WORLD CLASS OVER-HEIGHT VEHICLE DETECTION/WARNING SYSTEMS - WHY DO DRIVERS CRASH? A HUMAN FACTORS PERSPECTIVE

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ABSTRACT

A December, 2009 press release from the NZ Transport Agency advises that there are on average 25 bridge strike incidents per year on Auckland motorways. Such events can be costly, disruptive and have potentially immense safety impacts. One such incident occurred on the Orams Road Bridge on the Southern Motorway, the incident cut the link between two communities and cost ~$400,000 to restore. Given the potential negative consequences of these events it is vital that a smarter, stronger, safer approach be taken to minimise these incidents. This paper investigates from a Human Factors perspective why drivers of over-height vehicles hit infrastructure both internationally and on the Auckland Motorway Network and what counter-measures can be put in place to reduce the number of strikes.

INTRODUCTION

The legal height limit for a vehicle to travel on New Zealand (NZ) roads is 4.25m. For vehicles between 4.25m and 5m drivers must survey the route prior to travel and get written permission from owner/s of any 'overhead obstruction that the vehicle cannot clear safely'. For vehicles over 5m drivers must obtain an Over-dimension Permit from the NZ Transport Agency. This process is designed to limit the number of times over-dimension vehicles hit infrastructure such as overpasses, bridges and tunnel entrances. However, with this system in place in 2009 the NZ Transport Agency noted that there was on average 25 bridge strikes by vehicles on Auckland Motorways.

Given that a truck hitting a structure at motorway speed presents potential serious safety concerns for the driver of the truck, people in surrounding vehicles and may cause expensive damage to infrastructure and vehicles the NZ Transport Agency is interested in determining what is "best practice" for getting drivers to comply with height restrictions. A first step for this project was to determine the causal factors that can lead to over-head vehicle strikes.

INTERNATIONAL REVIEW ON OVERHEAD STRIKE CAUSAL FACTORS

A number of reviews have considered the causal factors that can lead to over-head vehicle strikes. It should be noted that in line with general traffic accident research the results indicated that accidents are generally caused by a sequence of causal factors occurring in conjunction with each other not due to one factor alone. Causal factors from the literature researched are provided in Table 1 below.

Category of Causal Factor	*Accident Factors*	*Source*
Incorrect or no knowledge of load height	Didn't measure the load	RSSB, 2012, Agrawal, 2011, Martin & Mitchel, 2004
	Didn't measure the load on this trip (assumed it was the same as previous loads that had been measured)	RSSB, 2012
	Load was measured incorrectly (note if the load was measured by someone else)	RSSB, 2012, Agrawal, 2011
	Load has moved since it was measured/Load was incorrectly loaded resulting in it being higher than expected, or left a truck-mounted crane or trailer component in the wrong position.	RSSB, 2012
Route Planning	No pre-trip route planning	RSSB, 2012, Martin & Mitchel, 2004
	Lack of alternative route	Martin & Mitchel, 2004

	Drivers directed to specific route by someone else and assuming that it was ok	RSSB, 2012
	Driver not reviewing the suitability of the route after an imposed diversion	Agrawal, 2011
	Use of GPS for route planning that doesn't alert of over-height locations	Agrawal, 2011
	Inadequate directions given to a driver	Agrawal, 2011
Poor implementation of Over-height signage	Inadequate signing (once drivers see the signage there is inadequate time to stop)	RSSB, 2012, Martin & Mitchel, 2004
	No signage/use an onramp after the signage	Martin & Mitchel, 2004
	Low-under-clearance signs on bridges not visible at night	RSSB, 2012
	Entrance onto the road, too close to the overhead structure to provide adequate signage (no signage on the connecting road	Agrawal, 2011
Drivers making incorrect assumptions	Drivers incorrectly thinking that the height limit includes a tolerance level.	RSSB, 2012
	On routes that have two structures ahead (with the lower structure first and the higher structure second), when drivers see signage for the first structure they think it is for the second structure and develop an incorrect model of the way the heights are measured. This may	RSSB, 2012

	lead to the driver ignoring the first sign.	
Poor Geometrics	Poor geometrics or road surfacing whereby the vehicle might be under the height limit but only if they approach on a direct alignment (or don't hit a bump in the road) RSSB, An example of this is given in Agrawal, 2011 of a bridge being hit as a result of trucks bouncing on a bump on the road under the bridge.	RSSB, 2012, Agrawal, 2011

Table 1: International Over-head Strike Causal Factors

The next stage of this project was to take the international overhead strike causal factors in conjunction with a review of Auckland Motorway over-height crashes to determine the main causal factors that occur in Auckland.

