SH1 Otaihanga Roundabout

Human Factors Review

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Contents

1 Executive Summary

This report outlines the findings of a human factors review into truck rollover crashes that have occurred at the SH 1/Otaihanga Roundabout. The roundabout is located 3.3km north of Paraparumu on SH1.

The review involved the following investigations:

- A compilation of existing data including: traffic counts, speed surveys and NZ Transport Agency CAS accident reports
- A review of NZ Transport Agency Crash Analysis System (CAS) accident reports for four nearby roundabouts
- A review of existing video of driver behaviour at the site and an on-site observations and truck drive overs during different lighting conditions
- Discussions with local Police, Police from the Commercial Vehicle Investigative Unit (CVIU), truck drivers and car drivers
- Discussion with NZ Transport Agency staff re: findings

The findings of this report suggest that there is a concerning trend of an unusually high number of truck rollovers for trucks travelling in the northbound direction (it is noted that the 18 month timeframe that the roundabout has been in operation is too short a timeframe to accurately access accident analysis). This concerning trend coincides with discussions with truck drivers, the CVIU and the local Police that indicates that there is a persistent strongly held belief that traveling in the northbound direction the Otaihanga Roundabout presents a greater propensity to rollover than other roundabouts in the nearby vicinity for larger trucks with a high centre of gravity or a moveable load.

As with most crashes it would seem likely that the rollovers occur not due to one factor but are a result of multiple factors lining up. Driver related factors specific to approaching the roundabout from the northbound direction occurred in the following driving stages: diagnosis, prognosis and action stages. Specifically these failures relate too drivers making an:

- incorrect evaluation of the road difficulty of the roundabout as a driver approaches the roundabout, and this is leading to a speed that is too high for safely negotiating the roundabout in the northbound direction
- when entering the roundabout for the first time there is no expectation that there is a perturbation ahead leading drivers to being “surprised” part the way around the roundabout with an impression that the circulating radius tightens-up
- At the point where a driver encounters difficulty there is limited ability to re-gain control of the vehicle (in the northbound direction)

Recommendations to address the above crash factors include:

- Re-aligning the northbound lanes to reduce the successive curve motion. This would need to take into consideration achieving appropriate entry and exit angles. There may be a possibility of achieving this by using one lane through the roundabout
- Provision of visual delineation cues to improve driver understanding of the pathway through the roundabout
- Improvements to the guide signage to cue the driver that the roundabout entry and exit angles
- Visual countermeasures to reduce high approach speeds

As with implementing any countermeasures it is important that if implemented these should be proactively monitored. Collecting and analysing speed data of heavy vehicles in relation to vehicle size, length, load and combination utilising the roundabout would provide a metric to evaluate if the speed of target vehicles are dropping.

2 Introduction

2.1 Background of the Project

The NZ Transport Agency commissioned Opus International consultants to undertake a Human Factors Review of the SH1/Otaihanga Road Roundabout (the roundabout) following 4 truck rollovers in the first 18 months of the roundabouts operation. The roundabout replaced a T-intersection that had a high crash history in April 2014, it currently forms part of the supporting infrastructure for the construction of the MacKays to Peka (M2PP) expressway. Once the MacKays to Peka (M2PP) expressway is in place this intersection will be bypassed and this section of SH1 will revert to being a local road.

The roundabout is located north of Paraparaumu at the intersection of SH1 and Otaihanga Road (Figure 1). It is located in a semi-rural environment with 80 km/h speed zone on SH1 each side of the roundabout and a 60 km/h speed zone on Otaihanga Rd.

3 of the truck rollovers were travelling northbound on State Highway 1, with the remaining truck rollover heading southbound. In addition there has also been a reported (and video recorded) incident of a truck heading southbound that went through the middle of the roundabout but did not stop. The NZ Transport Agency reports that all the drivers have been prosecuted for factors such as illegal or non-compliant loads and travelling too fast.

The brief of the project was to focus on vehicles going heading north on State Highway 1 which is thought to be the area of greatest concern.

Figure 1: SH1 / Otaihanga Road Roundabout

3 Why a Human Factors Assessment?

A human factors assessment was undertaken as previous crash investigations suggested that human error was a contributing factor to the rollovers. Where human error is cited as a contributing cause it is important to seek out where the failures occur in order to find appropriate treatments to reduce the likelihood of the same event occurring again. A report from Traffic Accident Causation in Europe (2008) categorises human error relating to road accidents into 6 different categories as shown in Figure 2 below.

