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Novel Car Carrier design- Prevention of falls from heights

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ARTICLE OUTLINE

ABSTRACT

This article reports the details of a research on novel design in the field of semitrailer sector and discuss design by hazard prevention techniques. The novel design made addresses occupational health and safety (OHS) concerns of fall from heights. The research includes a detailed survey of national data sources to examine the fatalities caused due to fall from heights in car carriers. The study investigates OHS recommendations in Australia for semitrailer sector. Often injuries are caused due to drivers working above 1.5 meter height for loading, unloading of the cars, moving the decks up, down, strapping the cars, and slippery. The new design is developed using latest computer aided design and engineering (CAD, CAE), product data management (PDM), virtual design process (VDP). The new car carrier design excels in reducing the risks of injuries to drivers and new bench mark for OHS standards. The new design has all the decks operated with hydraulics and uses unique ratchet lock mechanism (fool proof design) and loading happens at a safe working height (below 1.5 meter). All the cars are strapped on the safe working height, and then car decks operated hydraulically to transfer them to the required position. This also includes the car on the prime mover, which shuttles across from one deck to other using hydraulic and rack- pinion mechanisms. The novel design car carrier solves the problem of falls from height; next step would be to transfer this technology across other similar effected sectors.

Key words— *ADR, Semitrailer, Car Carrier, OHS, WHS, fall from heights, Product Design, injuries.*

1 INTRODUCTION

Injury prevention is a component of public safety, and its goal is to reduce injuries by preventing accidents. In this research accidental injury prevention strategies were used in the design by hazard elimination. Historically the car carriers are strapped from 1.5 M above ground level. Car carrier was an identified industry where the driver climbed over 1.5 meter height during operations and is subject to risk of fall from heights. Hence this research was funded by group of industries and governing authorities to formulate the solution to injury prevention by hazard. While strapping the cars above 1.5 M ground level, drivers fall due to slippery or gaps on the decks. The new model designed will have automated decks to load the cars and strap on the safe heights, avoiding fatal falls from heights. Thus whole car carrier design is automated, minimizing manual handling to possible smallest proportion. This approach restrict driver climbing to maximum of 1.5 M above the ground, and avoids a risk of falling from heights above 1.5 meter. Thus few outlines were made in defining the objectives of the research:

- To study fall related data and compile to formulate the statistics useful to evaluate the problem definition
- To explore the existing heavy vehicle sector for the knowledge gaps and design failures related to the fall statistics. To study the existing occupation health and safety (OHS) recommendations in Australia for semitrailer sector. Study the earlier research on the industry to understand the design failures. Compile the statistical data to evaluate the need for new design

- To design and validate the new car carrier which addresses crucial safety issues of falls from height and avoid accidents caused by loading the cars above 1.5 meter ground level. Development of new innovative car carrier which will be bench mark on OHS standards.
- To develop a novel design concept and loading techniques by bench marking development trends. To enlarge existing knowledge, encourage the development of new techniques, adaptations of design to handle different configurations of vehicle models.
- To automate the handling of decks for more efficient loading, unloading and adapting the safer techniques to suit loading conditions, initiating new applications, and spotlighting future needs.
- Use of technologies to develop advanced car carrier by validating the design throughout by virtual design process (VDP), finite element analysis (FEA) techniques and prototyping.

2 LITERATURE REVIEW

2.1 Fall from heights

Road transport is the most viable solution for transportation in Australia. The main problem with rail sector in Australia is that three largest cities of Melbourne, Sydney and Brisbane, some 36% of the mainline track fails to meet basic fast freight train standards and thus people have to depend on the road transportation .Earlier research study done by David Gargett et al. indicates that trucking industry is favoured over rail (Table 1) by failing to internalize many costs that current pricing tends (1999).

<Please insert Table 1>

Transport research board (TRB 2002) data as in Table 2, indicating the estimated costs of each mode, how much they pay under the current price structure and the balance of external costs. This study indicated that road transport was the most viable.

<Please insert Table 2>

With this increased road transport the potential accident fatality rate increased over years. To evidence this Bureau of Transport and Regional Economics (BRTRE) report as per data in Fig. 1, portrays annual traffic fatality rates in various countries which varies from 2 to 20 annual deaths per 100,000 populations. Thus traffic crash injury in life time is between 2.25% to 22.5% as discussed in the report (BRTRE 2000).

<Please insert Fig.1>

BRTRE report revealed Australia total cost of road crashes and fatalities has been conservatively estimated at $15 billion (Australian dollars) during 1996 (BRTRE 2000). The fatalities and the serious injuries accounted for approximately 25000 (Table 3) numbers as reported in. This report also covered the safety data of OECD countries including Australia. In comparison to other nations Australia's heavy vehicle fatality rate per kilometer travelled is higher (Haworth *et al.* 2003).

