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Factors influencing red light running – a Christchurch investigation

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Abstract

Drivers running red lights at signalised intersections risk causing crashes with other road users. Christchurch Transport Operations Centre (CTOC) and Christchurch City Council (CCC) collectively consider that there is a high level of red light running (RLR) in Christchurch City, and are attempting to quantify the extent to which RLR is a safety problem and explore methods of addressing it.

This paper gives a strategic overview of three projects currently being headed by CCC and CTOC to analyse and address red light running in Christchurch. The paper also summarises the work done to date to provide a theoretical framework for why people run red lights and to provide some quantitative analysis of the existing problem in Christchurch.

1 Introduction

Drivers running red lights at signalised intersections risk causing crashes with other road users. Red light running (RLR) crashes account for approximately 35% of all injury crashes at signalised intersections in Christchurch, and a strong correlation with right-angle (HA) crashes is evident. This proportion of RLR crashes is very high compared to the crash patterns exhibited in other New Zealand cities, where other crash types were more predominant.

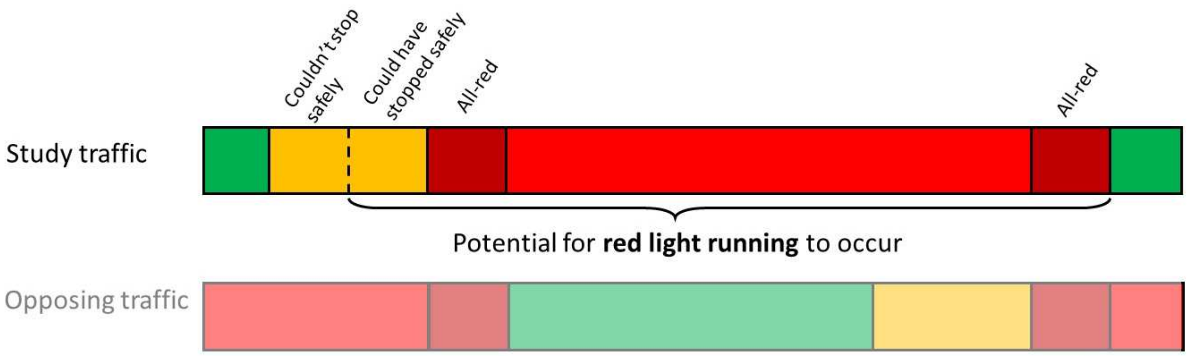
Based on professional experience and anecdotal observations, Christchurch Transport Operations Centre (CTOC) and Christchurch City Council (CCC) collectively consider that there is a high level of RLR in Christchurch City, and want to quantify the extent to which RLR is a safety problem and explore methods of addressing it.

This paper gives a strategic overview of three projects currently being headed by CCC and CTOC to analyse and address red light running in Christchurch. The paper also summarises the work done to date to provide a theoretical framework for why people run red lights and to provide some quantitative analysis of the existing problem. The concepts discussed in this paper are not limited to Christchurch and may be applicable throughout New Zealand, and abroad. While the three projects only study motor vehicles, many of the points raised may also be pertinent to other road users such as cyclists.

1.1 Red light running definition

In this paper, the term "red light running" (RLR) broadly covers all instances when a driver transgresses a traffic signal that they should have stopped for. This includes running a yellow signal when the driver could have (or should have) been able to stop safely, running a red signal during the intersection's all-red phase, running a red signal while opposing traffic has a green signal, and anticipating the onset of a green signal. Figure 1 graphically explains this.

Figure 1: Potential for red light running occurrence during signal cycle



1.2 Project descriptions

Three projects that consider RLR are currently being undertaken by CTOC and CCC:

1.2.1 (A) Red light running investigation

ViaStrada have been commissioned by CTOC to investigate the causes and extent of RLR, with a view to developing solutions to reduce its frequency of occurrence and / or consequences. This study has comprised two main streams of parallel work to date:

- A "think piece" was developed by ViaStrada, with input and validation by Mackie Research, to provide a theoretical framework for why people run red lights. This is discussed further in sections 3 and 4 of this paper.
- A separate quantitative study explored the existing prevalence of RLR and RLR-related crashes in Christchurch. This made use of the NZTA Crash Analysis System (CAS) data and RLR data reported by traffic signal controllers to the central traffic signal management system, SCATS[1].

Based on manual observations set up to validate the RLR events reported in SCATS, it was found that the signal controllers excessively over-counted for the study sites considered. While it was considered useful to analyse the trends from SCATS data, there were significant concerns with the ability to use existing traffic signal inductive loops to accurately gauge levels of RLR across the city.

As a result of these findings, ViaStrada decided to pursue the development of video learning technology (i.e. "machine vision" or "image processing") to detect and record RLR events, with assistance from Catalyst IT. It is hoped that this would make the process of trying to quantify RLR and observing trends at selected sites across the city easier. The task has started with "proof of concept" investigations to determine whether existing hardware (mainly CCTV cameras at intersections) and software can be used for this purpose. If it proves to be too difficult to use the existing images, the next step would be to trial other camera equipment. The option of purchasing a red light safety enforcement camera(s) (which can produce footage to the standard required for legal action) was rejected for this particular project, as the expense and effort required for each camera would limit the extent of coverage possible.

1.2.2 (B) Red light safety camera implementation

The second project regarding RLR is being undertaken by CCC's transport planning team, with assistance from Beca. The aim is to get a better understanding of detecting RLR in real time and applying enforcement to reduce RLR. This will involve purchasing a red light safety enforcement camera and using it to obtain video footage of RLR events at all approaches of

[1] Sydney Coordinated Adaptive Traffic System – i.e. the software that manages the dynamic timing of traffic signal phases in Christchurch.

selected intersections. Ultimately, discussions also need to be had with NZ Police regarding their ability to process infringements arising from the resulting footage.

