate in many areas.

In some Coronal jurisdictions (Western Australia and the Northern Territory) access to fatal cases was restricted – down to having to make hand written notes from the file by the research team with no copying of files or photos permitted. The Authors recommend that this process be reviewed as it severely limits injury prevention investigation, analysis and recommendations.

³⁰ The Authors note that whilst the prototype Quad bike has been tested under the ATVAP program, further independent rider/ user evaluation is still required if and when a production model is released by the manufacturer.

In regard to the hospital, workplace and other data collection systems, these lack a co-ordinated systematic data set which is able to provide the necessary incident details, and vehicle make, and vehicle model year (MMY) data for the Quad bike and SSV, for research and Star Rating purposes.

CONCLUSION 16: The handling characteristics and operating environment of Quad bikes and SSVs are sufficiently different from other licensed motor vehicles such as motorbikes, cars or trucks, that vehicle specific basic training and instruction is required for these vehicle types by specialist accredited instructors. This type of training and instruction is equivalent to what is required when first beginning to operate any type of mobile plant. It is not to be confused with advanced driver training. Other specialist training already occurs in other aspects of farming, such as accreditation for chemical and pesticide use.

CONCLUSION 17: The fatal incidents involving children operating adult Quad bikes and the inability of children to properly handle adult Quad bikes, identifies that children under 16 should not operate adult-sized Quad bikes.

CONCLUSION 18: Incidents involving child fatalities and serious injuries indicate that Quad bikes are not an appropriate vehicle for the transportation of children on farms or recreationally. SSVs (with appropriate child restraints fitted) could be considered as an alternative vehicle. Guidelines for age appropriate standard-compliant child restraint or similar to be used in SSVs needs to be developed.

CONCLUSION 19: Active Riding and rider separation are not considered reliable rollover risk reduction strategies for Quad bikes in the work/ farm setting.

10. RECOMMENDATIONS

The use of a Star Rating system to inform consumers has been widely used and accepted by the general public, stakeholders and much of Industry. Examples include star ratings for white goods product energy efficiency, water efficiency (dishwashers, washing machines, etc.), consumer financial products, and for vehicles the very successful Australasian New Car Assessment Program (ANCAP), e.g. stars on cars for vehicle safety. Indeed, ANCAP has been a catalyst for and helped promote large technological safety advances that have delivered major safety benefits in terms of reduced community trauma in the case of road vehicles.

It is hoped that ATVAP, if adopted, would provide similar benefits for consumers and workplace plant managers and plant controllers. The objective would be to introduce a robust, test based rating system, in order to provide workplace and consumer based incentives for informed, safer and appropriate vehicle purchase (highlighting 'Fit For Purpose' criteria), and at the same time generate corresponding incentives and competition amongst the Quad bike and Side by Side Vehicle (SSV) Industry for improved, safer designs and models.

Ideally the ATVAP Rating system would sit within ANCAP to provide consumers with the maximum benefits when considering Quad bikes and SSVs for the workplace and elsewhere.

Experience from NCAP has shown that it cannot not be taken as a given that farmers will recognise safety assessment and ratings for their equipment and even if they do will make an informed purchasing decision. Therefore there will be a strong requirement for an effective implementation strategy for ATVAP as well as learning from ANCAP of how this can be done successfully.

The Authors recommend that the following strategies should be considered, developed, and implemented as soon as practicable:

1. Require all Quad bike riders and SSV riders in the workplace or otherwise to receive vehicle specific basic training and instruction by specialist accredited instructors..
2. Mandate wearing a suitable standard-compliant helmet, that is comfortable for workplace use, yet offers protection against head impact and thermal loading. Industry should encourage the increase of helmet use.
3. No child under the age of 16 should be allowed to operate an adult Quad-bike. A separate study should be undertaken in regards to safety performance and requirements of Quad bikes marketed for use by children under 16. Industry should provide this advice.
4. Where children are carried as passengers in SSVs, an age appropriate standard-compliant child restraint or similar to that used for passenger vehicles is likely to be required, for the same reasons that current adult three point restraints in road vehicles are not appropriate for children. This requirement needs to be investigated. Guidelines for age appropriate standard-compliant child restraint or similar to be used in SSVs needs to be developed.
5. Farmers and the general community should be informed through media and education programs that carrying a pillion (including a child) and elevated loads (e.g. spray tanks) on single rider Quad bikes can be particularly hazardous in terms of considerably reducing the Quad bike's rollover resistance to dangerously unstable levels as well as negatively impacting the rider's control of the vehicle. Similarly, farmers and the general community should be informed the carrying of relatively small loads adversely affects the Quad bikes stability more that of the SSVs. In addition, a targeted program through rural schools and preschools similar to pool safety and general road safety program could be adopted.
6. Suppliers of aftermarket attachments for Quad bikes and SSVs should assess the effect of their products on the static stability, dynamic handling and crashworthiness of these vehicles and make this information available to prospective purchasers, possibly via a sticker attached to the product.
7. Industry recognise that the majority of farmers killed over the past decade are older riders who in all likelihood will not ride Quad bikes in an Active Rider as recommended by manufacturers and therefore the industry recommend alternate vehicles for older

riders. However, it is noted that the Authors do not accept Active Riding as an effective and reliable risk control measure.

