The Application of Crash Modification Factors (CMFs) from the Perspective of Road Safety Inspections within Ireland's Motorway Network.

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Abstract

Since the adoption of the Road Infrastructure Safety Management (RISM) Directive, Transport Infrastructure Ireland (TII) has developed a new standard that sets out the processes around road safety inspections. TII has been carrying out road safety inspections since 2012. The second programme of motorway inspections concluded in 2018 and a set of reports produced in early 2019. The reports identify safety related items along the motorway network and describe how they have been risk assessed and ranked. The reports also incorporate Crash Modification Factors (CMFs) as a means of assessing the likely safety benefit of particular interventions.

Challenges exist to keep the process resilient and less subject to individual bias. The process includes many stages from the initial data collected through to the assessment of this data and the final reports and recommendations. The challenge of improving road safety within a modern motorway network is not trivial. The network in question is approximately 1,000 km[1] in length. The number of items identified and risk assessed on this network are in excess of 2,800.

Many of the decision supporting the application of CMFs, as a tool to estimate the likely impact of intervention has come out of a number RSI workshops hosted by TII. Much of the time at these workshops was spent on issues around methods that measure the influence of planned engineering interventions. Another area of discussion relayed to methods to enhance consistency in risk assessment of items identified during the RSI drive through.

[1] Note 1 mi = 1.61 km

Background

TII introduced a new programme of RSI to comply with the EU Directive on Road Infrastructure Safety Management. TII have documented this process within its publications and standards portal. It has been referenced as Road Safety Inspection - TII AM-STY-06044. This process is a proactive approach to help improve the safety of the existing national road network (Transport Infrastructure Ireland 2017*)*. The RISM Directive defines RSI as "*an ordinary periodical verification of the characteristics and defects that require maintenance work for reasons of safety*" (Directive 2008/96/EC). TII's intention for these RSI surveys is to identify any safety related items that require further review and potentially require an engineering design solution. Excluded from the RSIs are the more routine maintenance items, such as vegetation cutting and routine road marking maintenance. TII identify and remedy these through existing maintenance programmes.

TII began its first RSI programme in 2012. The focus of the RISM Directive back then was on the section of road network designated as Trans-European Road Network (TERN). In Ireland, the majority of the TERN is classed as motorway. Geo-located video along the network has been captured from multiple 'drive through' surveys by the RSI teams. This remains the primary information gathering process for RSI. Road and roadside items identified during these surveys are later risk rated by the inspection teams. Competent inspection teams complete both the surveys and the review of the captured data. A competent inspection team appointed by TII consists of a minimum of two inspection team members, one of whom is an approved inspection team leader.

The RSI process in Ireland has evolved since 2012. Workshops helped identify useful changes to the process. These changes helped build robustness and greater consistency into the RSI process. TII's participation in research with its sister road authorities, via the Conference of European Directors of Roads (CEDR), has helped draw attention to the use of crash modification factors (CMFs). TII began promoting the use of CMFs as a means to quantify the safety benefit of proposed engineering countermeasures and interventions in recent years. The topic has been the subject of a number of workshops. These workshops allow the sharing of the RSI practitioners' experience including the application and use of CMFs. TII are keen for feedback from the RSI teams. This feedback is a collective and co-operative means to improve the processes involved in all areas of RSI. Figure 1 attempts to show the flow of information form CEDR dissemination activity. Some of the information has found its way into Ireland's RSI activities.