AUCKLAND OVER-HEIGHT HITS ACCIDENT DATA

Six sites with a known over-height crash risk on the Auckland Motorway Network were further investigated for the period spanning 2009-2013. The six sites were:

1. Penrose Rd overbridge
2. State Highway 1 / Main South Rd at Takanini
3. Orams Rd overbridge
4. Reagan Rd overbridge
5. Royal Rd overbridge
6. Walter Strevens Dr overbridge

A search was conducted of the NZ Transport Agency's Crash Analysis System (CAS) to find all crashes occurring in the five year period 2009 – 2013 at the identified sites. These crashes were then filtered to find crashes where over-height vehicles have struck overbridges, with 20 crashes being found across the six sites. Each crash's Traffic Crash Report was examined and factors contributing to the crash identified.

Common factors included incorrect loading, no measuring of load height, incorrect measuring of load heights, incorrect stowing of truck-mounted cranes and driver inattention. Cases of incorrect loading included excavators put on the trailer the wrong way around, and a vehicle transporter where the top deck was not lowered properly. One of the cases of incorrect measurement was when the loaders measured the back of the vehicle, not realising that the front was slightly higher. Two cases were recorded where the driver said they knew the height of their load, but drove under the overbridge anyway; this was classified as driver inattention (note the reports did not include information on whether the drivers read and/or saw the signs). In one of these cases the driver attributed stress, fatigue and the flu for contributing to this.

In five crashes the load hitting the overbridge was an excavator. Other specified loads included a forklift, vehicles (on a vehicle transporter), glass panels and an industrial rubber belt.
15 crashes were recorded at the Penrose overbridge which has electronically activated over-height warning signs installed. Several of the drivers who crashed at Penrose overbridge said they did not see the sign flashing (1 of which recorded an independent witness saying the signs did flash). 3

drivers said they saw the sign flashing but assumed it was not for them and continued into the overbridge.

Possible factors contributing to over-height strikes are outlined in table 2 below. Note that the columns to the left of the table are the accident factors found in the literature review in blue text with additional factors from the accident reports in black text. The column to the right provides examples of accident locations.

Category of Causal Factor	*Accident Factors*	*Number of Crashes that list these Causal Factors*
Incorrect or no knowledge of load height	Didn't measure the load	(Penrose) x8
	Didn't measure the load on this trip (assumed it was the same as previous loads that had been measured)	
	Load was measured incorrectly (note if the load was measured by someone else)	(Penrose x 2) (1 where it was not the driver who measured the load and 1 where it was the driver who measured the load)
	Load has moved since it was measured/Load was incorrectly loaded resulting in it being higher than expected, or left a truck-mounted crane or trailer component in the wrong position.	(Penrose) x 4, (Orams) x 1, (Reagans) x 2
Route Planning	No pre-trip route planning	
	Lack of alternative route	
	Drivers directed to specific route by someone else and assuming that it was ok	
	Driver not reviewing the suitability of the route after an imposed diversion	
	Use of GPS for route planning that doesn't alert of over-height locations	

	Inadequate directions given to a driver	(Penrose) x 1
Poor implementation of Over-height signage	Warning signs flashed but driver didn't see them	(Penrose) x 1
	Warning signs flashed and driver saw them, but ignored then	(Penrose) x 3
	Inadequate signing (once drivers see the signage there is inadequate time to stop)	
	No signage/use an onramp after the signage	
	Low-under-clearance signs on bridges not visible at night	
	Entrance onto the road, too close to the overhead structure to provide adequate signage (no signage on the connecting road	
Drivers making incorrect assumptions	Drivers incorrectly thinking that the height limit includes a tolerance level.	RSSB, 2012
	On routes that have two structures ahead (with the lower structure first and the higher structure second), when drivers see signage for the first structure they think it is for the second structure and develop an incorrect model of the way the heights are measured. This may lead to the driver ignoring the first sign.	RSSB, 2012
	Driver knowing the height of the load, but driving under the bridge anyway (no further explanation given)	(Penrose) x 1, (Main South Rd) x 1, (Takanini) x 1

Poor Geometrics	Poor geometrics or road surfacing whereby the vehicle might be under the height limit but only if they approach on a direct alignment (or don't hit a bump in the road)

Table 2: Causal Factor Frequency and Location

FURTHER HUMAN FACTORS LITERATURE REVIEW

Whilst the accident analysis provides some indication as to the causal factors a further review of the Human Factors literature suggests the following additional design considerations.