<Please insert Table 3>

Researchers globally identified fall from heights as major concern among the fatal accidents. In this research fall related data was compiled to formulate the problem identification. Research done in Australia by WSV (Work safe Victoria 2005) related to fall from trucking industry, covered the study on semi trailers and sizeable proportion of fall related claims. From 2000 to 2005/6, over 10,000 workers suffered fall injuries serious enough to make a claim. As reported by work safe the period 1993 to 2005, injuries from falls were spread across industry as follows:

• Construction, manufacturing and community services each with 17 % of all falls injuries;

• Trade with 13.5 % of all falls injuries; and

• Transport/storage and communication each with 11.3 % of all fall related injuries.

It was concluded from the report that, successful management of work where there is a risk of a fall of more than two meters required the adoption of specific control measures.

Department of Health and Ageing (DOHA, 2003) in Australia identified injury prevention as one of five National Health Priority Areas (NHPA), since its recognition in 1986.

Risk due to fall from height and subsequent fatal injury is caused when working at an unprotected height of over 1.5 meters. The risks associated with accessing the deck of a car carrier above 1.5 meters high can be exacerbated by:

1. Slippery or potentially unstable surfaces
2. Sloping surfaces on which it is difficult to maintain balance
3. Close proximity to the unprotected edge, particularly when walking along the

side of cars loaded on the upper decks of a trailer.

4. Gaps between trailer components and between trailer and cab frame.

5. Workplace factors such as traffic conditions and the condition of the surrounding ground

6. Environmental factors, such as wind and rain

7. Difficulty with maintaining balance while attaching load restraints.

Numerous earlier researches studied, falls from height have focused on the casualty of accidents and attempted to isolate the risk factors that contribute to accident severity. Safety control is most important element of accident prevention (Navon R. and Kolton O. 2007). The injury related data for hospitals studied in 2002/03, revealed that the lack of clinical data in Australia due to absence of the specific coding (McKenzie *et al.* 2006).

Study previously done on fall from has suggested the use of personal fall restraint systems (Campion C. 2000). Use of the steps and grab-rails approach to safety that emphasizes optimal design of entry/exit aids, resulted in a substantial decrease in the estimated probability of a fall and corresponding potential injuries (Fathallah F. A. *et al.* 2000).

A research study done in Workplace Safety & Insurance Board (WSIB) database for the year 1997 Ontario, Canada was conducted to identify fall as the major contributors to the workers injuries (Jones D. and Switzer-McIntyre S. 2003).

Paper published in 1997 on U.S. motor carrier (trucking) industry studied the largest database of its kind with more than dozen companies, three thousand and fifty three (3,053) accidents reported, indicating 'slips and falls', followed by 'struck by' and 'overexertion' injuries were the accident types most frequently reported over two dozen trucking companies throughout the USA, during the three-year period of program implementation (Lin L. J. and Cohen H. H. 1997). Other industry surveys of trucking companies and truck drivers indicated the need of a research for injury prevention (Spielholz *et al.* 2008).

USA Army personnel were studied from1994 to 2002 with the focus to find out what caused the falls (Shuping E. *et al.* 2009). Study done in Denmark on fall from heights analyses studied accidents, and the major cause for the falls (Shibuya H. *et al.*). In Italy the study identified few men were elevated risks in all age groups and for all levels of injuries and among them were truck drivers (Bena *et al.* 2005). Research on unintentional injury in New Zealand (Feyer and Langley 2000) over the last decade recognises need for prevention and falls as one of the cause. Other injuries to truckers are caused by falls during the descent from the cab of the truck (Patenaude *et al.* 2001).

During industry survey many interviews were conducted, manager work safe Victoria was interviewed for the falls in auto hauler industry in Australia. According to WHS, livestock and the car carrier drivers are more inclined to falls than the cargo drivers. The auto haulers and live stocks are pretty much similar in terms of operations. However WHS recognised the need of research in these industries to keep them work safe and avoid fatal injuries. The risk of death or injury due to a fall from a truck or trailer exists and is foreseeable:

- 150 truck drivers a year in Victoria suffer a serious injury due to falling from trucks (Source: WSV& ABS).

• 17% of all the serious injuries reported by truck drivers annually. (Source: WSV& ABS).

• About 70% of injuries from falls from trucks occur after jumping down or falling from a truck in Victoria. (Source: WSV & ABS).

• Any Falls can kill or injure.

Falls from heights in all states and territories represent major contributions to workplace injury statistics and workers compensation claims, with 'falls from heights' from trucks representing a sizeable proportion of these claims.

The Australian National Coroners' data source (Driscoll *et al.* 2008) for fatal injuries and deaths resulting from workplace injuries on or between 1 July 2000 and 30 June 2002 shows that Seventy seven (37%) of the 210 identified workplace fatalities definitely or probably had design-related issues involved.