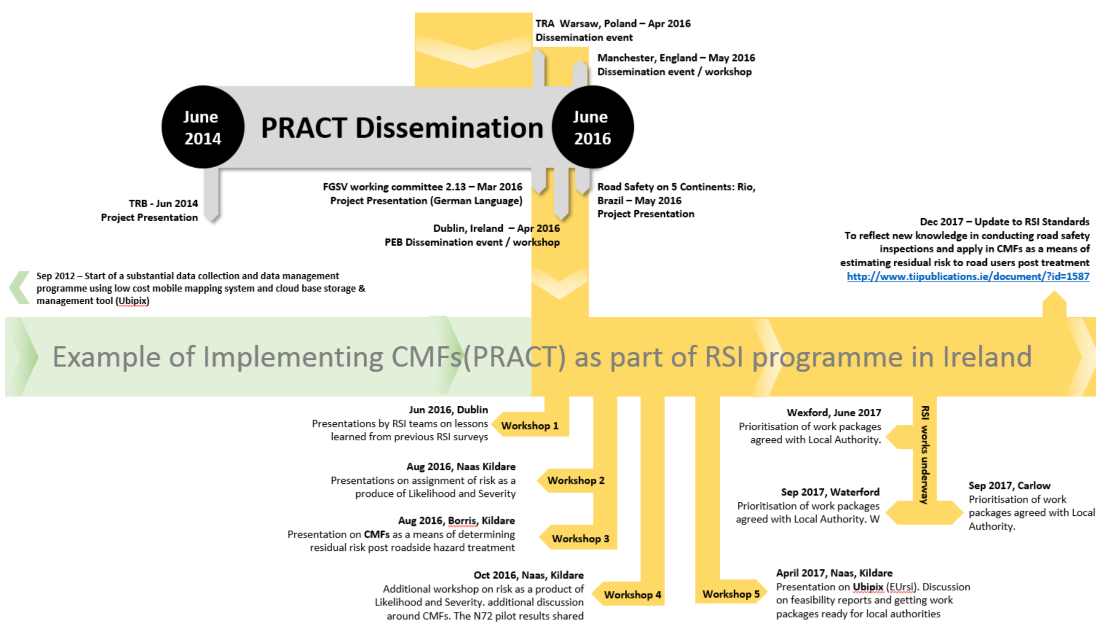

Figure 1 Graphic prepared for CEDR TG Safety to show how the findings from the PRAcT project were disseminated through workshops in Ireland and incorporated in the RSI process

TII are moving towards a more open and transparent process behind the practice of RSI. The reporting of issues, that substantially rely on engineering judgement, need to promote objectivity and evidence based decision making. The benefits behind engineering ethics and the practice of best engineering judgement are self-evident. Nonetheless, when opportunities arise to add robust quantifiable data to RSI reports, these opportunities are worthy of exploring. This endeavour is the premise for this paper; to explore the opportunities CMFs offer, to measure risk and quantify the effects of treatments to reduce it, in the context of RSI. Understanding through 'measurement' is a common phrase made famous by William Tomson (Lord Kelvin) 136 years ago. Kelvin said *"when you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory* kind." (Tomson 1883, p.73).

Literature Review

For a number of years Ireland's road safety record has been amongst the leading countries in reducing road traffic related causalities (Adminaite et al, 2018). Ireland has a long history of implementing road safety audits (RSA) as a proactive safety tool in addition to targeting the accident hot spots within its network. The inclusion of engineering interventions and actions within the current Irish road safety strategy recognise the important contribution engineering has made to improve road safety for all of Ireland's road users.

The introduction of new and revised standards is done so with the knowledge that reliance on older standards and existing programmes of countermeasures will unlikely yield the same safety benefits in the future as they have done in the past (Transport Research Centre 2008). This section covers some of the important text related to both the ideas behind road safety inspections and CMFs used to evaluate the impact of appropriately selected road safety interventions. Set out within the RISM Directive are requirements for member states to adopt, both reactive and proactive measures, to improve the safety of the trans-European road network. In short, the Directive provides a system for managing safety, covering different stages and aspects of planning, design and operation of road infrastructure.

The Directive requires all member states to conduct Road Safety Impact Assessments (RSIA), Road Safety Audits (RSA), Road Safety Inspections (RSI) and Network Wide Assessments to assess the safety of planned and existing road infrastructure. Proposed changes to the Directive will extend its scope to all primary routes, and EU funded roads outside of urban areas. In addition, greater focus is placed on vulnerable road users (Woolsgrove n.d.) and reporting findings from RSI (Curtis 2018).

Figure 2: How the EU can improve its road infrastructure safety management (Woolsgrove n.d.)

In general, the language and structure of EU Directives strikes a balance between instructions to take action while leaving it to member states to interpret how these actions can be executed. Like other member states, Ireland had some existing policies in place that conformed to the RISM requirements. However, in Ireland the policies and processes on road safety inspections had some deficiencies in terms of the RSIM Directive's objectives.

TII had previous experience in 'star rating' its road network from its involvement with EuroRAP during the mid-2000s (Road Safety Foundation, 2008). Opportunities to participate on safety inspection research, for example, through CEDR research calls also contributed to TII's knowledge around the mechanics and practical steps needed to analyse its network. This knowledge included the areas of data collection, analysis and data management. All these skills are important to acquire to help support large data dependant programmes like RSI.

As reported elsewhere (Santacreu et al., 2019), the number of countries reporting that they collect information about their road network now number in excess of one hundred. The European institutions have placed emphasis on the potential benefits of proactive safety procedures for some time (Directive 2008/96/EC, Road Safety Foundation 2008, Transport Research Centre 2008). The number of road deaths is still in decline across Europe but since 2015, the decline has slowed (Adminaite et al, 2018). Amongst the aspirations for RSI is that by providing resources to this type of proactive approach, the observed slowdown in reducing road deaths can be reversed.