The camera is due to arrive in Christchurch in September 2017. It is understood that these cameras are also able to undertake speed enforcement as well. Three indicative sites to be observed have been selected. However, alternative sites could be used, particularly to align with project (A) in 1.2.1. Assuming that the trialling is successful, the resulting data can be then analysed for trends, compared with the results from project (A), and passed onto the Police for their assessment of enforcement practicality.

1.2.3 (C) Red light running road safety campaign

The third project is being undertaken by CCC's travel demand management team, with the help of Opinions Market Research. Their aim is to gather information that will inform an educational campaign around influencing behaviour at intersections. The project aims to understand the attitudes and perceptions to yellow/red traffic signals, in particular:

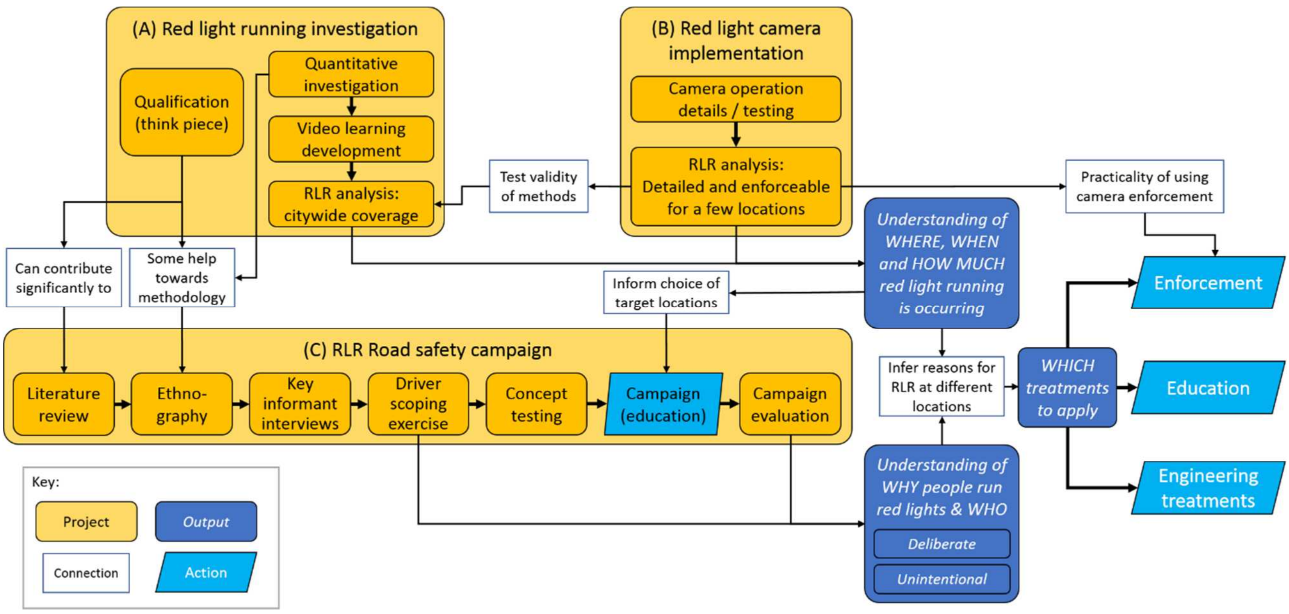
- Why drivers run yellow and red lights
- What are the factors that lead to these?
- Identify which statements resonate with the audience that can result in these people rethinking their driving behaviour.
- When and how this message should be delivered.

The project team is currently reviewing background information to help inform the development of the qualitative survey instruments. The findings from the resulting market research will then be used to develop and deliver suitable RLR campaigns.

1.3 Relationships between projects

The key linkages and considerations between the three projects are shown in Figure 2:

Figure 2: Relationships between red light running projects and combined outputs



The combined findings from these three projects should help with the following actions:

- **Enforcement:** Successful testing of a red light safety camera (project B), and acceptance by the Police of its validity and practicality could lead to the beginning of regular camera enforcement of RLR in Christchurch. Additional safety cameras might also be purchased, and the data from projects (A) and (B) can help to inform the best locations to target enforcement.

- **Education:** The market research work (project C) and previous think piece investigations (project A) will help to confirm the most effective ways to influence road user behaviour and to guide the subsequent campaign(s) developed and delivered.
- **Engineering:** The quantitative analysis of RLR incidence at different sites (projects A & B) will help to identify site-specific factors that may be contributing to higher-than-average RLR rates. This evidence can be used to justify the implementation of engineering works to reduce the likelihood or consequences of RLR events.

It should be noted that interventions such as red light safety cameras or education should not be used as a band-aid over existing deficiencies with a site. A high standard of intersection layout and signal design should be a prerequisite before considering other options.

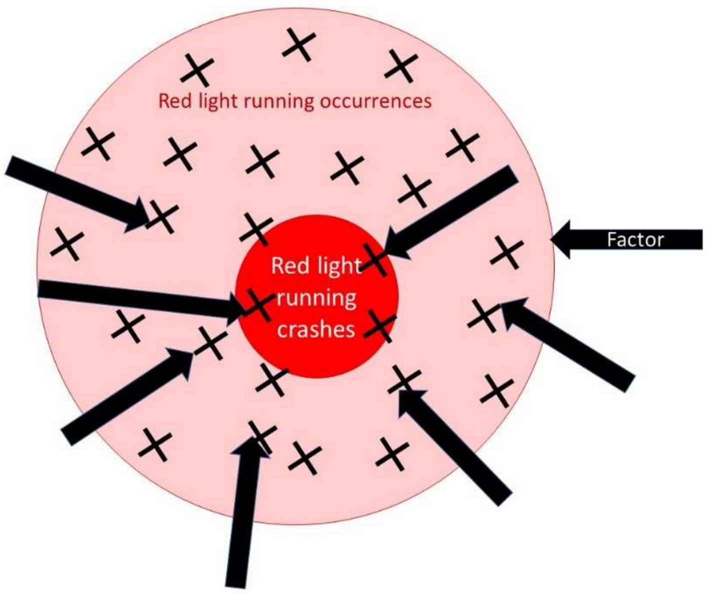
2 RLR factors, occurrence and crash outcomes

The first step towards addressing RLR is to understand its causes. The "safe systems" approach recognises that the whole transport system (roads, speeds, road use and vehicles) can contribute to road safety. Therefore, a number of different causal factors can contribute to the occurrence of RLR occurrences.