- Drivers that are not familiar with the route and the specific tunnel concerned do not notice relevant signs (PIARC, 2008).
- When approaching a tunnel drivers focus narrow to the tunnel entrance at about 150m, with their eye blink frequency decreasing at about 200m, this makes them less likely to take in additional information in this area (PIRAC, 2008). The PIARC report does note that a study by ACTEURS (Ricard, 2005) noted that drivers did seek out speed signs within this area.
- Once a driver arrives at a bridge, the likelihood of deciding to try to squeeze under the bridge is increased, because of:
  - » Uncertainties in relation to vehicle height
  - » Uncertainties in relation to bridge height and safety margins
  - » The difficulties involved in turning around and time lost retracing steps
  - » Psychological mechanisms which lead people to ignore evidence that contradicts their beliefs or course of action. RSSB (2012)
- Drivers deliberately choose the tunnel route because using the alternative route involves a lengthy diversion (PIARC, 2008)

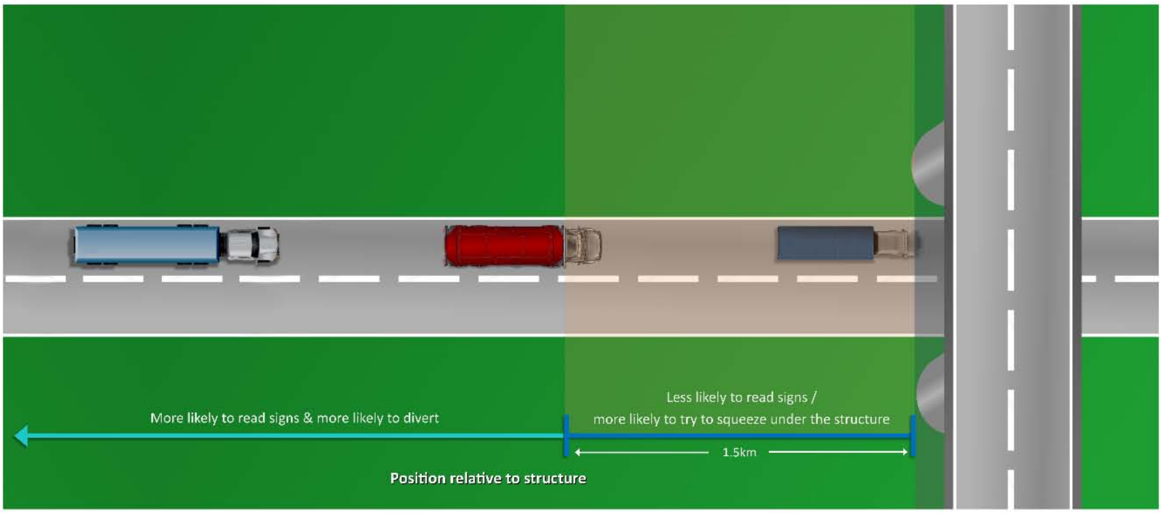

Figure 1: Compliance Risk to Counter-measures versus Distance to the Structure

These factors have the following design implications for designing an over-height detection warning system:

- It is important to divert or stop over-height vehicles as early as possible, prior to the entrance area of a tunnel or structure. The PIARC report suggests' to: warn road users that they are approaching a tunnel and do so prior to the last possible exit from the road.
- Provide enough time for drivers to comprehend the meaning of the sign and hence to choose an alternative route.
- Signs should be repeated. Note that repeating signs is beneficial in two ways 1) it gives drivers another opportunity to see the sign if they miss the first one and 2) it gives drivers time to assess the situation and decide on an alternative route.
- Signage should be consistent and easily recognizable in order to prime the driver to look for feedback as to their vehicle height. The detection system should be signed and indicated in a consistent way to the rest of the system. An example of such consistency is where the UK Department for Transport requires fixed speed cameras to be either coloured yellow in an area with good street lighting and where not treated with yellow retro-reflective sheeting to make them more conspicuous, an image of these cameras is then shown on the signage.
- Sign should clearly indicate an alternative route as this will reduce the drivers' cognitive load.

A Programme of Countermeasures

Given the wide range of causal factors it is recommended that a range of different counter-measures needs to be undertaken. The following counter-measures were developed from the above work as well as with additional inputs from Jeff Gerbich (NZ Police) along with the wider project team. The recommendations include the following.

Driver Education

- It is noted that the NZ Transport Agency is already providing an awareness campaign to aid in increasing the number of drivers measuring their load and to ensure that the load is secured.
- Other potential education could include educating drivers as to under what conditions they are more likely to have an over-height accident, including knowledge of the type of errors that can occur when stowing a load, measuring a load and in-route (particularly when they have to re-route mid-trip) to encourage them to do good route planning.