Truck driver is subject to stress and fatigue during the driving of semitrailer. Variations in driving-hours increases stress, affects other duties like loading, unloading the cars (Arnold *et al.* 1997, Dick *et al.* 2006). The changes in the allowable driving hours needs be evaluated as to reduce the risk of driver fatigue (Hanowski *et al.* 2009). The current car carriers are capable of carrying cars but the driver has to climb up more than 1.5 meters height to load and restrain the cars at the top deck levels. While loading sequence, driver climbing the carrier over 1.5 M high is at risk of fall from the heights and the fall from heights becomes even more risky if he is stressed during the climb. The resistance of various climbing surfaces and the fall from climbing is at becomes risk for the drivers (Miller J. M. *et al.* 1991, Schad 2000). Poor design contributes to considerable damage to the product and the industry

(Campion C. 2000).

<Please insert Fig.2>

Any fall can injure a person seriously, it can occur while working on top of the tray, trailer (Fig. 2), while climbing on or off the tray trailer, loading and unloading of the vehicle, or when cleaning the vehicles; Slips, trips or falls while moving about on the platform; crush injuries if load restraints fail, a vehicle moves or from hydraulic failures; Cuts or bruises from recoil of tie- downs; Other sprains from jumping off a trailer deck onto hard or uneven surfaces. Now with all of above reasons the problem is not limited to redesigning new concept for the new design. The other considerations like regulations, space constrain, mechanisms, and keeping all synchronized with new development is an issue. Following are few examples of the existing car carriers studied by work safe Victoria showing the falls from heights while restraining the cars above safe height of 1.5 M (Fig. 3). Fig. 4, shows some driver fall hazard examples collected by work safe, areas needs to addressed where there is a gap, overheads and wheel chocks which are unsafe for driver. The problem identification is the first and fore most process of the design phase and fall is identified as an issue in the sector.

<Please insert Fig.3>

<Please insert Fig.4>

2.2 Injury Analysis

Injury costs for worker falls is substantial and need for preventing these falls is essential (Bunn *et al.* 2007). The one of the cause of injury death in Victoria is motor vehicle accidents, where as falls are the leading cause of all non-fatal injury (Watson and Ozanne-Smith 2000). Minister responsible for the Transport Accident

Commission, Rob Hulls, said at the launch of a new road safety campaign that about 20 per cent of fatal crashes in Victoria involve fatigue, causing about 70 deaths and almost 500 serious injuries each year (Transport accident commission 31 August 2004). The earlier research data is gathered for all injury events related to fall, which was used in the research by McKenzie et al. for injury prevention initiatives (2006)

Defining the epidemiology of injuries and their outcomes, focusing on the identification of causal patterns and risk factors is an important step in injury prevention (Mackenzie E. J. 2000). Research done in Italy has identified that among men in some occupations truck drivers were elevated risks in all age groups and for all levels of injuries severity (Bena *et al.* 2005). Study was done in Sweden on occupational injury problem and recommends use of protective equipment in a vehicle and the use of safe vehicles (Bylund *et al.* 1997). Work health safety agency (WHSA), Canada, finds in its study the need of industry data based on compensation and recommends prevention programs to be designed (Choi *et al.* 1996). Research on US Army trucks revealed that three hazard scenarios were associated with back injuries among Army truck drivers research revealed falls major cause for accidents (Lincoln *et al.* 2004). Studies done in Newzeland gives directions for the future to reduce the injuries (Feyer and Langley 2000). In UK during 2003-04, 67 people killed by falls at work and there were 4,000 major injuries, making this the single biggest cause of workplace deaths across all industries (Hill A. 2005). In road transport falls from truck caused one death, 148 major and another 160 injuries which required the victim to be off work for more than three days. The study suggested that the reduction in driving hours reduces the hours of drive (Dick *et al.* 2006). There should be efforts in office-based counseling for unintentional injury prevention to drivers to reduce the fatalities(Gardner *et al.* 2007). To develop better prevention, clearer understanding for causes of these traumatic incidents measures fatality assessment and control evaluation methodology to nonfatal injuries is essential (Helmkamp J. C. and Lundstrom W. J. 2000). Study on drivers and the related environment with focus of injury prevention is another research topic to be considered. Literature review in this section identified that there is clear evidence that the injuries caused due to falls from heights is significant, and there is a need for research in the sector to prevent these injuries.

2.3 Car carrier industry

It is understood from the literature review that the falls have attracted more attention in the recent years and many researchers across globe identified this as one of the prime issue with the industry (1978, Lambert Bros 1978, Turnbull and Dawson 1997, 1999, Turnbull 2000, 2007, Barclay 2007). The research study in the past on car carrier covers more than just road transportation.