8. Recognise that the current configuration Quad bikes are promoted by Industry as Active Riding machines and that riders should not use them if they are not trained, or the task does not allow active riding, etc. The Authors therefore recommend a new safety warning label on Quad bikes with a continuous specific communication campaign to support this:

WARNING for QUAD Bike Riders

THIS VEHICLE IS DESIGNED AND REQUIRES THE RIDER TO USE ACTIVE RIDING - IF YOU HAVE NOT BEEN TRAINED IN ACTIVE RIDING, DO NOT HAVE THE PHYSICAL CAPACITY OR CAN NOT APPLY ACTIVE RIDING WHEN YOU ARE RIDING, THEN DO NOT USE THIS VEHICLE. IT IS UNSAFE FOR YOU.

However, again it is noted that the Authors do not accept Active Riding as an effective and reliable risk control measure.

9. Considering that farmers often work alone in the field, development of a suitable Personal Locator Beacon (PLB), which ideally would activate automatically should a Quad bike roll over, should be developed or resourced from existing technology (e.g. from other industries such as mining) such that this would facilitate assistance as early as possible to a rider in distress.
10. Promote, implement and support the 'Australian Terrain Vehicle Assessment Program (ATVAP)' as a consumer guide for Quad bike and SSV buyers, that provides independent information about these new vehicles on the Australian market concerning their rollover resistance and rollover crashworthiness. The Authors recommend that the ATVAP rating should be listed at point of sale, a rating sticker on the vehicle, and ratings presented online as with the ANCAP Ratings. All relevant rating tables and graphs for static stability, dynamic handling and rollover crashworthiness should be included in any ATVAP rating literature or presentation.
11. Any SSV should not be sold in Australia unless it complies with the ANSI/ ROHVA 1-2011 Industry voluntary standard as a minimum, and upgraded as per the recommendations of this, the supporting Part 1 to Part 3 reports, and the US CPSC latest September 2014 recommendations for improved stability, handling and crashworthiness performance requirements.
12. Any Quad bike should not be sold in Australia unless it complies with the ANSI/SVIA 1-2010 Industry voluntary standard as a minimum, and upgraded as per the recommendations of this, and the supporting Part 1 and Part 2 reports for improved stability and handling performance requirements.

13. Evaluation. The Authors strongly recommend a thorough evaluation program be developed and implemented that examines and reviews the safety performance of Quads bikes which comply with ANSI/SVIA 1-2010 and the safety performance of SSVs which comply with the ANSI/ROHVA 1-2011 and ascertain what further safety improvements to these Industry voluntary standards are required, e.g. rollover crashworthiness. These results should be published.
14. Hold workshops in capital cities, major regional centres and agricultural shows to disseminate this project's findings and safety improvement strategies.
15. Industry consider the standard against which occupant containment and protection are evaluated against, and upgrade the ANSI/ROHVA 1-2011 to include a dynamic rollover crashworthiness test for Side by Side Vehicles for occupant containment and protection.
16. A self-assessment be carried out by farms/workplaces with sloped and/or rugged terrain access roads on farms and terrain to aid in the selection of a vehicle best suited to the task and workplace. Access roads on farms and terrain over which Quad bikes travel should be speed limited taking into consideration the vehicle's TTR and dynamic handling characteristics. Vehicle distributors should consider this information in making recommendations to prospective purchasers. A template should be developed that assists farmers with such assessments.
17. Identify, mark out and sign post using reliable low cost methods, workplace areas inappropriate or hazardous for Quad bikes to travel over. All users should be informed of no-go areas. A template should be developed that assists farmers with such assessments.
18. A co-ordinated Australia wide comprehensive data collection and reporting, of mobile farm equipment injury and fatal incidents, including explicit details of make, model, year (MMY) to enable on-going evaluation of safety performance be established.
19. Carry out Australia wide exposure surveys to better identify exposure variables for Quad bikes and SSVs to enable risk and Star safety ratings to be further developed for these vehicle types. Such exposure surveys would include MMY data, hours and time of use, kilometres travelled, terrain type, loads carried and attachment types, etc.
20. Engage with insurers, industry, suppliers, government and the community regarding economic factors that currently encourage or discourage (e.g. price) the purchase and operation of vehicles 'Fit For Purpose', and identify mechanisms to facilitate safer vehicle selection.
21. OPDs. A minimum of 4 stars rated vehicles should be considered in the first instance when purchasing new vehicles for the workplace. In the circumstances where Quad bikes have been assessed as acceptable in the workplace, new Quad bike purchases should be fitted with OPDs prior to sale, noting they are likely to offer a net safety benefit in slow speed crashes typical of most farm use.