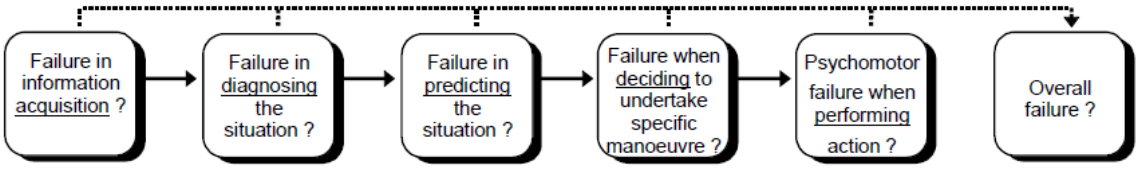

Figure 2: Stages of human failure from TRACE Project No. 027763, 2008

Determining which of these failures has occurred can reveal where investment into treatments would be best targeted. The type of failures that can occur are further described in Figure Y below.

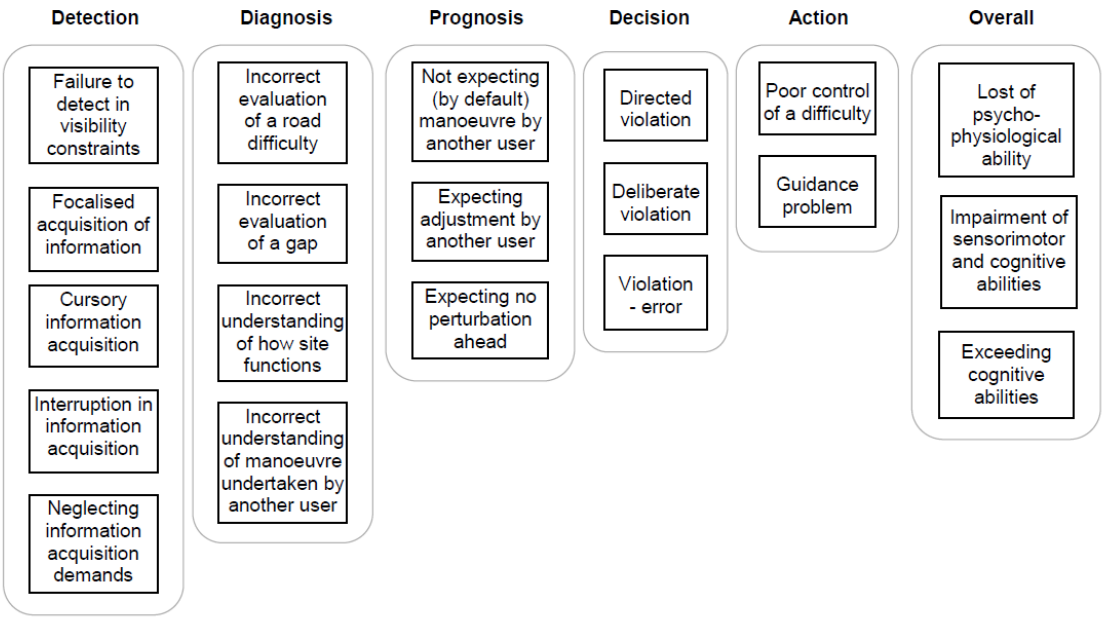

Figure 3: Delineation of Functional Failures from TRACE Project No. 027763, 2008

4 Methodology

This investigation included the following review tasks:

- A compilation of existing data including: traffic counts, speed surveys and NZ Transport Agency CAS accident reports.
- Existing video of driver behaviour at the site, on-site observations, and truck drive-overs during day and night conditions.
- Discussions with local Police, Commercial Vehicle Enforcement Unit, New Zealand Police (CVIU), truck drivers and car drivers.
- Discussion NZ Transport Agency staff re: findings.

5 Existing Data

5.1 Traffic Count Data

To understand the volume of heavy traffic utilising the roundabout Table 1 below provides the traffic counts on State Highway 1 south of the roundabout. The traffic volumes were are from November 2014.

Table 1: Traffic Counts on State Highway 1 south of the Otaihanga Roundabout

Direction of Travel	Date of Count	Weekday (*) indicates number of heavies)	Weekend (*) indicates number of heavies)	% Heavies
Southbound	November, 2014	12,006 (1,081)	12,187 (1,097)	9
Northbound	November, 2014	11,820 (1,064)	11,558 (1,040)	9
	Total	23,826 (2,144)	23,745 (2,138)	9

5.2 Speed Data

Speed data was provided by the Transport Agency, it was collected over the period 23:54 Tuesday 15th July – 19:56 Monday, 4 August 2014. The data was filtered by the Transport Agency to provide:

- Speed data collected during off-peak periods where free flow traffic conditions were likely to have occurred to gain an understanding of the speed that truck drivers choose to enter the roundabout (as opposed to the speed that they followed other traffic into the roundabout)
- Speed data for trucks that were Axel Class 6 and above in the NZ Transport Agency Classification Scheme. This equates to vehicles that are classed from heavy trucks (with 4+ axels) through to A Trains (with 8 Axels).