The research was done in past for shipping carrier, used to carry the motor vehicles across different nations using international deep-sea transport. Another research area is car carrier industry was with wheel-train, equipped with its own carrying cross-structures and the cars are loaded on the decks. In 1998, historical development on combined road-rail transport was studied, which discusses the importance of increase in the permissible length of semitrailer trucks and in the permissible total weights/axle loads of motor vehicles for deliveries in combined traffic (Mohr 1985). Union Pacific's new design used tough lightweight material and improved suspensions to protect new vehicles from damage before they get to the showroom (1990). During 1994/95, the Australian rail freight task was approximately 100 billion tonne kilometers (btkm) which included some 37 btkm for the haulage of iron ore in Western Australia, 28 btkm for coal haulage in Queensland and New South Wales and about 16 btkm for interstate rail freight (Laird 1998). The latest trends and technologies have made the market more competitive, an example was illustrated in the paper using German company, Deutsche Bahn AG (Held 2004). Use of composite materials for light weight and loading optimizations are some trends researched in the car carrier industry (LeMaster 1991, Agbegha G. Y. *et al.* 1998).

There has been some evidence of studies done in Australia on road transport designs covering trucks and bus designs (Clark B. 1978-04.). During the end of the 90's the study indicated that B doubles are generally as safe or safer than singles, even when specifically controlling for roadway, traffic, and environmental conditions (Jovanis Paul P. *et al.* 1989). Another study done on B Doubles by another industry also supported this and simulation of the B-Doubles dynamic behavior indicated that fears of adverse safety performance are groundless (Orford D. J. and McKay M. E. 1991).

TRL and Heriot-Watt University explored the government for allowing longer truck-trailer combinations for economic benefits, however the statistics collected from trials that fuel consumption per cubic meter of load is 9.46 percent better for an artic with a 16-meter semi-trailer and 15.66 percent (Dickson-Simpson J. 2007). Thus encouragement of long articulated lorries would enhance safety and accident prevention. A six-wheeler towing a dolly coupled to a 13.6-meter semitrailer is widely accepted in the Netherlands for its organizational flexibility, but there are handling shortcomings compared with a mid-steering B-train. These lorries would carry proportionally more weight, which give much better drive-wheels traction and good, arrow-like, straight-line stability, less affected by side-winds. The research revealed that the truck driver training is required through printed publications and video training to avoid accidents (Benekohal R. F. *et al.* 1995, McKnight A. J. and Bahouth G. T. 2008).

Different areas of semitrailer have been studied including FEA on king pins, maneuvers (Deligiannis V. *et al.* 2006, Zabel and Weyand 2008). Other areas of study in the sector includes design standards and guidelines for mounting steps and handhold/handrails in trucking industry and the study on the falls from the truck cabs and use of hand rails in cabs (Zwahlen Helmut T. *et al.* 1995, Patenaude *et al.* 2001). Research on balancing the loading aspect of the delivery problem using optimizing methods thus replacing the empirical methods (Agbegha G. Y. *et al.* 1998). Hirth & Khalil studied design related issues in the existing standards and guidelines for trucks and agricultural vehicles (2004).

The three modes of car carriers discussed which included, ship carrier, train carrier and road carriers. The literature review on shipping industry, train industry was done in the past but not extensive. The literature review identified that road carriers are least researched at this point in time. The research done in many countries is more diversified and includes studies on frames, finance, safety of drivers, vehicle dynamics, roll stability control and braking and other aspects related to drivers and drivers fatigue levels. The shipping carriers, train carriers also have done some studies on the light weight material and new design solutions. Though industry research lacked the data required in this field at this point in time, few of the major design practices were used were from the rail car carriers, decks shapes, ramps were used from the RORO ships (roll on roll off).

The literature review on falls from heights highlighted the importance and significance of research in car carrier sector. Research revealed that fall from height is a global issue and heavy haul sector contributes significantly to accidents caused. In Australia, road transport is used in all the major commercial capitals and the statistical studies shows increasing trends in the road transport. The injuries and the costs associated with injuries highlighted concludes that in spite of safe transport rules, Australia is spending more on the fatalities and the it stands third from top in the number of fatalities, for e.g. OECD reports. The cost and the fatalities need to be addressed by accident prevention and safe design practice in Australia. Current designs and the existing car carriers lack the safety by design and studies on safety by design are essential (Hirth and Khalil 2004). The cost incurred for workers compensation is substantial incase of accidents (McCall and Horwitz 2005). The driver fatigue and the existing design can contribute to fall when loading and unloading of the cars on the car carrier. The study done by work safe (Work safe Victoria 2005, Clarke R 2006) and national falls from the height heavy vehicle sector identifies the necessity of the research in the sector.

It was evident from the study done by NORTGC, OHS, and ABS data which identifies that driver climbing the height of 1.5 meter and above was under risk of fall from the heights. The problems occur, as the driver has to load the car above the permitted ground level. However this requirement of deterministic quality of the design solution makes it more critical. Falls from heights in all states and territories represent major contributions to workplace injury statistics and workers compensation claims. It was decided that the compliance program for the transport industry would focus on 'fall from Heights in the Heavy Vehicle Sector'. The gaps and deficiencies of OHS data in Australia (Mandryk et al. 2001) which may need further attention and proper research to collect and analyse the data. This research on car carrier was initiated as an action from all the government authorities, Toll logistics and JSS.