Not all incidents of RLR result in a crash; certain factors that cause RLR may have a stronger influence on whether a RLR occurrence results in a crash, and may also influence the severity of the crash. For example, a person running a red signal late at night may encounter less opposing traffic (and hence less chance for a crash) but may be more able to make the manoeuvre at higher speed (thus increasing the likely severity of the crash).

These elements (causal factors, RLR occurrences and RLR crashes) are illustrated conceptually in Figure 3.

Figure 3: Conceptual relationship between causal factors, RLR occurrences and crashes



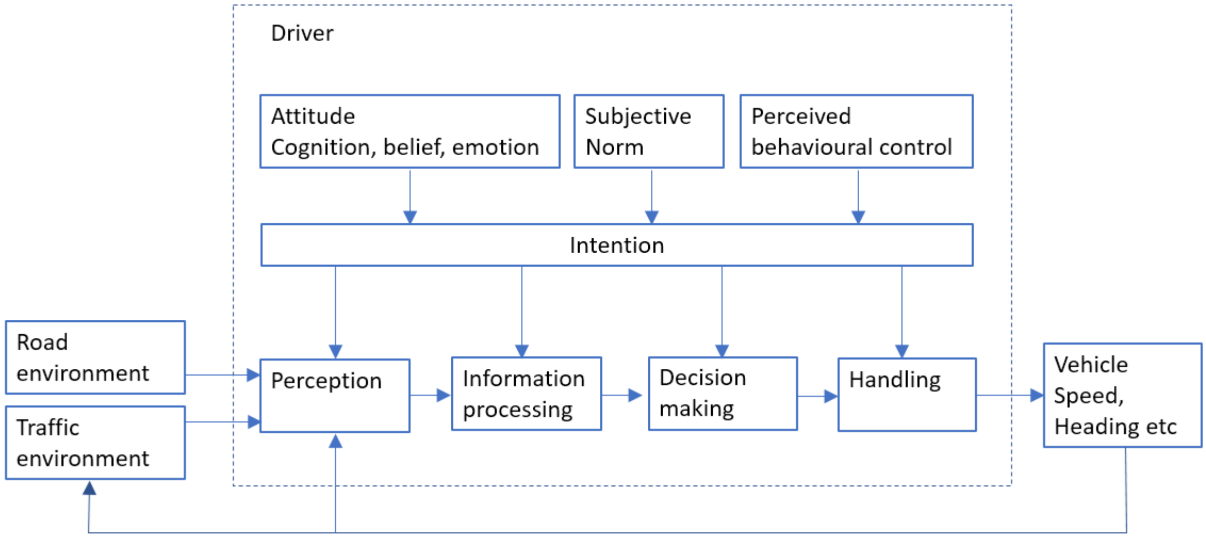
The intention of this theoretical work was to focus on the factors that influence the occurrence of running of a red signal, or a yellow signal where the driver could have stopped safely, without narrowing this down to only include those occurrences that result in a crash.

Different structures can be used to explain the significance of and interactions between the identified factors. Two particular structures are presented in this paper: a driver behaviour model (section 3) and a RLR factor framework (section 4).

3 Driver behaviour model

To understand the key system components that are likely to relate to driver performance as they negotiate signalised intersections, it is useful to draw on existing conceptual models of driver behaviour. A number of models exist (e.g. Summala, 1996; Fuller, 2005), which all have slightly different areas of focus. An example that may be useful for the study of RLR was developed by TNO ("The Netherlands Organisation for applied scientific research"):

Figure 4. TNO model of Driver Behaviour; reproduced from (FHWA, 2005)



The TNO model is influenced by Ajzen's Theory of Planned Behaviour, and by the widely used Perception-Decision-Action (PDA) cycle. Basically, the model shows that a driver responds to the surrounding road and traffic environment, but their behaviour is also moderated by established attitudes, norms and the extent to which a driver feels in control of their situation (which is highly influenced by competency).