The speed data is provided in Tables 2 and 3 below. It should be noted that the speed data does not show the roundabout circulating speed as this data had not been collected. The closest speed site to the roundabout is approximately 50 in the northbound approach and 40m in the southbound approach. Data in Table 2 and 3 suggests the following:

- For both the Southbound and the Northbound direction the trucks are slowing as they approach the roundabout from 300m back.
- Approach speeds not too dissimilar from both directions – given that the closest sites do not appear to be equal-distance from the roundabout no further assessment has been made
- From the closest location to the roundabout (in both directions) the mean speed, 85% and 95% is higher than drivers indicated was safe for larger vehicles.

Table 2: Northbound Truck Speed Summary Data

Northbound	Mean	s.d	Median	85%	95%
300m south of the roundabout	60.1	6.18	60.1	65.9	69.1
Street light at the start of the footpath	55.3	6.61	55.4	61.6	65.2
1 Street light back from the roundabout	40.8	7.74	41	47.5	51.5

Table 3: Southbound Truck Speed Summary Data

Southbound	Mean	s.d	Median	85%	95%
300m north of the roundabout	60.8	6.4	60.8	67	70.6
From the 3rd street light north of the roundabout	55.6	6.15	55.4	61.6	65.2
At the beginning of the walkway	44.2	6.83	44.3	50.4	54.4

5.3 Crash Data

Crash information was retrieved from the CAS (Crash Analysis System) database and assessed for the period May 2014 (when the roundabout became operational) until September 2015. Note that not all accidents are recorded in CAS due to a delay between an accident occurring and information being uploaded to the system. In addition only accidents reported to the Police are recorded and the police must then enter all crashes that involve a motor-vehicle. They can also record accidents not involving a motor-vehicle but are not required to do so.

The CAS data of all vehicle types was reviewed as we were interested to know if there was a similar high incidence of non-truck vehicles experiencing difficulty at the roundabout. CAS contained 14 crashes at the roundabout (from May 2014 until September 2015). In addition to these crashes we know that there has been an additional truck rollover in the Northbound direction. The details of this crash has not been entered into the CAS system yet and more recently there was an additional truck rollover in the northbound direction. Details of the crashes are provided in Table 4 below.

Table 4: Crash Details for Otaihanga Roundabout

Number of Incidents	6 Southbound Crashes	Injury Crash	Crash Involving a Truck	Solo truck rollovers (no other vehicle involved in the crash)
3	Vehicle rear ended vehicle in front when front vehicle gave way	(1 minor injury)		
1	Lost control and hit guard rail (report noted alcohol and speed factors)			
1	Car hit van when changed lanes			
1	Truck lost control turning left and hit traffic sign		1	1
Number of Incidents	**8 Northbound Crashes**	**Injury Crash**		
4	Vehicle rear ended vehicle in front when front vehicle gave way			
1	Car overtaking/changing lanes to right hit van			
1	Car lost control turning right on right hand bend			
1	Truck lost control when turning, load to heavy, curve not well banked	(1 minor injury)	1	1
1	Truck too fast entering corner, lost control when turning		1	1

5.3.1 Common themes from the crash reports

While it should be noted that 18 months is a short time frame to detect trends in accident analysis, the following themes appear to emerge:

Truck rollovers

- The northbound direction has a greater incident of truck rollovers than the southbound direction
- Two of the crashes occurred in light rain and one in fine conditions. One of the light rain conditions occurred at 3.08am and the other two were around mid-day.

Car Crash Trends Outside of Scope

- There are rear-end accidents occurring in both directions, with the most common cause being the car behind following too closely or not noticing that the car ahead was slowing down.

- There are crashes occurring where cars are overtaking within the roundabouts

The following factors were identified from the crash reports for the truck rollovers:

- Roundabout appears to be designed with a negative camber on the northern side. To exit left towards Waikanae the design causes a driver to make an extended turn to the right prior to exiting left.
- Driver entered roundabout too fast for the layout
- Negative camber of the roundabout and also sharpens as vehicles head north[1]
- Top heavy vehicle 15 tonnes frozen fries on-board
- One noted that the speed of the truck was low and thought not to be a cause of the crash (Speed 31 km/hr entering the roundabout (video footage NZTA – shows truck followed Petrol tanker around roundabout speed not fast)

5.3.2 Crash Factors relating to Truck Rollovers – Southbound

The following factors were identified from the crash reports for the truck rollovers:

- Road was a little wet due to rain.
- Speed is a factor.
- Unknown whether any physical driver factors like fatigue were a result of crash.
- Brakes were applied which is what caused the truck to crash, driver going too fast.

6 Comparison with nearby roundabouts

As many of the trucks that currently utilise the Otaihanga roundabout also use nearby roundabouts. We analysed truck crash data for four nearby roundabouts (Plimmerton, Paremata, Otaki and Pautahanui). 5 years of crash data was used for all the roundabouts except Otaihanga where 18 months of data was used due to the roundabout not having been in use for 5 years. The results are provided in Table 5 below.