3 RESEARCH METHODS

Car carrier industry was researched by field studies at Toll premises. The video capturing of the loading, unloading sequence was analysed in methodological way (Fig. 2). The questionnaires to drivers, managers and work safe authorities helped in concluding the findings. Research led to explore more on old design issues, and collected different competitor's broachers, customer feedbacks, ADR and OHS guidelines. The interviews and the surveys defined the existing issues, in addition to the work done by work safe Victoria for falls from the heights. The competitor's data and third world information of the global leaders like Lohr and Rolfo helped in design conclusions and bench marking car carriers.

Following are the methods used in research (refer Table 4) of car carrier to conclude the findings.

1) **Site visits:** The car carrier was subjected to direct observation for the studying of the concepts. In this research site visits were made for studying existing car carriers

for loading unloading sequences. These studies were refined to formulate issues in the current designs. Study was done by video filming the operations of the drivers then the issues were highlighted using the designs and the video captures. The interviews done with customer (Tolls) (Chen *et al.* 2004) and drivers revealed the issues related to falls and need for resolution. Existing car carriers are video captured to analise step by step to there difficulties in loading-unloading of existing car carrier (Fig. 2), Tolls premises, Study on loading and unloading sequence of existing car carrier was conducted. The issues associated with the existing car carriers was analised by using video recording-and-playback systems (Bonneson and Fitts 1995). New design was constructed using virtual reality explained in the car carrier design.

2) **Questionnaire-based survey:** This method is written data from interviewees, or responses from tolls drivers for fatigues, car carrier related issues (Binder *et al.* 2008, Spielholz *et al.* 2008, Morad *et al.* 2009).

3) **Interview-based survey:** This communications to the other people in time zone is documented, normally unstructured interviews or meetings.

E.g.: Meeting manager Toll's logistics for interviewing at initial stages to identify the need of customers.

Interviewing of manager Work safe Victoria in identifying the falls as major issue and key finding was that livestock and car carrier sector drivers were subject to falls from heights.

4) **Secondary research and case studies:** This method is study of Journal Articles, books and other available resources for literature reviews and studying the competitor's developments and supplier's new advancement in the technology. Rather

than producing new data, this technique analysed the contents of existing documents. Studying existing car carrier designs, other existing data to formulate the solution for the design.

The data analised typically consisted of old work contents, split works, old data, layout and production information, presentation, thesis, journals etc. The interviews, surveys were analised, which indicated falls from the heights as one of the issue. The competitor's data and third world information of the global leaders like Lohr and Rolfo supported developmental activities. Drivers filling out the questionnaires or surveys was one of the method used to understand from there perspective. Requests were made to experienced people, drivers, managers, at Tolls, about their past, or manipulate things in their environment. The archival research of car carrier helped in using published information as the source of data in the study. These entire data surveys pin pointed lack of design safety in the existing car carriers.

<Please insert Table 4>

Following are few findings emerging from the study:

- Site visits identified access and egress during loading and unloading cars on trucks and trailers as a major hazard as it contributed towards falls from heights and falls at the same level. In addition poor systems for securing vehicles loaded above drivers cab.
- Drivers were required to stand on areas that were unprotected from the risk of falls while carrying out tasks associated with restraining or securing cars to the trailer or truck.

- Operators need to take into consideration access and egress to cars being transported when implementing control measures.
- Anecdotal evidence from drivers and observations of inspectors indicated a lack of adequate loading and unloading areas at a number of car dealers.
- Traffic management at car sale yards while unloading vehicles was also identified as an issue.
- Manual handling of the trailers loading/unloading ramps was identified as an issue.
- Issues to be considered for the introduction of containers are the consideration of the working environment during the loading and unloading of the cars, especially the thermal and atmospheric environment as well as the inspection and maintenance of the vehicle hoist.
- Difficulty with maintaining balance while attaching load restraints.

4 NOVEL CAR CARRIER DESIGN

Typically design process consisted of ideation, proposal, design, verification, validation and launch. Design process highlights the use of technologies like VDP to validate and eliminate hazards at early stages.

4.1 Design by elimination of hazards

Designing of car carrier was done to eliminate fall hazards by automating the deck motion using different mechanisms. The initial step was to address the identified areas through new design principles to avoid accidents. Following are series of activities for car carrier designs, which were identified and addressed in design stage for fall related issues.

- To define the areas above 1.5 m ground height where driver need to access. The loading of car 1 and car 7 were bottle necks as they go over height of 1.5 M and driver has to climb the car carrier to load the cars and restrain them. Solution to this problem was concepts with mechanisms for automation to allow the car to be loaded below 1.5m from ground level
- Loading, Unloading is important phase, to create conceptual models to understand the loading sequence and making use of current loading sequence for series of cars.

Examining the design for human intervention and avoiding possible human intervention by automation.