Short (2017) observes that "*the success or otherwise of road safety policy has until now been evaluated almost entirely by the reductions in the number of fatalities*." His argument highlights that "*the consequences of road crashes cannot be fully or accurately summarised by the fatality total*" (Short, 2017). So the success or otherwise of road safety programmes has to be expressed differently. Success needs to be defined to be more than just the number of road deaths reported annually by countries. Therefore, road safety practitioners, including national funding authorities, local authorities, police etc. need to demonstrate, with greater transparency, how they target the road network for specific safety interventions. In addition, road safety practitioners need to quantify the impact these interventions will have on the future safety experienced by all road users.

The proposed revisions to the RISM Directive will challenge road authorities to advance their own safety initiatives (Curtis 2018). The principles underlying RSI are to support initiatives that will reduce both the frequency and severity of collisions through systematic inspections of the road infrastructure and those elements that most influence risk. The CMF tools offer a way to quantify the likely improvements, for the road user, from engineering interventions proposed through programmes like RSI. Adopting tools such as CMFs into existing programmes, although not an explicit requirement of the Directive, are challenging. TII considered the requirements, both personnel and financial, needed to fulfil its commitments under the RISM Directive. The finances supporting the RSI programme cover the expense of conducting the inspections, analysis and management of the captured data, in addition to the production of final RSI reports. The programme also includes the resources required to implement the recommendations on the ground.

During Workshops (as indicated within Figure 1), held between TII and the RSI teams, discussions would often centre on 'measuring' the impact of engineering interventions. These discussions concluded that the use of existing CMFs was appropriate if selected using best engineering judgement, particularly CMFs developed for motorways. This decision, to make use of CMFs, relied heavily on the inspection teams using 'best engineering judgement' to review and select the most appropriate CMF for each item identified and risk rated. This decision meant that TII could press ahead with funding interventions without the additional delay of developing or calibrating CMFs in order to adjust to the local context and conditions.

The CMF clearinghouse (http://www.cmfclearinghouse.org/) has in excess of 7,000 CMFs, at the time of writing, that help quantify the likely impact of thousands of documented engineering interventions. Those involved in road safety research add numerous new CMFs to the clearinghouse each year. An average of 340 CMFs have been added to the portal annually since 2015. From this single resource, many well-researched CMFs are freely available to review and select those most appropriate to mitigate common road and roadside issues identified during RSI surveys.

CEDR have funded research into the development of CMFs via the 2013 safety research call. One of the deliverables from this research was the PRAcT repository for CMFs (https://www.pract-repository.eu). As reported on the PRAcT web portal, the repository exists to assist European road authorities with tools in the area of "*Predicting Road Accidents*" and provides a "*Transferable methodology across Europe*" as a way to calibrate these tools to fit better the local conditions. The European funded PRAcT repository appears less well maintained compared to the US supported CMF clearinghouse. This is likely due to lack of financial support post the completion of the PRAcT project in 2016. The research material associated with the project provides valuable insights into the efforts required to produce robust and transferable CMFs. Yannis et al., (2016) reported that in order to develop some of these CMFs the number of sample sites could be small but others have sampled data from thousands of sites. Additionally, the collision data required, used for these site-specific studies, spanned from just 1 to 18 years. The authors cite these numbers to help get across the point that there is no standard set of septs to follow in order to develop new CMFs.

TII's participation on CEDR research is long standing. TII have made headway in implementing the findings from a number of research calls (de Beer et al., 2016). As one of the funding countries for the PRAcT research, TII is aware of the challenges of developing or calibrating a spectrum of local CMFs. The task of developing CMFs, large enough to address a range of risks likely needed for Ireland's road network has, to a small extent, just begun. The number of CMFs required, may now be estimated from the information gathered and processed during this recent RSI conducted in Ireland.

CEDR continue to investigate best advice and evidence on roadside safety and will soon have published research from the PROGReSS (Provision of Guidelines for Road Side Safety) project. PROGReSS is part of the activities from the 2016 safety research call. Some of the first deliverables from PROGReSS has suggested that even the textual data collected in Ireland, collected as part of reporting on RSI, has "*indirect associations among conditions that have hereto gone unreported*". The project suggests that data mining and "*topic modelling over RSI can expose yet unnoticed associations*" (Cardoso et al., 2016). For Ireland, this research will also help point to where 'gaps' exist in its current RSI process.