[1] These factors are from the Crash Reports. The Transport Agency reports that the as-constructed survey indicates that the camber is consistent all the way around the roundabout

Table 5: Crash details for five roundabouts

	Location	Weekday Heavy Vehicle Count	Weekend Heavy Vehicle Count	# of trucks involved in accidents	# of trucks rolling	Comments	Solo truck rollovers (no other vehicle involved in the crash)
Otaihanga[2]	Southbound	1,081	1,097	1	1		1
	Northbound	1,064	1,040	4[3]	4		4
Plimmerton	Southbound	1,038	1,016	1	1	Trailer rolled – travelling too fast and failed to negotiate the roundabout	1
	Northbound	1,288	1,135	4	0		
Paremata	Southbound	1,064	996	2	1	Sideswiped or changed lane in roundabout	
	Northbound	1,479	1,247	1	1	Changed lanes due to a stopped vehicle as entered the roundabout	
Otaki	Southbound	847	901	1	0	1 passing manoeuvre	
	Northbound	864	876	6	0	2 where trucks failed to give way 4 involved a passing manoeuvre	

[2] Note only 18 months of crash data have been used for the Otaihanga roundabout, all other roundabouts include 5 years of data

[3] CAS data indicates 2 rollovers, we understand from the Transport Agency that another one had occurred prior to this project starting and since this project started there has been a fourth vehicle roll in the northbound direction

	Location	Weekday Heavy Vehicle Count	Weekend Heavy Vehicle Count	# of trucks involved in accidents	# of trucks rolling	Comments	Solo truck rollovers (no other vehicle involved in the crash)
Pautahanui	Eastbound	380	287	0	0		
	Westbound	464	477	0	0		

To provide a further comparison The United Kingdom has about 20,000 roundabouts and have 50-60 injury crashes per year involving truck overturns[4], which without taking into account size or vehicle kilometres travelled is a rate of .003 injury crashes per roundabout. The authors note that most truck rollovers occur at low speed and do not cause serious injury. It is difficult to equate these numbers to New Zealand due to the lack of ability to compare the specifics of the roundabout.

6.1 Crossfall

Crossfall refers to the slope of the road across the width of the road. To gain an understanding of whether the crossfall at Otaihanga is contributing to the crash rate crossfall data was taken from the RAMM database. The data is provided in Table 6 below.

Of note in the Table 6 below is that the crossfalls for Otaihanga are of a greater magnitude and positive than a majority of those for the other roundabouts. Whilst this crossfall difference may not be perceptible (in either feel or visibility) it would have an effect on the dynamic handling of a vehicle.

Table 6: Crossfall for five roundabouts

Otaihanga		
	Southbound Direction	Northbound Direction
	The carriageway is falling from the RAB towards the outside of the lane with a crossfall of +3.3	The carriageway is falling from the RAB towards the outside of the lane with a crossfall of +3.7
Plimmerton		
	Southbound Direction	Northbound Direction
	The carriageway is falling from the outside towards the RAB with a crossfall of L1= -0.9, L2=-2.1.	The carriageway is falling from the outside towards the RAB with a crossfall of R1 & R2 = -1.9
Paremata		

[4] Waddell et al, 2009

	Southbound Direction	Northbound Direction
	The carriageway is falling from the outside towards the RAB with a crossfall of L1= -3.1, L2 = -0.9	The carriageway is split, with the lane closes to the RAB falling towards the RAB with a crossfall of -0.2 (very flat). The outside lane then falls the other way with a crossfall of +2.7.
Otaki		
	Southbound Direction	**Northbound Direction**
	The carriageway carriageway is falling from the RAB towards the outside of the lane with a crossfall of +1.4	The carriageway is falling from the outside towards the RAB with a crossfall of R1 & R2 = -1.9
Pautahunui East		
	Increasing Direction	**Decreasing Direction**
	The carriageway is falling from the outside towards the RAB with a crossfall of -3	The carriageway is falling from the RAB towards the outside of the lane with a crossfall of +3.7

7 Truck Drive-Overs and Onsite Observations

7.1 Northbound Approach to the Roundabout

The images below show the northbound approach to the roundabout from SH1.

Figure 4: Northbound approach to the roundabout, showing the existing guide sign

Figure 5: Northbound approach to the roundabout

Figure 6: Northbound approach to the roundabout

Figure 7: Entering the roundabout, figure is from passenger side of truck

7.2 Southbound Approach to the Roundabout

The images below show the southbound approach to the roundabout from SH1.