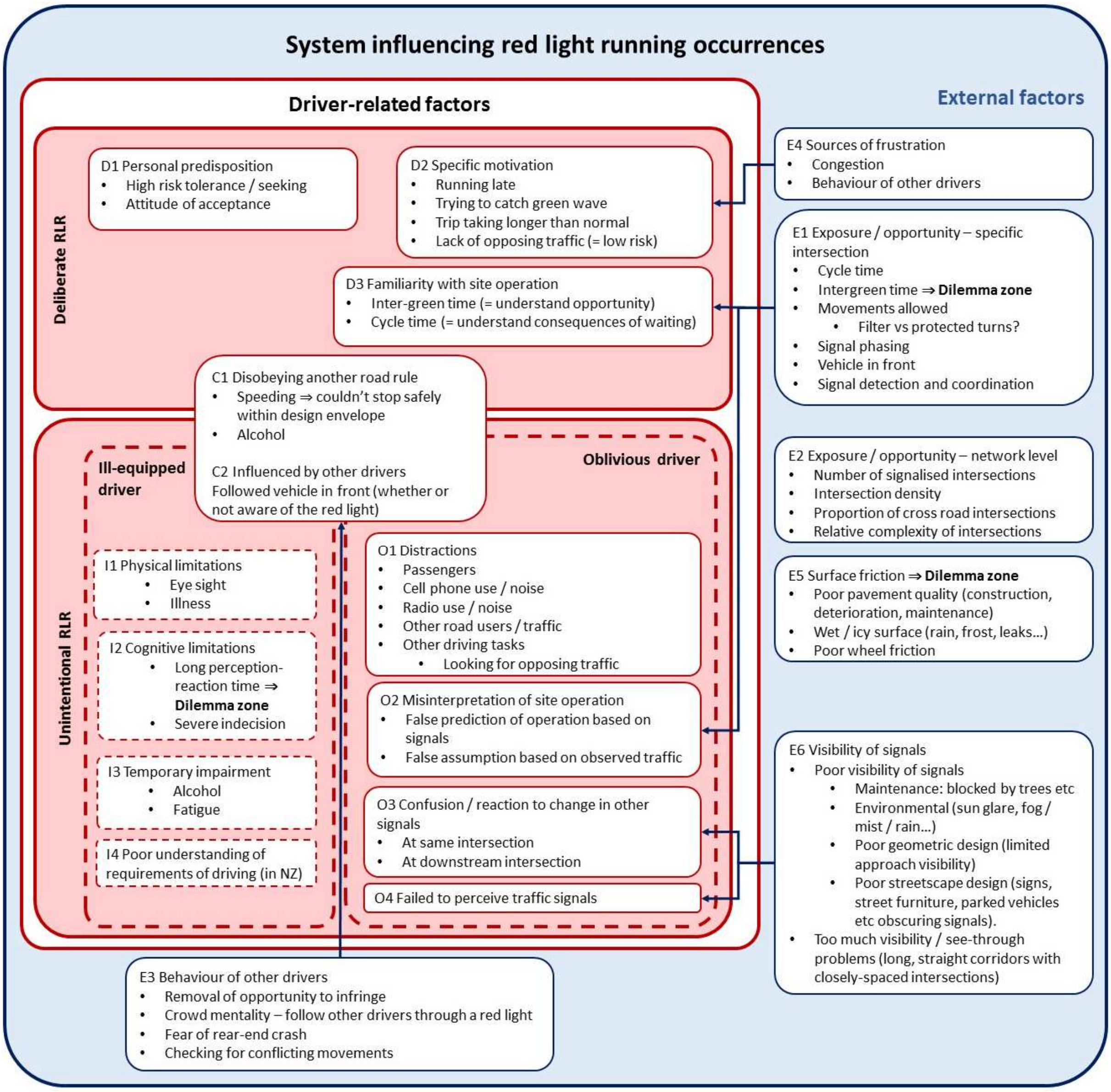
This model is useful for understanding RLR because literature, as outlined later, suggests that both environmental and personal factors are likely to influence the likelihood of RLR (e.g. Porter and Berry, 2001; Bonneson and Zimmerman, 2004; FHWA, 2009; Palat and Delhomme, 2012). However, a limitation of this model is its lack of deeper explanations of the potential perception, information processing and decision-making mechanisms. For example, a driver may inadvertently miss a red light or they might deliberately choose to run through it. Because, the mechanisms and likely countermeasures to address the mechanisms are very different, it is important also to consider basic theory of error types.

James Reason's "Swiss Cheese" model (Reason, 1990), explains that unsafe acts have either errors or violations at their origins. Errors include skill, decision or perception based errors and all lead to situations where a driver inadvertently commits an unsafe act. Violations on the other hand, include "routine" and "exceptional" violations. A driver pushing the limits by deliberately proceeding through a yellow light, perhaps due to time pressure, might be an example of a routine violation – it is commonplace and routine for many drivers. Conversely, A driver, making a calculated high-risk manoeuvre to speed through a red light, perhaps under extreme duress, is an example of an exceptional violation. For RLR, it is important to distinguish at least between inadvertent (oblivious) and deliberate RLR, so that interventions can be matched to error mechanisms and planned accordingly.

4 RLR factor framework

Figure 5 presents a proposed framework of factors influencing RLR, derived from literature review and experience in the traffic engineering field. It reflects the driver and external factors that are likely to affect RLR and also the different error types that are possible by drivers. The framework focusses less on the mechanisms of driver behaviour and more on factors that might be influenced by interventions of various kinds.

Figure 5: Proposed framework of factors influencing RLR



This theoretical exercise focuses on first understanding the general dynamics and behaviours involved in the driver's response to the system – i.e. whether they ran a red signal as a deliberate choice, or due to being oblivious to the present situation (even though they would normally be capable of undertaking the desired behaviour), or because they are ill-equipped to undertake the task of driving safely through a signalised intersection.

The framework also acknowledges that there are a number of factors in the system that are external to the driver, and can influence the driver's behaviour. Many engineering treatments focus on modifying these external factors so that drivers respond more appropriately to the system, and there is a reduction in occurrences of RLR.

These groups, the various sub-factors, and the major linkages between factors are discussed in the following sections (NB: factor codes given refer to those used in Figure 5).

4.1 Drivers deliberately choosing to run a red signal (code D)

Many RLR infractions are deliberately undertaken by a driver for a variety of situational or behavioural reasons. While some drivers are recidivist red light runners, others choose to ignore a particular red/yellow signal only on a few specific occasions.

4.1.1 Personal predisposition (D1)

This refers to a person's general attitude towards RLR. The tendency towards RLR varies from driver to driver; some are more predisposed than others (i.e. more likely) to run a red light, in general. Personal predisposition may also be influenced by the behaviour of other drivers (and crowd mentality, referred to in section 4.5.3, particularly at a specific location or in a certain area, in that if the driver considers that "everyone else does it", they may be more likely to do so as well. People's practices at one location may, by habit, be translated to another location where RLR is not so endemic.

Drivers who choose to run a red light *deliberately* (with a clear understanding of the situation and the risks involved) have a high risk-tolerance and may be described as thrill-seekers. A number of studies (e.g. Porter and England, 2000; FHWA, 2009; Palat and Delhomme, 2012) have shown a correlation between RLR and not wearing seatbelts, which is another behaviour that indicates either a high level of risk-tolerance or a poor appreciation of the risks involved.

Alternatively, drivers may make a deliberate choice to run a red light because they don't fully understand the dangers involved, and weight their perceived consequences of RLR as less important than other factors (e.g. specific motivations – see 4.1.2).