Methodology

The RSI related data collected and processed by the TII contractors is a rich resource and has helped formulate a number of important questions. The first set of questions TII asked are the obvious and simple ones, like what were the most common CMF values and how many different CMFs were identified and considered for engineering mitigation. TII have instructed all the RSI teams to reference standard work rates to build pricing consistently across all teams (Transport Infrastructure Ireland, 2016). The second set of questions the CMFs can help determine are around the costs associated with these interventions. Answers to the questions about the ratio between collision costs, and the costs of the proposed engineering interventions are important. A serious investigation into the benefits versus costs from RSI is beyond the scope of this paper. TII have yet to undertake this exercise. Sufficient data is now available to start evaluating, at least in part, the return on the RSI investment.

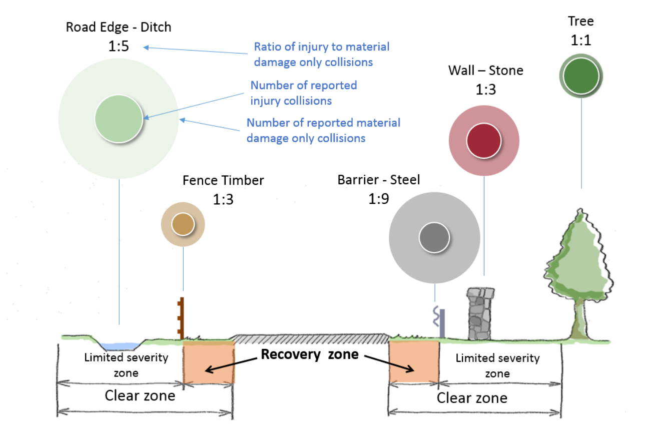

Figure 3 Examples of run off road (RoR) collision data used as a proxy for 'consequence' to the road user involved in such a collision.

The mechanism for collecting RSI data on the Irish road network has been described elsewhere (O'Connor 2016) but the process around the risk rating of items has developed further in the interim. The centralised online platform, used to risk rate and store the results from RSI surveys, also provides resources to the RSI teams. These resources are necessary to refer to during the review process. Regular reviews help to build robustness and repeatability around the process. The first resource is a set of results comparing the ratio of reported injury collisions to the reported set of material damage only collisions by primary collision type. Some examples are shown in Figure 3. Figure 3, is particularly useful in that it shows how the likely consequence for the occupants of a vehicle in a 'run off the road' type collision is determined. These consequences, together with a value for likelihood, are used within a matrix to estimate the overall risk to the road user. The likelihood of whether a collision will occur is a difficult task to establish with certainty.

CEDR has also experience tackling the topic of RSI and issues influencing the likelihood of collision occurrence via the EuRSI project (European Road Safety Inspection). This was a research project funded through the ERA-NET Road / CEDR 2009 safety call. The EuRSI project considered RSI implementation on rural roads. This work included reporting on the factors contributing to risk and the reasoning for limiting the risk model to a subset of physical road features that do not change or change very slowly over time (McCarthy 2011). Using similar reasoning, TII have estimated a range of values for collision likelihood from static road elements. Roads that narrow, change alignment abruptly or have more roadside development are assigned larger likelihood values.

The RSI platform, in use by TII, offers proxy values for the consequence and likelihood that contribute to collision risk. Using their own engineering judgement, the RSI teams can leave these values as they are, increase or decrease them accordingly (Figure 4).

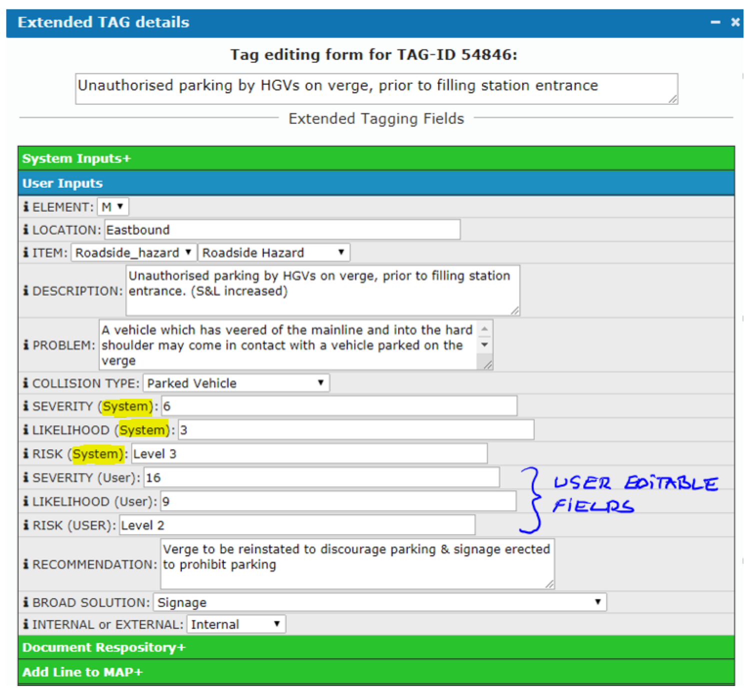

Figure 4 Risk rating from data collected during RSI, showing default (System) values and editable (User) values