Figure 8: Southbound approach showing guide sign

Figure 9: Southbound approach

Figure 10: Southbound approach

Figure 11: Southbound approach

Figure 12: Southbound approach

Figure 13: View from Southbound of the Roundabout, showing oncoming vehicles from the Southbound approach

7.3 Truck Drive-Overs

Truck drive-overs were undertaken on Tuesday the 27th of October during the day and in the early evening, giving exposure to different lighting conditions. During the drive-overs there was also periods of clear sunshine as well as light rain. The drive-overs involved drivers from two companies who operated from close by the roundabout. The first was with a driver from Higgins in a 6 wheeler with 4 axle trailer unit that was delivering metal for the M2PP project. The second drive-over was with a driver from Clive Taylor Ltd in a 6 wheeler tractor unit with a quad axle low loader transporter. The following observation and driver-feedback was obtained.

- No issues were observed with sun strike, low light or driving at night. No issues with lighting were reported by the drivers
- Drivers noted where the roundabout appears to tighten-up in the northbound direction as the main issue. The drivers whilst aware of the concerns within the industry felt that for their configuration of trucks the roundabout was generally ok, but for trucks with a higher centre of gravity, with moveable loads (such as Curtain sided B-trains) it would be more of a problem.
- The difficulty in seeing that the roundabout "tightens up" can be seen in the image below.

Figure 14: Northbound approach sightline

- There were comments regarding fatigue, speed and unfamiliarity carrying a particular load being a factor in previous incidents.
- The sightlines to the right is excessive

Figure 15: Northbound approach sightlines to the right

7.4 Onsite and Video Observations

On-site observations were undertaken at the Otaihanga roundabout. Whilst no formal driver workload analysis was undertaken it was noted in the observations that driver's highest workload appeared to occur when travelling in the northbound direction, particularly at the point where the roundabout tightens before the exit. In one fifteen minute period 3 car drivers were observed turning the steering wheel tightly whilst looking visibly uncomfortable.

To allow for comparisons with behaviour at nearby roundabouts that had not been identified as having a high truck rollover risk short observations was also undertaken at the following roundabouts:

- Paremata (On State Highway 1. Speed drops from 100km to 50 km, there is two lanes in both directions both in the roundabout and out each side, therefore no merging required.)
- Plimmerton (it was noted by the Police that the Plimmerton roundabout had had a truck rollover incident). On State Highway 1. No merging in or near the roundabout, lower speed environment, with traffic signals and "your speed" changeable message signs.
- Pauatahanui (On highway 58 in an 80km zone. One lane through the roundabout)
- Otaki (On State Highway 1 50 km speed zone, smaller radius roundabout slows traffic, relatively flat.)

It was not intended that these observations are a full review of the roundabouts or provide formal workload analysis, rather they were undertaken to ascertain any behaviours that might be specific to Otaihanga that might contribute to the higher truck rollover rate. Overall from the following observations were made:

1. Overtaking in the roundabout is higher at Otaihanga than the other roundabouts.

2. Proxy measures of mental workload indicate that mental workload when navigating Otaihanga (particularly in the Northbound direction) is higher. For example, there was a drop-off in secondary tasks (passenger driver communication and drivers undertaking other tasks such as eating and drinking) when navigating Otaihanga. The mental workload appeared to increase in the northbound area from Otaihanga Road north.

3. Vehicles (particularly cars) in the right-hand lane in the northbound direction were observed tracking very close to the central island within the roundabout at Otaihanga, the same behaviour did not occur at the other roundabouts. It was unclear why the drivers did this, two potential explanations could be that they are keeping away from the traffic in the outside lane to avoid conflicts or that they require the extra room to comfortably make the manoeuvre to exit the roundabout. Drivers asked about this were unaware that it was occurring.

4. The video also indicated incidents of car drivers going the wrong way around the roundabout when entering from the northbound direction when there was no other vehicles present. Whilst this is outside scope of this project it is noted due to the potential seriousness of the incidents.

In addition in the northbound direction at the roundabout there was evidence of issues occurring in the Otaihanga Road to the exit of the roundabout while circulating. The issues are outlined in the table below:

Table 5: Roundabout Issues Images

	Vehicle observed stopped in the roundabout whilst circulating picking up an object that had fallen out of the horse float. Stopped in the roundabout between Otaihanga Road and SH1 northbound exit.

	A broken tie-down strap was in the gutter between the exit for Otaihanga Rd and SH1 northbound direction.
	Evidence of a vehicle having run off the road at the exit of the roundabout travelling in a northbound direction.
	Evidence of a second vehicle having run off the road at the exit of the roundabout travelling in a northbound direction. The location of this run off suggests that excessive entry speed is a factor.