The Theory of Planned Behaviour (the foundation of the driver behaviour model presented in section 3) defines driver "attitudes" as being their personal preferences, and distinguishes this from "subjective norms" (how the driver perceives what their significant others would think of their behaviour, or the observed behaviour of other drivers) and "perceived behavioural control" (the chance the driver thinks they will have of 'successfully' running the red light, i.e. without crashing or getting caught). In this framework, the concept of 'personal predisposition' to RLR includes all three elements, without distinguishing between them.

4.1.2 Specific motivation (D2)

In conjunction with (or even, in-spite of) a driver's predisposition to running a red light, there may be specific factors at a particular time or location that increase their inclination to running a red light in a specific situation.

Motivations may be brought about by the state of the system, for example:

- Congestion (see also 4.5.4) increasing delays and travel times
- Lack of opposing traffic (i.e. the driver perceives there is a no/little risk of their RLR resulting in a crash)
- Green wave coordination (see also 0) – e.g. a driver turning onto the coordinated corridor from a side street may be inclined to run a red light to catch the end of the green wave along the corridor (Ranasinghe, 2005).

Motivations may be directly related to the driver's personal experience, for example:

- Running late, thus trying to make up for lost time
- Personal circumstances that cause anger or frustration and lower a person's fear of consequences, thus increasing their risk tolerance.

Note, though, that when Porter and Berry (2001) surveyed 880 licensed drivers in the United States, they found that frustrated drivers are more likely to speed, tailgate, weave and gesture angrily than to run red lights and thus postulated that RLR may simply be a form of aggressive driving, i.e. a **predisposition** (see 0).

4.1.3 Familiarity with site operation (D3)

A driver who understands how a specific intersection is operated understands the risks involved, and can identify the times where their signal may be red but there is no crash risk. These drivers might undertake manoeuvres such as:

- Anticipating the green – noticing that the signals for opposing traffic have turned to red, understanding that their phase will be called next and proceeding during the all-red phase, just before their signal turns green.
- Pushing the red – if the driver understands the all-red phase, and/or knows the next phase doesn't include any conflicting movements, they may be more likely to continue through at the start of the red phase.

Also, if a driver perceives that the consequences of stopping for a red signal are particularly high (e.g. they know that the intersection has a particularly long cycle time) they may be more likely to tolerate the risks involved in running a red light, in favour of being subjected to the certain consequences of waiting.

4.2 Drivers who are ill-equipped and run red signals (code I)

Some drivers who run red signals may do so simply because the task of identifying, processing and responding to the situation is beyond their capacity, either due to long-term or temporary factors. The driver licensing system is designed to help reduce such instances, through supervised learning to drive and assessments of medical fitness to drive.

4.2.1 Physical limitations (I1)

Physical factors that limit a driver's capability to respond appropriately to a red light include:

- Poor eye sight – unable to distinguish the red light (e.g. colour blindness)
- Physical weakness – e.g. lacking the necessary strength to brake strongly
- Physical disability – e.g. lacking the necessary physical elements and / or coordination

4.2.2 Cognitive limitations (I2)

Personal cognitive factors that limit a driver's capability to respond appropriately to a red light may include:

- Having longer perception-reaction time than is designed for (often gets worse with age)
- Being subject to severe indecision

Each of these would increase the chances of a dilemma zone occurring, i.e. the driver not making a decision until they no longer have a safe option available, or of the driver making the wrong decision (i.e. to continue through when they should have stopped, or vice versa).

Learner drivers are a particular category of people who often suffer from poor decision-making at signalised intersections. Often, they are still determining the capabilities of their vehicle (e.g. in terms of braking deceleration), still learning to judge how long it takes to go through an intersection, and may also have difficulty quickly discerning a change in traffic signals from the other stimuli they are observing. While typically their skills will improve with practice, at any given time there is likely to be a proportion of drivers in the network who are still learners.

4.2.3 Temporary impairments (I3)

A driver who is otherwise capable of responding to a red light may be temporarily impaired by factors such as:

- Alcohol / drugs
- Fatigue
- Illness / medical emergency

4.2.4 Poor understanding of NZ road rules and driving requirements (I4)

Some drivers may have insufficient understanding of the specific requirements for driving in New Zealand. Such people could include:

- Overseas visitors – who may be competent in their home country but not understand the differences for driving in New Zealand (e.g. the amount of time given to yellow and all-red phases).
- Learner drivers – who are going through the process of acquiring the capability of driving, but are not yet fully competent.

4.3 Drivers oblivious to running a red light (code O)

Some drivers who run red lights may be objectively competent to identify, process and respond to a red signal but are rendered oblivious to a particular instance of a red signal, perhaps due to one of the following factors.

4.3.1 Distraction (O1)

A driver may not have noticed the red signal because their attention was diverted to something else. Such distractions could include:

- Passengers
- Cell phone use or noise
- Radio use or noise
- Other road users / traffic
- Other interesting things outside the vehicle (e.g. advertising)
- Demands of other driving tasks (high mental workload) – e.g. someone wanting to filter turn, looking for a gap in opposing traffic, and not noticing that the signal has changed.

4.3.2 Misinterpretation of site operation (O2)

Drivers may misinterpret the site operation, which could lead to RLR. This could involve:

- Drivers incorrectly assuming they understand the site operation – e.g. assuming their movement will follow another (compare with section 4.1.3 which discusses what might happen when the driver does correctly understand the operation)
- Drivers seeing traffic coming towards them in the opposing direction and mistakenly assuming that they must also have a green signal.

4.3.3 Confusion from change in other traffic signals (O3)

Drivers react to change. A driver waiting at a red light may react to the traffic signals changing:

- For another movement – a common example is a location where opposing right turns are operated; through-traffic often makes a false head start when the green arrow for the adjacent right turners is displayed.
- For the immediately downstream intersection (**see-through effect** is discussed in 4.5.6).

Drivers reacting to a change in traffic signals for other movements may either make a false start but then stop before properly entering the intersection, or continue through.