The most recently collected and processed RSI data is from Ireland's motorway network. The motorways inspected account for just over 17% of the national road network under TII's administration. For practical reasons, TII divided the motorway network into five sections; most are several hundred kilometres in length. Each section was surveyed by one of the five RSI teams. TII selected RSI teams from an established framework through a formal call off process. Inclusion on this framework required RSI teams to demonstrate that they met the required competencies (Transport Infrastructure Ireland, 2014). The five motorway sections have common elements and the majority are controlled by the same speed limit of 120 km/h[2]. While all sections are designated motorways, some sections were built to older standards. Public Private Partnerships operate approximately 29% of the overall length of motorway network (section 1). Another 4% of the motorway network is urban, carrying significantly more traffic but operating with a lower speed limit of 100 km/h (section 2). The older motorway sections around Dublin account for another 14% of the network (section 3). The remaining motorway sections (section 4 and 5) make up 23% and 29% respectively of the overall motorway length.

Figure 4, shows the type of information entered, post the video capture process, by the RSI teams. For each item identified and risk rated, additional textual information is entered under the headings Element, Item, Description, Problem Collision Type, Broad Solution etc. When the RSI team has captured sufficient information, suitable engineering countermeasures can be considered. For each item identified a corresponding countermeasure is recorded in the final RSI report. TII review the submitted RSI documentation. The countermeasures selected relate to CMF values. Included with the submitted documentation are estimates of costs from countermeasures relating to CMF values. These costs reference TII's own schedule of rates (Transport Infrastructure Ireland, 2016). However, they do not include pricing for temporary traffic management during construction or any costs associated with road safety audits.

Nonetheless, reviewing this information has yielded a number of insights. The following section develops these ideas further and discusses the documented results.

Results

The RSI teams identified and risk rated 2,878 (100%) items over the entire 1,000 kilometres of motorway. When all the suggested mitigation costs are taken into account, the final figure ends up in excess of €25 million. The highest risk level (level 1) are those items that present the most severe consequence to the road user within the motorway network. A summary of the number of items by their risk level shows the following;

- 1,898 items (65.9%) were rated as level 3 risk (lowest level). As a road type, motorways have the lowest collision rates in Ireland and therefore would be expected to have a high proportion of the lowest risk rated items.
- 943 items (32.8%) were rated as level 2 risk.
- 39 items (1.4 %) are rated as level 1 risk (highest level). These are items where the likelihood of a collision occurring and the consequence of the collision are high. As expected motorways contain very few level 1 risk items.

The corresponding estimates, for interventions costs, is as follows;

- Estimated total costs for engineering interventions is in excess of €25 million (100%).
- Level 3 risk rated items contribute to 55.5 % of the total costs.
- Level 2 risk rated items contribute to 31.0% of the total costs.
- Level 1 risk rated items contribute to 13.5% of the total costs.

It is important to remember that these costs do not consider costs for associated traffic management or road safety audits.

From examination of the results displayed in Figure 5, the considerable financial resources needed to target interventions for items at risk level 3 are apparent. An approach would be to prioritise engineering interventions targeting level 2 and level 1 risk. This would mean that only three of the five motorway sections require funding for engineering interventions. This single visualisation can only summarise part of

[2] 1 kilometre per hour = 0.62137 miles per hour

the evidence gathered that describe risk within the motorway network. Of equal interest within this data, are the type, quantity and costs of the recommended interventions. Aggregating the data provides insights at an appropriately high level, and sufficient information to based funding decisions on.