8 Feedback from Truck Drivers and Police

Comments were collected from the following participants

- Truck drivers (included drivers of curtain sided B-Trains and Container Units)
- A Police Commercial Vehicle Enforcement (CVIU) officer who had attended 3 of the truck rollovers at the Otaihanga Roundabout
- A local Police Sargent who had attended truck rollovers at the Otaihanga Roundabout
- Capital Journeys Foreman who had responsibilities in the area

The findings have been separated into four categories:

1. Overall Comments
2. Northbound on State Highway 1
3. Southbound on State Highway 1
4. Out of scope issues

8.1 Overall Comments

The following comments were made:

- Drivers noted that "for the trucks that have rolled they have gone through two roundabouts and that this one is the one that trips you up, which suggests that there is something wrong with this roundabout"
- "Worst roundabout had encountered (worst by far) in 25 years driving. Had EBS (Electronic Braking System) for the past 7-8 years and this is the only time it has gone off for the trailer in all that time. As approach roundabout are going downhill, at the point are turning trailer starts to push truck. Cars push truck to outside lane." Don't talk to new drivers about it specifically as they are already aware of it. (Truck Driver/Manager operating in the lower North Island with moving loads such as CO2)
- Two of the drivers had asked other drivers in their company for comments/feedback about the roundabout prior to meeting. The comments the drivers received were from drivers of larger trucks and indicated that they did not feel safe in the roundabout and that it did not drive well in the northbound direction.
- The roundabout is safer than the previous T-intersection. But it is more disruptive to SH1 traffic. (CVIU, Police and most of the truck drivers)

- When becomes a local road, will have less traffic so may have more of an issue as traffic may enter at a higher speed (CVIU Officer 2)

8.2 Navigating the Roundabout

- Noted that are often driving to the full limit of the truck (Truck drivers)
- Try to enter the roundabout in the centre of the left lane, right lane gets used for overtaking, was way were taught. Don't want to frustrate the drivers behind (Truck drivers)
- Drives through the roundabout at 32 km-40km if not loaded (Truck driver with a low load)
- "At night might go faster as not expecting other traffic so can use both lanes 35-40 km roundabout – definitely 40 km is upper limit unless both lanes are used at night." (Truck driver with a low load)
- Driver perception that the safe speed for this roundabout is slower than Plimmerton. Plimmerton 20-25 km, Otaihanga 15-20 km/hr (Truck Drivers of high-sided trucks)

8.3 Positive Comments

- There is no sun-strike issue or issue re: lighting at night (All truck drivers)

8.4 Northbound Findings

8.4.1 Location of any problems

The following comments were made:

- " The roundabout is big, wide and open when coming in, then tightens up, inside the roundabout is much tighter" (Truck Driver)
- Roundabout is badly designed. When going northbound the part after Otaihanga Road "get pushed out" (Truck Driver & Co-ordinator)
- "Problem is 3 switchbacks in short time frame. All the weight goes from one side to the other. Issue is going northbound on SH1." (Police).
- "Could fix the camber in the northbound direction" (Truck driver)
- Concern regarding the footpath – comments re: it only being a matter of time before someone is hit on it (Truck driver)
- Identified the main issue as in the north-bound approach – the S motion particularly for loads with a high center of gravity (CVIU)

8.4.2 Magnitude of the problem

People were asked how this roundabout compares with other sections of road, intersections and roundabouts that they typically encounter, with a further prompting question of where is their biggest area of concern:

- "This roundabout represents the biggest safety issue on the network, the worst part is going north from Otaihanga" (Roading Foreman, Truck Drivers of B-Trains)
- "There has been a few cars spin out and then carry on" (these wouldn't be countered in the CAS data. (Roading Foreman)

8.4.3 Do you communicate anything about this roundabout to new drivers

One operator did not talk about it with his drivers as he assumed that they would already know. For the other companies they would point it out, with one company operating from the Lower Hutt area noting that this was their main concern and as such it was mentioned to all new drivers as well as regularly at their safety briefings as the biggest issue within the area they operate.

8.5 Southbound Findings

No concern was expressed regarding the southbound movement from the truck drivers.

9 Feedback from Car Drivers

Six car (two female and four male) drivers who regularly use the roundabout were spoken with regarding the roundabout. A summary of their feedback is presented below:

- Of the six, two drivers had no problems with the roundabout. One of these drivers reported that they routinely use the roundabout to pass other vehicles as there are not passing opportunities in the nearby vicinity. When asked if they were aware of the truck rollovers, one of the drivers was and the other was not. When asked the driver who was not aware of the rollovers correctly guessed where they might have occurred.
- One driver noted that there are "several different planes causing different gradients meeting at the roundabout which may affect how you approach the roundabout"
- One driver described the roundabout as "looking like a big roundabout – but it isn't a fast roundabout" similarly another driver noted that it "has the appearance of the Hawkes Bay expressway roundabouts which are high speed roundabouts, but this one is not."
- Four drivers expressed concerns regarding the danger to pedestrians from vehicles (northbound on the footpath on the far side of Otaihanga Rd)
- One driver had followed a truck whose trailer wheel lifted as they navigated the roundabout in the northbound direction
- Concern that trucks were tracking between the two lanes. Noted that when approaching from the northbound direction they keep an eye on where trucks are tracking