4.3.4 Failure to perceive traffic signals (O4)

Drivers may be oblivious to a red signal because they cannot adequately see it. The factors that may influence this are outlined in section 4.5.6. This is ideally dealt with by having multiple signal sets for each approach around the intersection, although large vehicles blocking views and signals not working will reduce their effectiveness.

4.4 Factors that could be common to all types of drivers (code C)

There exists a great number of inter-relationships and overlaps between the factors that have been discussed thus far, but it is considered even more difficult to categorise the following factors as relating to deliberate, oblivious or ill-equipped drivers.

4.4.1 Violating another road rule (C1)

Disobeying a different road rule could lead to running a red light. For example:

- Speeding – a driver approaching an intersection at speed may not be able to stop safely within the design safe-stopping envelope, and thus continue through a red light.
- Driving under the influence of alcohol or drugs.
- Trying to escape a Police officer.

It could be debated whether drivers in these categories have been rendered oblivious or ill-equipped, or whether their deliberate choice to violate road rules relating to speed or alcohol constitutes a deliberate choice to accept the associated risks involved.

4.4.2 Influenced by other drivers (C2)

Drivers may be influenced by the presence / actions of other drivers and run a red light by following another vehicle through the intersection (in a situation where they would have stopped had they been the lead driver). This could be either:

- Deliberate – i.e. the following driver knew the signal had turned red, but chose to continue, comforted by the fact that they 'weren't the only one doing it.'
- Oblivious – i.e. the following driver was focusing on the vehicle in front, not the traffic signals (this also fits in section 4.3.1)
- Ill-equipped – i.e. the driver was not capable of judging the situation for themselves and used the actions of the vehicle in front to guide them.

When considering a particular driver, all other drivers are effectively external factors – hence the influence of other drivers is also considered in 4.5.3.

4.5 External factors (code E)

Not all RLR factors are related to the infringing road user; there may also be aspects of the surrounding road environment and other road users that also influence the propensity to run red lights and to suffer RLR crashes.

4.5.1 Exposure / opportunity – specific intersection (E1)

RLR can only occur if drivers have the ***opportunity*** to infringe. At a given intersection approach, only drivers with a clear path to the limit line during a yellow or red signal have opportunity to infringe. A driver going through an intersection on a green signal cannot run a red signal, nor can a driver that is following a vehicle that stops at a yellow or red signal.

At a specific intersection, the opportunity to infringe can be influenced by:

- Intersection cycle time / frequency of cycle – a longer cycle time means that there are fewer phase transitions between green and red across a given time period. People are more likely to run a red light at the start or end of the phase (Bonneson, et al., 2002); increasing the cycle time decreases the chances for this to happen.
- Intergreen time (i.e. yellow plus all red time) – a longer intergreen time arguably increases opportunity to infringe, as people are exposed to a longer time window in which they may violate a yellow / red signal while opposing traffic still does not yet have a green (see for example: FHWA, 2009; Webb and Williamson, 2014; Elfar, et al., 2017).

  - Conversely, a shorter intergreen time is more likely to result in a **dilemma zone** for certain drivers, where they may not have the time to progress through the intersection in time to avoid conflict with the opposing movement but are also at risk of overshooting the limit line (and rear-end crashes) if they stop instead (see for example: Menzies, 2002; FHWA, 2009).

- Movements allowed - Movements that are more complex (i.e. are more demanding to undertake) are more susceptible to driver error, and those that have a smaller window of opportunity during the phase are more open to drivers choosing to infringe. Also, including more movements through the intersection increases its overall complexity.
  - In particular, filter turns through opposing traffic place a high demand on drivers' cognitive ability (therefore, a higher risk that drivers will make mistakes), they are also susceptible to a higher degree of driver **frustration** (while waiting for a gap – see 4.5.4) which can lead to deliberate RLR at the end of a filtered phase.
- Signal phasing – drivers waiting at a red signal often react to signals for another movement changing to green, e.g. a driver heading straight through making a false start when a green arrow appears for a lead right turn movement, whilst the round disc remains red (a similar problem can occur when green cycle signals are used). This is particularly likely if the intersection phasing does not follow the expected sequence, either because it varies at the particular intersection, based on demand at the time, or because it is different to that at nearby intersections.
- Vehicle in front – a driver who stops at a yellow or red signal has rejected their opportunity to infringe, however, the driver following behind them has no opportunity to infringe. If the first driver had not been present, the second (and subsequent) driver(s) may well have chosen to run the yellow or red signal. Note that this is linked to **behaviour of other drivers** (4.5.3).
- Signal detection and coordination – FHWA (2009) found that signals that are vehicle actuated (i.e. demand-responsive) and those on coordinated ("green wave") corridors have greater rates of RLR, due to higher numbers of vehicles being exposed to the intergreen period.

Most studies measuring RLR use metrics such as number of RLR occurrences per hour, or per vehicles entering the intersection. These metrics assume that the opportunity to infringe is roughly constant across all intersections but in reality, as illustrated by the discussion above, different factors can influence the opportunity to infringe. It would be more appropriate to normalise the rate of RLR occurrences against the number of drivers who had the ***opportunity*** to infringe, rather than including those who went through on a green signal or were blocked by preceding vehicles, although even this metric is not infallible.

4.5.2 Exposure / opportunity – network level (E2)

Drivers making a trip generally encounter more than one intersection. Therefore, there are factors at a network level that can affect drivers' opportunity to infringe; these include:

- Number of signalised intersections in the network – a greater number of signalised intersections increases a driver's chance of encountering a red signal along the journey.
- Intersection density – if intersections are more closely-spaced, drivers encounter more signals over the same journey length (and **congestion** – see 4.5.4 – is also likely to increase). They may also be able to see other nearby intersections and be confused by which signals they are meant to be obeying (see 4.5.6).
- Proportion of cross-road intersections – intersections with straight-through movements (e.g. cross-roads) provide greater chance to travel at higher speeds through them. This increases the likelihood of not being able to stop safely when the signals change, and

increases the relative severity of any red-light running crashes. T-intersections and intersections with curved approaches result in slower movements through them.