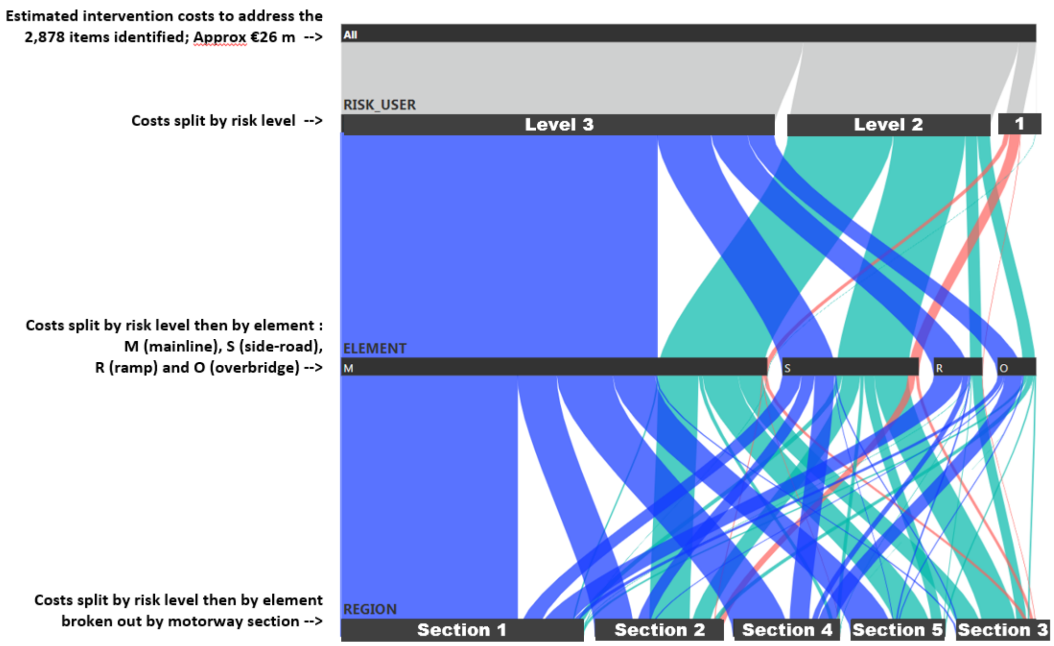

Figure 5 A breakdown of estimated interventions costs by motorway section, showing risk levels (red = level 1) and the motorway element associated with the risk as a Sankey chart.

The remaining text covers the analysis of CMFs. The colours used in Figure 6 show the broad solution categories where the CMFs have been grouped together as they share some common properties. Both Figure 6 and Figure 7 display only a portion of the visualised results. The presentation of the data as 'bubble charts' allows a large amount of numeric data to be communicated in a more consumable manner than in tabular format. Nevertheless, some explanation is required.

The X-axis has no measurable meaning. Its use is to separate CMF solutions into categories so they are clearly distinguishable. The Y-axis shows the range of CMF values. The size of the bubble shows the frequency of the CMF value found within the data collated by the RSI teams.

Out of the 366 items identified during RSI for the motorway section, referred to as section 3, the most frequent CMFs belong to the broad category of 'Signing & Lining'. The CMF values within this category range from 0.98, to 0.024. The closer the CMF value is to 1.0, indicates the intervention it describes is likely to have a limited influence on reducing the risk level. Conversely, values closer to 0.0 substantially reduce the risk. The least frequent CMF solutions fall into the categories of intervention to do with 'Drainage' and "Lighting". The RSI teams have recommended a diverse number of CMFs to deal with the 'Road Layout' category. This may indicate that, where they identified that road layout was an area to improve, each location was rather unique and requires a different intervention. It was encouraging to observe this pattern within the data, as it is an indication that the RSI team did use engineering judgement to consider all the options available.