- Noted concern re: other cars taking a straight line approach through the roundabout and overtaking, with one driver saying that they see frustration on a daily basis at the roundabout
- Negative comments regarding the high level of congestion at the roundabout
- Difficulties in accessing the properties off the roundabout as well as concerns regarding where vehicles either navigating the roundabout to go Southbound (from either Otaihanga Road or Sh1 northbound cross the entry from SH1 Southbound. The roundabout "turbo" markings indicate that shouldn't go close to the roundabout but most vehicles observed went over the hashed lines. Vehicles that did not go over the hashed lines were observed stopping at the entry point for the Southbound vehicles and giving way to them.

10 Truck Rollover Research

To investigate further the role that successive curves may have in truck rollovers research from the Transport Research Laboratory (TRL) in the UK and literature from the United States was reviewed. The term successive curve is used in this context to describe a significant tightening of radius part way around the roundabout. The quote below summarises the issues involved.

"In roundabouts, as at horizontal curves, vehicles with a high center of gravity can overturn or shed their loads if they fail to reduce their speed adequately.

In most cases, truck overturns at U.S. roundabouts have been attributed to excessive speed or hard braking on adverse superelevation. The U.S. roundabout crash sample is small and the commercial driver population is still inexperienced with roundabouts. However, the United Kingdom has about 20,000 roundabouts and 50-60 injury crashes per year involving truck overturns. Most are low speed and do not cause serious injury. The Transport Research Laboratory (TRL) reports five common characteristics of roundabouts with truck overturns:

1. *Long, straight, high-speed approach*
2. *Inadequate entry deflection*
3. *Low circulating flow past the entry*
4. *Clear visibility to the left (U.S. left) and*
5. *Significant tightening of radius part way around the roundabout.*

The U.K. Highways Agency adds three features that may contribute to overturns:

1. *Excessive grade breaks/cross-fall changes on circulatory roadway or exits*
2. *Excessive adverse superelevation on the outside lane of the circulatory roadway, and*
3. *Excessive entry path deflection*

Trucks have sometimes tipped at very low speed (10-15 miles per hour), and the physics are not due to a single radius. A combination of speed, mass, center of gravity and successive curves rocks the suspension at a critical frequency.

Successive reverse curves introduced a rocking motion that increased as trucks traversed the curves, leading to overturn. Timing of the rocking depended on the speed of the vehicle and the harmonics of the suspension. The speed that matches the harmonic may be low, so a faster or slower speed would not cause tipping.

The countermeasure proposed by Crown is to introduce a short tangent section after radius 1 – stabilizing the truck suspension before radius 2. Increasing radius 2 then reduces rocking at that turn, dampening the harmonic." Pp 40-45 Trucks in Roundabouts: Pitfalls in Design and Operations

When reviewing the Otaihanga Roundabout in light of the above research Otaihanga has the following features:

- Clear visibility to the right
- Perception of a significant tightening of radius part way around the roundabout that is not apparent when entering the roundabout
- Low circulating flow past the entry

11 Discussion and Recommendations

This reports suggests the following:

- The incidents of truck rollovers at Otaihanga Roundabout in the northbound direction indicated a higher rate than other nearby roundabouts. The rate from 18 months of data is greater than that for 5 years comparison at the other roundabouts. Whilst 18 months of data is not conclusive the trend is concerning.
- This higher rate of truck rollovers in the northbound direction also includes a higher rate of incidents where the truck was the only vehicle involved which could suggest that driver error is a bigger contributing factor to these crashes.
- The ride-alongs, onsite and video observations indicated that both the northbound and the southbound approach has clear visibility to the right, with the southbound direction providing more readability cues as to the layout of the roundabout, with the northbound approach providing little readability of the curve radius from the Otaihanga Road entry point to the northbound exit..
- Feedback from truck drivers, police and car drivers notes that the most negative comments came from drivers of larger trucks. The negative comments related to the northbound direction and that both the Police and truck drivers indicated serious concerns for travel in this direction.

From a human factors perspective using the human error failure model that is presented in Section 3 of this report the main areas where errors are occurring relate to the diagnosis, prognosis and action stages of navigating the roundabout when travelling in the northbound direction. Specifically these failures relate too:

- There is an incorrect evaluation of the road difficulty of the roundabout as a driver approaches the roundabout, and this is leading to a speed that is too high for safely negotiating the roundabout in the northbound direction.
- When entering the roundabout for the first time there is no expectation that there is a perturbation ahead.
- At the point where a driver encounters a difficulty there is limited ability to re-gain control of a vehicle

A discussion of proposed treatments to address the above treatments is provided in the following sections.