22. OPDs. Wherever possible and practical, the replacement of existing Quad bikes with four star rated vehicles should be considered. Where it has been assessed that existing Quad bikes are still acceptable or cannot be replaced, then OPDs be retrofitted to existing on-farm Quad bikes noting they are likely to offer a net safety benefit in slow speed crashes typical of most farm use.
23. OPDs. In order to provide the ongoing monitoring of the effectiveness and safety of OPDs in a workplace application, a field based monitoring program should be established. Also there is a need to develop a more effective rollover crashworthiness test protocol for evaluation of OPD's for Quad bikes.
24. Quad bikes. Retrofit programs be considered that improve quad bike stability and dynamic handling characteristics to achieve at least a three star rating.

Signed:



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12. APPENDIX A: Project Reference Group and Quad Bike Performance Research Team

Quad Bike Performance Project Reference Group Members³¹

No.	Country	Project Reference Group Member	Position - Organisation
1.	AUS	Mr. Tony Williams	Director of Operations - WorkCover NSW
2.	AUS	Ms. Diane Vaughan	Project Officer - Industry Solutions Program, Strategic Specialist Services Group, OH&S Division, WorkCover NSW
3.	NZ	Dr. Dave Moore	Senior Lecturer - School of Engineering, Faculty of Design and Creative Technologies, Auckland University of Technology
4.	NZ	A/Prof Stephan Milosavljevic	Associate Professor - School of Physiotherapy, University of Otago
5.	USA	Prof Jim Helmkamp	Senior Epidemiologist - NIOSH Western States Office, Denver Federal Center
6.	USA	Prof Gordon Smith	Professor - Department of Epidemiology & Public Health University of Maryland School of Medicine
7.	AUS	Mr. Charlie Armstrong	Chair - National Farmers' Federation Workplace Relations Committee
8.	AUS	Mr. Robert McDonald Ms. Allison Crase-Markarian	Senior Manager - IAG Research (NRMA) Personal Assistant
9.	AUS	Mr. Dan Leavy	Manager - Safer Vehicles, NSW Centre for Road Safety
10.	AUS	Dr. Yossi Berger	National OHS Director - Australian Workers' Union
11.	AUS	A/Prof Tony Lower	Director - Australian Centre for Agricultural Health and Safety
12.	USA	Dr. John Zellner	Technical Director - Dynamic Research Institute
13.	AUS	Mr. Cameron Cuthill Mr. James Hurnell	Motorcycle Manager/Consulting - Federal Chamber of Automotive Industries
14.	AUS	Dr. Isabel Brouwer	Senior Forensic Pathologist - Department of Forensic Medicine
15.	AUS	Dr. John Crozier Dr. Danny Cass	Head Surgeon - Vascular Surgery, Liverpool Hospital Westmead Children's Hospital
16.	AUS	Mr. Steve Hutchison Ms. Jillian Hylton-Smith* Mr. Todd Owen	Australian Competition & Consumer Commission (ACCC) Deputy General Manager - Product Safety Personal Assistant Project Officer - Chemicals & Regulated Products, Product Safety,
17.	AUS	Mr. Neil Storey Ms. Leila Gato Mr. Peter Seal	Safe Work Australia Director - Plant and Structures Team, Work Health and Safety Assistant Director - Plant and Structures, Work Health and Safety
18.	AUS	Mr. Tony Hegarty	Executive Councillor - NSW Farmer's Association
19.	NZ	Mr. Al McCone	National Manager - Staff Relations & Training, Landcorp Farming
20.	Aus	Ms. Samantha Cockfield	Manager - Transport Accident Commission (TAC)
21.	USA	Dr. David Renfroe	Engineering Consultant - Engineering Institute
22.	USA	Dr. Chandra Thorbole	Adjunct Assistant Professor - Biomedical Engineering, University of Arkansas
23.	AUS	Mr. Ken Higgins	Chair – Australian Quad Distributors Association (AQDA)
24.	AUS	Mr. Bruce Gibson	Manager - Agriculture Prevention Strategy Division, WorkSafe Victoria

³¹ Affiliation at time of joining the Quad Bike Performance Reference Group

25.	NZ	Ms. Kelly Hanson-White	Senior Policy Advisor - Workplace Health & Safety, Labour and Commercial Environment, Ministry of Business, Innovation & Employment
26.	AUS	Mr. Richard Dawson	Assistant Director, WHS Design, Comcare
27.	AUS	Mr. Sam Doecke	Research Officer - Centre for Automotive Safety Research, University of Adelaide
28.	AUS	Dr. Daryl Wall	Director of Surgery - Princess Alexandra Hospital
29.	AUS	Lt Col Colin Blyth Lt Col Damien McLachlan Maj Bill Collins Lt Col Andrew Heron	Australian Defence Forces Deployable ATV requirements Technical aspects of all ATVs in defence Australian Defence Force
30.	AUS	Mr. Greg Vincent	Manager, Rural Unit, Workplace Health and Safety Queensland Department of Justice and Attorney-General
31.	AUS	Anant Bellary	Principal Engineer (Vehicle Standards & Regulation), Transport Regulation Branch, Customer Services, Safety and Regulation, Department of Transport and Main Roads

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³² Affiliation at time of joining Quad Bike Performance Research Team