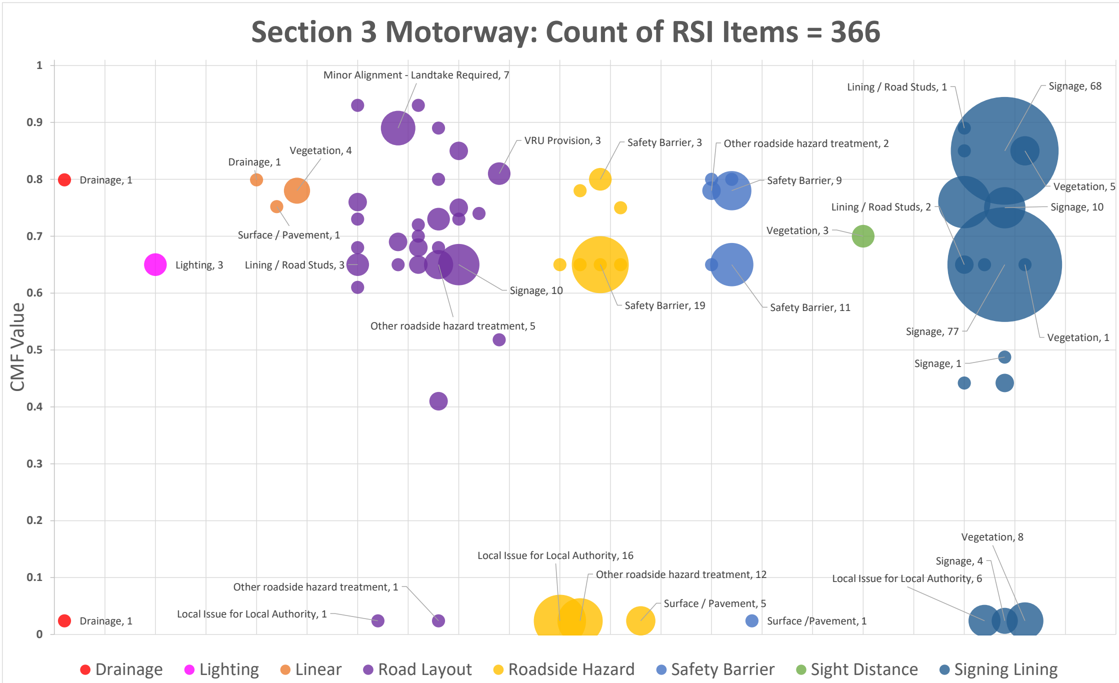

Figure 6 A visualisation of CMF values from section 3 of the motorway network classified by intervention type

Figure 7 shows the same data, visualised using the estimated cost. The larger the bubble the greater the cost estimate for the engineering intervention. The X and Y-axis remain the same as used for Figure 6. Within the roadside hazard category, the CMFs describing the use of safety barrier are the most expensive intervention. Comparing Figure 6 and Figure 7 shows that while items like linear elements and roadside hazards may be infrequent they do require substantial resources to mitigate.

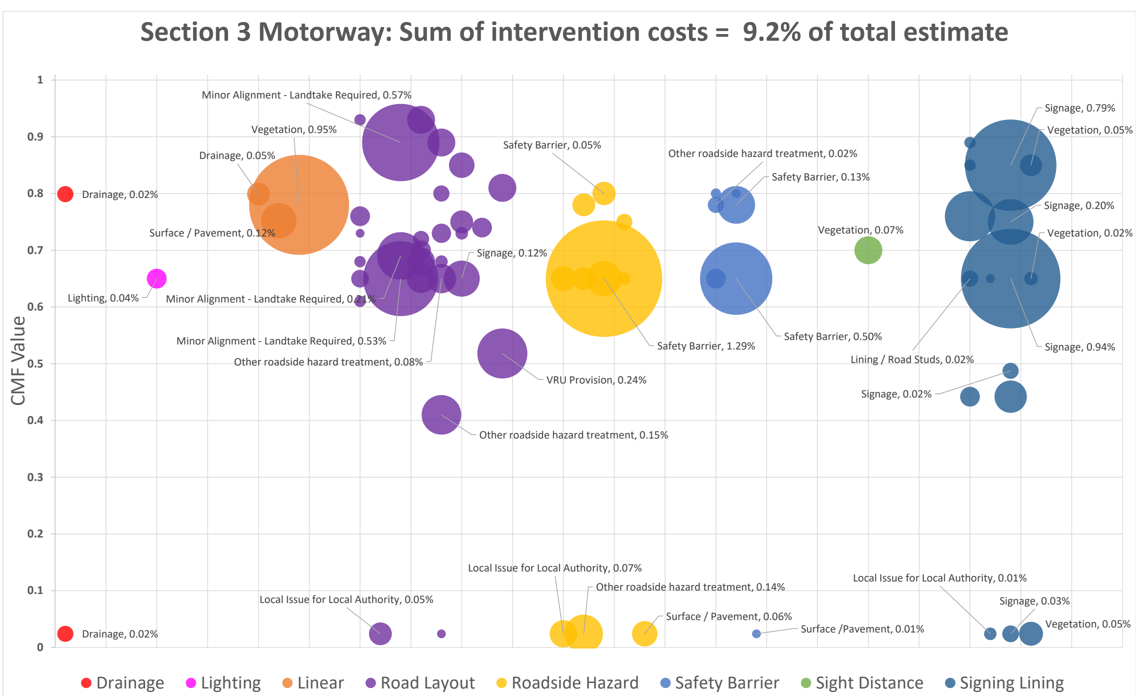

Figure 7 An alternative visualisation of CMF values broadly classified by intervention, bubbles sized by estimate costs

Costs from CMF interventions have been captured and information on costs associated with collisions by crash severity have been made. Any type of 'costs to benefit' analysis is beyond the scope of this paper but the figures look promising. As noted in the results earlier, the total estimate for interventions identified through the RSI process is in excess of €25 million. Over the period of 2016 to 2018, the fatal, injury and material damage only costs, estimated by TII, are in excess of €135 million. Considering that the CMFs identified by the RSI teams are delivering risk reduction in the order of 10% (CMF values of 0.9) to 35% (CMF values of 0.65), if implemented, these interventions could contribute to avoiding future collision costs between €13 million and €34 million over a short period of time

In Figure 8, are data from two other sections of the motorway, section 4 and 5, showing the count of items by broad solution. The difference in the size of the 'bubbles' is proportional to the number (count) of the same recommended CMFs.