- Relative complexity of intersections – as complexity increases (and often the relative congestion), so does the proportion of red time within a cycle that drivers are exposed to. This may encourage more red-light running, as drivers try to get through the intersection as soon as possible.

4.5.3 Behaviour of other drivers (E3)

When considering a particular driver, all other drivers are effectively external factors. A driver's opportunity to infringe a red light and decision to do so may be influenced or restricted by the actions of the driver in front or behind them:

- Removal of opportunity to infringe – as noted in the discussion on **opportunity to infringe** (0), a driver who stops at a yellow or red signal restricts the options of the driver following behind them - they can no longer choose to run the red signal.
- Crowd mentality / behaviour – drivers who would have otherwise stopped at a yellow/red signal may choose to run the light because they have been influenced by the driver in front of them that made this choice first (see 4.4.2). Poor crowd behaviour patterns in a particular area/site may well be a reflection on the level of service provided there.
- Fear of rear-end crash – if a driver perceives that the car behind them is close, they may be more likely to run a yellow / red signal, to avoid the risk of being hit by the following vehicle if they chose to stop.
- Checking behaviour of conflicting motorists – a red-light running crash also depends on the behaviour of the other potential party. For example, if drivers are in the habit of checking for crossing traffic before they enter a signalised intersection (either while continuing through or when starting off) then they are less likely to collide with a driver running a red light.

4.5.4 External sources of frustration (E4)

A driver who is frustrated is more likely to take greater risks. Sources of frustration that are external to the driver may include:

- Traffic congestion – due to network inefficiencies, or insufficient capacity for the level of demand. A driver may not wish to wait another signal cycle to depart the intersection.
- Undesirable behaviour of other drivers – e.g. travelling behind a slow driver along the midblock, and not wanting to get stuck at the signals as a result.

4.5.5 Surface friction (E5)

Surface friction affects the ability of a vehicle to stop within the design stopping distance, and can therefore result in a particular driver encountering a dilemma zone (perhaps without knowing it). Poor surface friction may occur due to:

- Poor pavement quality - as a result of low-texture surfacing, poor construction, deterioration, and / or insufficient maintenance.
- Wet/icy surface - due to rain, frost, leaking service pipes, etc
- Poor wheel friction - due to worn tyres, ineffective shock absorbers, lack of anti-lock braking system, etc

Drivers who are aware that the surface friction is poor and would affect their ability to brake effectively may choose to run a yellow/red signal rather than risk stopping ahead of the limit line (or losing control). Conversely, drivers who are unaware of the situation may attempt to brake but find that they cannot stop prior to the limit line and must run a red signal to clear the intersection.

4.5.6 Visibility of signals (E6)

The extent to which drivers can see the traffic signals can influence their ability and willingness to make appropriate decisions regarding yellow or red signals:

- Poor visibility of signals – if approaching drivers are unable to see the signals in sufficient time, they are unable to make appropriate decisions.
    - This could be due to: poor maintenance (trees blocking view, signals not working); environmental conditions (sun glare, fog, rain, etc); poor geometric design (limited approach visibility); poor streetscape design (signs, poles, etc obscuring signals).
- Too much visibility of signals – the ***see-through problem*** occurs when a driver can see the signals at a downstream intersection and reacts to them as if they related to the intersection the driver is actually at. Drivers respond to *change* in signals (especially when in their peripheral vision), thus see-through is a particular problem if the driver is waiting at a red signal and the downstream signals change from red to green. Long, straight corridors and signalised intersections in close proximity to others are most at risk of experiencing see-through problems.[2]

5 Validation of theoretical models

As described in section 1.2, more comprehensive evidence for RLR patterns is being sought via the red light safety camera and machine vision trials. However, some indicative data from the quantitative work to date can already be used to determine whether the factors described above are significant.

5.1 Factors affecting prevalence of RLR events

An initial analysis of the RLR events reported by SCATS was made (whilst bearing in mind that the absolute accuracy of the SCATS data had not, at this point, been validated as a true representation of the actual situation). The "top 20" RLR crash sites from a previous study (ViaStrada 2009) were used, i.e. those with working loops that had the highest costs associated with RLR crashes. One week's worth of RLR data was obtained from the SCATS system for the period 15-21 May 2017. One site was excluded as it was not possible to obtain data for the same analysis period; the remaining 19 sites were analysed.

Figure 6 analyses RLR incidence over time of day. It takes into account the effects of exposure and *opportunity to infringe* (i.e. a driver only has the possibility to run a red light if they're approaching the limit line and unobstructed by other vehicles, when the signal is displaying red), by dividing the RLR recorded events by the SCATS traffic volumes for the same period.

At lower volumes, opportunity to infringe is greater, as each driver passing by has a greater likelihood of being the first driver in the queue at the limit line. By this reasoning, it is not surprising that Figure 6 shows highest RLR rates during the off-peak periods, but it is interesting that there are not similar highs during the interpeak periods, i.e. where traffic volumes are also lower and opportunity to infringe is slightly higher than peak periods. Differences between the off-peak and interpeak periods that might explain this include:

- The interpeak is more likely to involve opposing traffic than the off-peak, so motorists are aware that the risks of red light running are greater.
- Drivers in the off-peak period are more likely to be affected by factors such as alcohol or fatigue, and may be more likely to overlook traffic signals during hours of darkness.