- Improving the structure of the carrier, as more space was required to accommodate the new mechanisms. New methods of operating the decks, so as to achieve higher automation
- Inclusive design approach, increased flexibility in the car carrier; this provides more effective usage of different range of cars thus decks to suit the requirements (like Partial decks).

4.2 Use of technology advancement to validate new concepts

Products like car carrier are difficult to model due to complexity involved in modeling of design criteria. In today's world design and development is more complex due to new challenges associated with them like sustainability, collaborative approach and faster time cycles. The design methodology in this research uses most of advanced technologies like CAD, CAE and PDM which covers most of the design advancements. Synchronizing all these to effectively to design and develop a car carrier sets bench mark for car carrier development considering challenges of globalisation. Incitation, make or buy, services, partnership it is necessary to find out success key factors for a given business model to be adapted to these new strategies (Gehin A. *et al.* 2008). Virtual design process (VDP) an interactive environment made it user friendly in collaborative environment, supporting globalised product development. VDP process is tool for addressing complexity of the design phase due to advent of concurrent design and challenges of sustainable product designs in 21st century. In car carrier design, it needed suitable validation before it was manufactured, for e.g. car one was trialed (Fig. 5) using VDP at the initial stage to validate the function of the design concept. VDP tool is used in this research to cut down the design time, improving the design quality of the car carrier design by validating the design at the early stages of the life cycle. It also reduced prototyping costs and additionally the schematics, models used to create VDP were used as input for the detailed design and drafting. The process consisted of schematic layout of the cars and the car carrier, which were animated to meet the design constrains. This approach supported collaborative engineering which is major advancement essential for globalisation.

<Please insert Fig.5>

The challenges in this global competition are the reduced cost and light weight structure without compromising on the quality of the product. Knowledge reuse integration was used on some of the parts in the design. Automated design optimisation tool from FEA, was used on car carrier parts to ensure that the over all weight of the product is reduced without affecting the loading condition.

4.3 Concept evaluation

In addition to these design productivity tools, variety of DFM analysis tools were utilised to evaluate car carrier designs to make it suitable for manufacturing. This tool helped in improving car carrier design with reducing the number of parts. These tools effectively helped in achieving:

- Car carrier design alternatives and develop them economically
- Evaluate these alternatives against DFM objectives
- Establish car carrier designs based on DFM principles which use knowledge base to retrieve the data.
- Utilize car carrier design reviews and use the manufacturing process to validate the design

The design phase of car carrier involved generating concepts which are sketched to evaluate and to proceed to the next phase (Vignesh *et al.* 2007). The past experience of the industry was used to validate the alternative concepts (Chironis N P 1991). Virtual prototype system was developed and a design case was presented to illustrate the feasibility and practicality of the proposed methodology for Car 1, 2, 3,4and 7 which are loaded and strapped below 1.5M ground level, then brought to required position using automation . Conceptual design of complex mechanisms is used to convert between one type of motion and another. Some of different mechanisms evaluated at conceptual stages are:

- Bevel Gear

- Cam
- Chain
- Gears
- Geneva Stop
- Lever
- Linkage
- Piston
- Pulley
- Rack and Pinion
- Ratchet
- Reciprocator
- Balls screw mechanism
- Wheel
- Worm Gear

Different design concepts were evaluated based on the cost effectiveness and function parameters. For e.g. Hydraulic and ball screw mechanisms were illustrated in the Table 5, where the costs of ball screws were higher in comparison with the hydraulic, ratchet lock mechanism, hence the hydraulic concepts were used in the car carrier design which not only met the design requirements but also served economically.

<Please insert Table 5>

Following are the summary of concepts used in car carrier research:

- Rack & pinion for transfer deck car1
- Chain drive mechanisms for car7 deck transfer.
- New frame design with towers
- New deck designs, partial decks
- Increasing the space constrains by design evaluation process in all areas of car carrier.
- The novel design of box type chassis in the research was result of FEA validation. The box type frame used simplified the design by tower design on three ends of the car carrier to accommodate the mechanisms like hydraulics, pulley and the ratchet locks.

4.4 Prototypes and test rigs

Both Virtual and rapid prototyping techniques were used to examine the cross-functional integration in car carrier development (Nihtila 1996). Though advancement in digital world was used in the car carrier design, the need of prototype and actual prototype build was required in the car carrier. As the main goal of the industry funding in this research was to realize a prototype vehicle and commercially sell it.