Technology

- A truck GPS or smartphone app that notifies drivers in-vehicle of low-over-height structures (Agrawal, 2011). Note that consideration would need to be given to ensure that such a system did not induce driver distraction.
- An in-cab warning system that notifies the driver if the load moves or is not secure
- Development of a smartphone app for measuring the height of the load

Enforcement

- Failure to divert or stop when requested could be treated as a traffic violation with penalties.
- Recommendations from the Agrawal (2011) in the US have suggested banning the use of consumer GPS in trucks and restricting access to certain roads and making it a legal requirement that drivers display the height of their load (note that where this is a rule in the UK there is a very low compliance rate RSSB, 2012).

Road Geometry/Monitoring of Accident Sites

At a site that has an over-height hit or has a high risk profile the following should be checked on-site:

- Road/over-height alignment and measurement
- Lighting of the over-height structure and signage
- The signage (check that it is not being obscured by vegetation and that it is still visible)
- If an over-height detection system is in place, check the number of false positives

In terms of implementing an on-road vehicle detection and warning system the following recommendations are made:

- Signs and treatments should not be located in areas where drivers frequently perform lane-changing manoeuvres in response to static guide sign information, or because of merging or weaving
- Information should not be positioned at locations where the information load on drivers is already high because of guide signs and other types of information

Further specific recommendations are included in the table 3 below.

Over-height Vehicle Warning Detection System

Timeline	Element	Message to be Communicated	Specifications/notes	Benefit
Pre-Trip	Route Planning Measuring of load	Measure your height before you leave and plan your route accordingly Awareness of common mistakes that drivers make (e.g., load not stowed properly)	Reinforcement of the need to do this through raising awareness, education, and enforcement	Prevent over-height vehicles being on the Motorway
In-Trip at locations that are main Freight feeders to the Motorway Network	Information Only signage	Know your height Plan your route accordingly	Use billboard signage	Prevent over-height vehicles being on the Motorway
On the Motorway Network - Prior to the last exit	Advanced warning & repetition of signage	Structure of X height ahead Over-height check X m ahead (could include an image of the measuring device) You must exit if advised to do so	Needs to warn that there is a low structure ahead, need to give the height limit and clearly state what to do Must be far enough back from the junction that it allows drivers to comprehend the meaning of the sign and have time to decide on an alternate route.	This will prime drivers to start thinking about if they need to divert and to look both for the detection and the feedback on their height.

			Suggest that this should be further than the standard motorway exit signage as the driver has to consider how they might re-route to their destination.	
	Measuring device	You are being measured Look at the next VMS to see if you are over-height	Should be clearly marked, easy to see during day and at night Recommend using yellow retroflective materials to indicate the location of the measuring device (eg on the pole and the measuring device) Should be set back from the messaging system, to allow sufficient time to measure and inform driver of their height System should have minimal false detections/warning or it will be ignored (note that the Police noted that this had as occurred in early iterations of the Penrose Over-height warning system)	This will prime drivers to look for feedback on their load height 
	First warning device	You are over-height must exit at XXX (include distance to the exit) Wording of the exit name should exactly match naming of the actual exit Consider including the distance to the exit if it cannot be seen	Needs to indicate if over-height and if so that they must exit and follow the signed over-dimension route Need clear signage of a full alternative route (signed as an over-dimension route).	Get over-height vehicles off the motorway well before the low structure when a driver has more time to consider what to do.
	Monitoring device		If driver does not exit, need to set-off an alarm to the traffic operations centre to monitor the vehicle/situation and trigger the next warning Needs to be far enough back from the	Escalating the seriousness of the event.

			structure to allow time to give a final warning to pull-over	
	Warning to pull-over and stop	Depending on the site, set-up a clear instruction as to what to do next should be given. Potential scenarios include: Moving into a pull-over bay Using a slip lane Stopping in the lane (close all traffic lanes down) Should be prior to 150 m before the structure	Sign needs to indicate that need to stop now and contact a control centre to get further instructions This should follow the procedures in section 12.3.7 in AUSTROADS Guide to Tunnels Part 2 for guidance for designing a pull-over bay. If this is implemented need to ensure that there is adequate storage for the likely number of vehicles Needs to include ability to turn the vehicle around. Recommend ability to remove central barrier and turn vehicles at that point.	This is the penultimate final defence.
Just prior to the structure	Close all traffic lanes down	Bring the motorway to a stop	Need to consider the stopping distance of vehicles	This is the final defence.

Table 3: Overheight Vehicle Warning Detection Systems

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CONCLUSION

This paper has presented a number of countermeasures that could be adopted for the Auckland Motorway Network to aid in the reduction of Over-height vehicle crashes. Recommended counter-measures include: driver education, use of in-vehicle technology, increased enforcement, checking of road geometry after an accident and implementation of a comprehensive over-height warning detection system.

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