11.1 Northbound Direction of Travel

When approaching the roundabout from the northbound direction it appears that there is a clear, wide visual angle in both directions. However, it is not visually apparent that the roundabout has successive curves, that is, the curve radius significantly tightens part way around the roundabout, before the curve reverse. This may cause drivers to enter the roundabout at a speed higher than is optimal to safely navigate the roundabout (Waddell et al, 2009).

As the speed for different configurations of trucks is likely to be different, a blanket lowering of speed for trucks is unlikely to have prevented the rollovers, as at least one truck was travelling under 30 km/hr (it is unclear what speed the other trucks were travelling, though speed is noted as a factor in some of the reports). Lighting or sunstrike does not appear to present any concerns at this roundabout.

The greatest issues appear to be trucks with particularly of loads with a high centre of gravity or a moveable load (e.g., B-Train curtain side trucks, fuel tankers etc). It would be possible to establish for these types of vehicles the speed required to get a wheel lift using simulation software (e.g. using PC Crash). This would provide an objective value from which speed interventions could be based as well as provide an objective check with respect to perceptions regarding the geometry. In addition, other factors identified from both discussion with drivers, CVIU, Police and the crash reports suggests that there are issues relating to vehicle loading, driver fatigue and drivers driving different loads to what they are used to. While these factors are not specific to this roundabout it is important to note that they are also relevant contributing factors.

11.1.1 Potential Countermeasures

Based on the evidence to date, a realignment to remove the successive curve should be considered as the ideal solution for the northbound direction of travel. Discussion with NZ Transport Agency staff suggested that this could potentially be achieved when the road reverts back to being a local road via implementing a single lane operation.

In addition, to remove wider potential risk to pedestrians, consider closing/shifting the footpath that runs between Otaihanga Road and the Northbound exit of the roundabout. It is not clear that this section is used or needed.

If the above solutions are not selected as an option, the following potential countermeasures could be considered to invoke a sense that this roundabout requires a drop in speed and has successive curves.

To change the guide signs to better represent the path of the roundabout, and to make it visually clearer that there is a tight curve and switchback when entering the roundabout.

- Guide signage could be used to provide meaningful information to prime drivers to the exact pathway represented at this specific roundabout (i.e. explicitly show a roundabout diagram that shows the exit locations, including how the SH1 Northbound exit is further offset than previously encountered roundabouts). The signage needs to indicate that this roundabout differs from the ones ahead (in both directions) and that trucks need to be navigate it at a lower speed.
    - Additional visual delineation cues to improve understanding of the exact pathway earlier. This could include consistently spaced visual markers on the edge of the roundabout (both the outside North bank and on the roundabout). For example, edge marker posts or a similar consistent vertical visual treatment could be investigated (as drivers already have familiarity with and look for these cues in path negotiation).
    - The centre line delineation could also be examined for improvement if trucks are primarily taking the outside lane, as the tangent point on this inner curve is a critical cue.[5]
    - Visual countermeasures could be considered to reduce high approach speeds. It is noted that a 2008 conference paper from report from Kennedy indicates that screening of the central reserve, until 15m of the limit line can reduce speeds. They note that the screening would need to be at least 2m and could be man-made or vegetation. They further note that care needs to be taken that drivers don't continue into the roundabout at their current speed if they are not accustomed encountering circulating traffic (which may be a problem at Otaihanga). Given the downhill approach to the roundabout this may be difficult to achieve.

11.2 Southbound Direction of Travel

Whilst the southbound direction of travel presents less of a concern than the northbound. Given the two incidents of trucks going straight through the roundabout a low cost countermeasure ensuring that the bounds of the centre island are demarcated.

[5] When negotiating horizontal curves drivers rely on the "tangent point" (extreme point) on the inside curve, scanning this location about 2 seconds in advance (e.g. Land & Lee, 1994). For a right turning curve at this roundabout this would mean drivers primarily utilise the centre line delineation and the edge line delineation beside the roundabout (based on whether they are in the left lane or right lane respectively).

11.2.1 Potential Countermeasures

For the Southbound direction consider extending the existing chevrons in the roundabout further to the left, so that they are directly in front of a driver when stopped in the inside lane.

11.3 General studies to consider

- A human factors observation study be conducted if the above treatment recommendations are trialled to determine evaluate if the treatments improve driver behaviour at the roundabout. This should be combined with a speed survey to evaluate if drivers are entering the roundabout at lower speeds.

- Undertake wheel lift analysis to provide evidence-based speed guidelines to drivers of trucks with a high centre of gravity. This could also be used to determine the threshold of operational truck speeds at which successive curves become problematic.

11.4 Outside Scope

It is further recommended that the Transport Agency revisit how the markings and entry/exit into the existing properties accessed from the roundabout is working to determine if their intent could be achieved in a safer way.

12 References

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