While designing of the car carriers prototypes for rack and pinions were made to validate the designs by laser cutting the steels. The whole car 1 and car 7 tracks were built as a test rigs and the function evaluation was carried. The unique process of VP was used in the design process to identify the working principles of the concepts, mechanism evaluated. The test rig was first designed with the Solidworks (Fig. 6) hydraulic motor, pinion, rack and bottle jack was used to simulate the flex in the decks and frames. The load thrust and the capability of rack and pinion to move it across affirmed the novel design. During the prototyping stage several materials for gear design and profile shapes were tested. Different kinds of plastic mainly Nylon 66 which is wear resistant, different glass filled material was tried as an alternative to the gears (Fig. 8), however due to low load bearing capacity the concepts were dropped. The test rig was actuated by use of power pack and the bottle jacks were placed on the front ends. The motors actuated on the either ends provided enough torques to move the deck with load of more than 2200 Kgs to the other deck. Thus the test frame for deck 1 car confirmed the functionality and adaptation to the design solutions.

<Please insert Fig.6>

<Please insert Fig.7>

<Please insert Fig.8>

Similarly test frame for Car7 deck was constructed as shown in the Fig. 7. The car was able to climb with the load and it was identified that gear teeth was yielding due to combined loads one from the car and the other from gravity due to inclination of car 7 deck. The resultant of forces acting included the weight of the car and the gravitation pull, all the force got concentrated at the edge of the pinion. Thus the friction and the stresses caused it to yield substantially, when it operated in the longer cycles. Hence it was decided to use the chain drive system for this deck with a track to guide the deck properly. Thus prototypes and test rigs evaluated the mechanisms and concepts before the production runs.

The over all car carrier was designed with these concepts and evaluated using latest technological advancements.

5 CONCLUSIONS

This research has developed novel car carrier which eliminates the issues of falls from heights, meeting the main objective of the research. In general, this research enabled to raise standards in car carrier industry. Following are the key outcomes of this research:

(1) Consolidating useful data on road transport in Australia.

(2) Identifying key issues of car carriers with respect to design and operational safety.

(3) Developing a new virtual design methodology for car carriers.

(4) Design methodology for novel design automation e.g. FEA validation.

(5) Designing a new car carrier that enables improved safety and more cars.

(6) Test program confirming sound designs.

(7) New standards for car carriers.

The new design methodology enabled to achieve the following advantages compared to conventional car carriers:

- Increased number of cars that can be carried at a time and also it is capable of carrying wide range of cars
- Reduces loading / unloading time.
- Improved safety by eliminating hazard by design
- High degree of automation

In spite of achieving significant acceptance in the sector, few areas were identified which needs to be addressed. One of the major problems in the research identified was availability of quality data for analysis in the heavy vehicle sector. The cited few articles in literature from different research areas of heavy vehicles, discussed concerns over the data available and the methodology used for collecting the data. In this research effort was made to segregate the data, more needed to be done in Australia. Standards and regulations are confined by transport department. The dimensional requirements need to be accessed by transport authorities to help cater more flexibility so that safe practice can be implemented comparing with European standards.

The future research is to implement these techniques using modular concepts in B doubles design of car carrier. The similar sectors like live stock carriers, long semitrailer needs research and development in the field. It would be useful to investigate the sector for similar issues of falls from heights and design re-evaluations.

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transport department for providing with requested data.

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Figure(s)

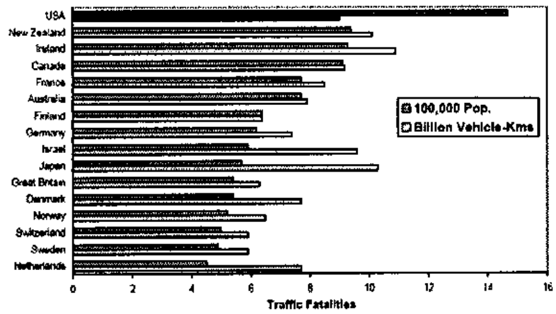

Fig.1. International traffic fatality rates (BRTRE)

Fig. 2. Fall from height (Toll premises)

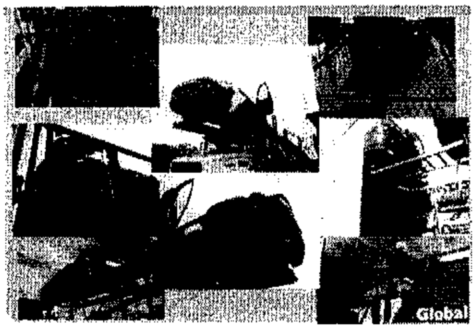

Fig. 3. Examples of fall hazards (Work safe Australia) (Drivers strapping the cars at more than safe height from the ground level)

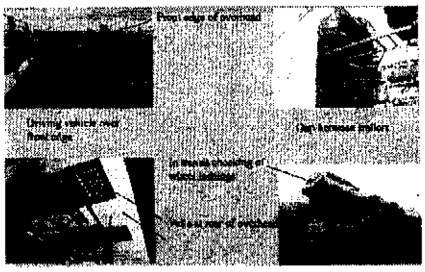

Fig. 4. Examples of problem areas (Work safe Australia)