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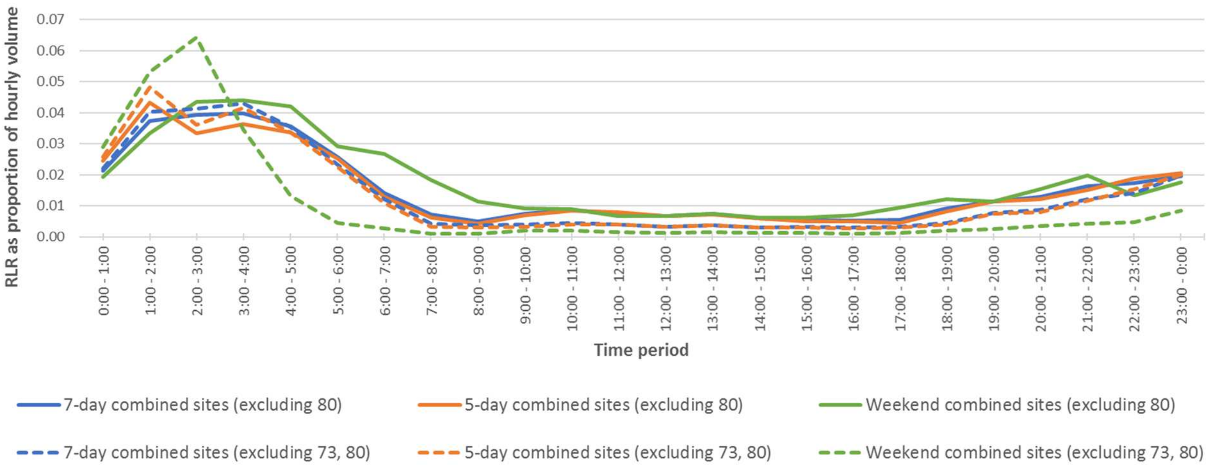
[2] An example of the see-through problem occurred in Christchurch along Montreal St (one-way) at the intersections with Tuam St and Oxford Tce, 30m apart. The phasing was modified so that traffic on Montreal St approaching Oxford Tce was given a green signal while traffic at Tuam St (upstream) still had a red. RLR was observed at Tuam St almost every cycle, and the phasing change was discarded.

- The average demographic of people who drive at night is likely to be different to that of those who drive during regular daytime hours. For example, it is expected that night-time drivers include a higher proportion of young male drivers, who tend to be more predisposed to RLR (and other risk-taking behaviours) than the average population. Also, elderly people are generally reluctant to drive at night time.
- Speeding is more prevalent during the middle of the night, with speeds often significantly greater than those that would allow a driver to stop during the yellow period (the length of yellow time is closely related to the speed limit).

Figure 6: Red light running – hourly profile of combined sites and days, normalised by volume

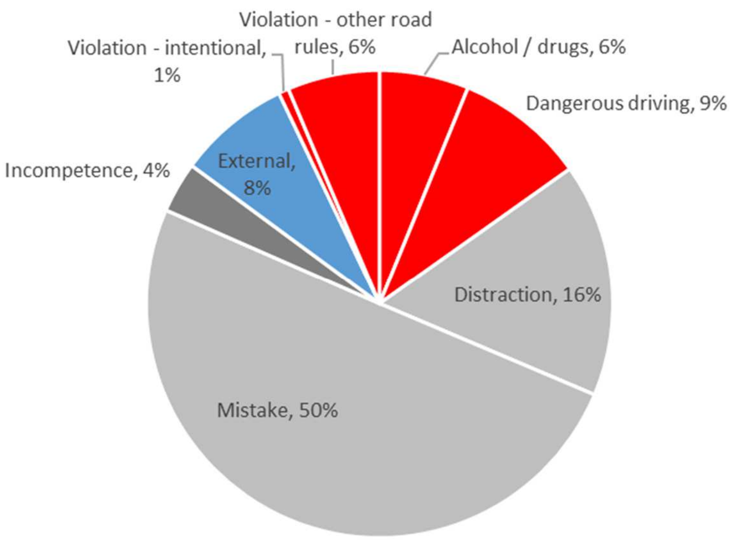


5.2 Factors involved in RLR crashes

The CAS factor codes recorded in conjunction with crashes identified as having RLR factors in Christchurch during 1997 to 2016 were interrogated. Note that some crashes had multiple (up to six) associated codes, with the average being 1.8 codes per crash. A total of 101 other factor codes (in addition to the RLR codes) were associated with RLR crashes.

The codes were separated into those that further explained reasons behind RLR occurrence (e.g. driver inattention), and those that described additional information (e.g. "stolen vehicle", "lights not switched on"); only those in the former category were considered further. The explanatory factors were then grouped into the general categories shown in Figure 7.

Figure 7: Explanatory factors in red light running injury crashes (Christchurch)



The colours used in Figure 7 are grouped more broadly as described in Table 1.

Table 1: Explanation of broader categories used in Figure 7

Colour	Description
Red	Involve some form of conscious rule violation (section 4.1)
Dark grey	Involve some form of driver incompetence (section 4.2)
Light grey	Involve some form of temporary driver ignorance from drivers assumed to be otherwise generally competent at driving (section 4.3)
Blue	Involve some form of external influence, outside of the driver's control (section 4.5)

The CAS factors are partially based on statements that drivers involved in a crash make to the responding Police officer. It is likely that drivers involved in RLR crashes may have emphasised some of the external factors (blue category in Figure 7), or even the distraction or mistake factors (light grey category), rather than admit that they deliberately ran a red light. In addition, almost one-quarter of crashes involved a blatant violation of the law (red category) and some forms of driver incompetence are also violations of law. Therefore, there is scope for enforcement to play a significant part in reducing RLR.

While the external (blue) factors seem to have only a small contribution, it is likely that improved engineering could reduce the occurrences of mistakes (light grey) by improving the readability of the built environment.

6 Conclusions

This paper shows that a wide range of factors can contribute to occurrences of RLR, both in terms of the errant driver, other road users, and the surrounding road environment. A theoretical framework has been developed that identifies these factors, and preliminary quantitative work provides some indication of the relative prevalence of the different factors in RLR crashes.

The next steps in progressing this work are to:

1. Invite industry input to identify any further factors / models that should be included.
2. Trial and analyse more advanced methods for monitoring RLR behaviour, including video learning technology and red light safety enforcement cameras.
3. Determine which factors are more likely to result in RLR crashes (as opposed to those that result in RLR without any crash outcome).
4. Identify which treatments would be most effective in addressing the critical factors (enforcement, education, engineering) and where.

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