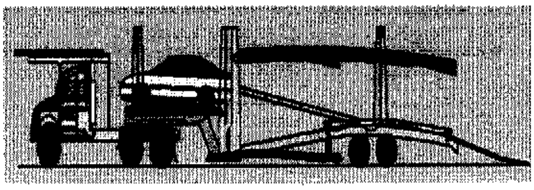

Fig. 5. VDP used to demonstrate the loading sequence of the cars in 3D

Fig. 6. Actual Prototype Car deck1

Fig. 7. Actual Prototype Car deck7

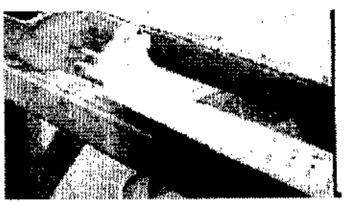

Fig. 8. Rack and pinion prototype

Table(s)

Table 1. Cost comparison Rail and trucking in Australia (BRTRE)

	Rail			Truck		
	Cost	Payment	Balance	Cost	Payment	Balance
Infrastructure Use	0.87	0.87	0.0	0.97	0.64	0.33
Accident Costs	0.03	0.01	0.02	0.32	0.16	0.16
Enforcement Costs	NA	0.0	0.0	0.05	0.0	0.05
Congestion	NA	0.0	0.0	0.03	0.0	0.03
Air Pollution	0.004	0.0	0.004	0.01	0.0	0.01
Noise	0.02	0.0	0.02	0.034	0.0	0.034
Totals	*0.924*	*0.88*	*0.044*	*1.454*	*0.84*	*0.614*

This table indicates the estimated external costs of each mode, how much they pay under the current price structure, and the balance of external costs that result.

Table 2. Comparison of Inland Waterways and Surface Freight Modes, (TR NEWS 221, Transportation Research Board (www.trb.org), July-August 2002, p. 10-17)

	Costs	Fuel	Hydrocarbons	CO	NOx
Units	*Cents*	*Gallons*	*Lbs*	*Lbs*	*Lbs*
Barge	0.97	0.002	0.09	0.20	0.53
Rail	2.53	0.005	0.46	0.64	1.83
Truck	5.35	0.017	0.63	1.90	10.17

Table 3. Costs of fatalities and injuries in Australia, (BRTE)

Country	Fatalities	Serious injuries
Australia	1,634	22,000
Austria	730	6,774
Canada	2,936	17,830
France	5,318	39,811
Germany	5,842	80,801
Netherlands	987	11,018
New Zealand	405	3,950
Sweden	440	4,022
UK	3,221	31,130
United States	42,815	356,000

Table 4. Research methodology

Methods	Techniques	Resources	Conclusions
Question based	Questionnaires Interviews	Drivers, Managers, people in car carrier industry	All of them strongly feel the need for safe practice in car carriers. Manager and drivers at Tolls identifies fall as major cause of accidents
Field Study	Capturing videos Stake holders reports	Operational sequence of car carriers	Drivers are subject to climb the height over 1.5 meters which is unsafe as they are subject to slippery. The stress factor due to long working hours is an additional cause for the drivers safety.
Design analysis	Layouts Catalogues Photographs Competitors data	Old car carrier layouts Rolfo and LOHR data	Old designs and the layouts were analised to find out need for design in car one and seven areas which are typical due to the fact that they are loaded above 1.5M height
Secondary research	Journal Articles Case studies Statistical data	Study from USA, Canada, Newzeland European countries	Research across globe identifies falls as one of the major cocnern.

Table 5. Comparison of concepts for car carrier

Hydraulics				[illegible]
GSN 25/30 Nordon	312	4	1248	[illegible]
cartridge poppet 2way	75	4	300	
12V coil, hydraulic cartridge	39.5	4	158	
Electrical Plug	4	4	16	
Cables				
Nylon chain 1020	463	1	463	
Front 8mm, 7/19 E/L3565	11	1	11	
Rear-2895 LGTH 7/19	11	1	11	
PVC safety cable	1	8	8	[illegible]
Ratchet lock mechanism				
Material for Ratchet teeth48+4S	283	1	283	[illegible]
Ratchet lock F	290	2	690	[illegible]
Ratchet lock R	529	2	1058	[illegible]
Pin	148	4	593	[illegible]
Lock lug	29.7	4	119	[illegible]
Lock tag	23.1	4	92.3	[illegible]
Slider box	195	2	390	[illegible]
Pneumatics				
D25DAD S 5A	66	4	264	[illegible]
Hinge mount	11.4	4	45.6	[illegible]
Solenoid 3/2 NC 12V DC	77.4	2	155	[illegible]
Elbow 6mm 1/8	4.8	4	19.2	[illegible]
Tee 6mm	5	5.4	27	[illegible]
Common parts				
Tube 8 mm 20 Meters	2	20	40	
STR connector	1		2.4	
Filter regulators			16	
Bearings				
[illegible]	7	10	70	
8mm cable mount pulley	12.9	10	129	
Mounting costs				
Consider@ 20hrs X 45$			900	
Total cost P2			6048	

[redacted]