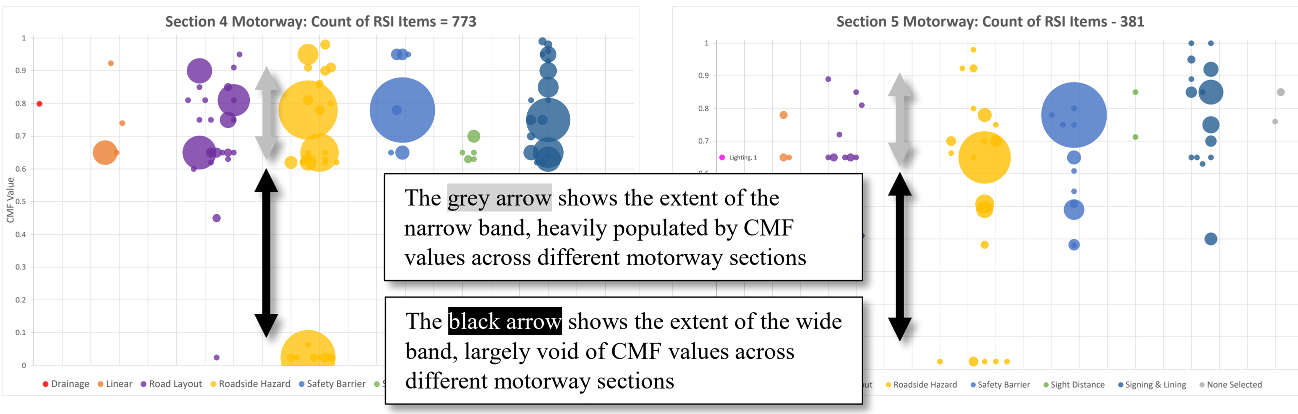

Figure 8 Distribution of CMFs from motorway sections 4 and 5

Figure 8 and Figure 6 show the common and more frequently cited CMFs as large 'bubbles' within the chart. TII should consider these CMFs for development into a localised version of the CMF. Calibrating these CMFs to reflect the conditions within the Irish motorway network will require further effort. The other side to this argument is that amount of CMFs that may need to be developed could be numerous. Finding sufficient locations to build new robust CMFs could hinder this task. This may be true for even the most common CMFs reported within the RSI data.

The top two most common CMFs by motorway section and broad solution classification are;

- Motorway Section 1: Signage; CMF value of 0.65 (103 items)
  Safety barrier; CMF value of 0.78 (102 items)
- Motorway Section 2: Safety Barrier; CMF value of 0.78 (140 items)
  Safety Barrier; CMF value of 0.65 (92 items)
- Motorway Section 3: Signage; CMF value of 0.65 (88 items)
  Signage; CMF value of 0.85 (70 items)
- Motorway Section 4: Safety Barrier; CMF of 0.78 (130 items)
  Other roadside hazard treatment; 0.024 (92 items)
- Motorway Section 5: Safety barrier; CMF value of 0.49 (243)
  Signage; CMF value of 0.65 (99)

Conclusions

One of the observable patterns, shown in Figure 6, Figure 7& Figure 8 are the noticeable gaps in the range of CMF values. This was a consistent gap, observed in all the data from all five of the motorway sections. Most of the CMF values were distributed between 0.65 and 0.9. Another smaller cluster of CMF values was found to occur between 0.0 and 0.1. This result was not surprising. It is well known that motorways are built to high standard and have well-resourced maintenance regimes in place. Therefore, the amount of risk the road user experiences from the road and roadside hazards is expected to be low.

The large group of CMFs that target interventions, between the ranges of 0.9 to 0.65, if implemented, are likely to reduce the risk of collisions and injuries by 10% to 35%. The smaller group of CMFs, between the ranges of 0.0 to 0.1 are effectively removing the hazard completely and the potential reduction in collisions and associated injuries is larger, in the order of 90%.

The information gathered so far from RSI and CMFs on Irish motorways is valuable. This, as far as the authors are aware, is the first and largest attempt in Ireland, to systematically rate and quantify hazards, within a proactive safety programme. The use (or reuse) of existing CMFs, described within this paper, may not be strictly correct. However, it has introduce the concepts underpinning CMFs into the local engineering community. Despite TII having a number of years' experience in RSI, it is still at the beginning of a process but already has shown signs of evolving and maturing.

As the RSI process changes over the next period of time, TII need to show the benefits of RSI in terms of reducing collisions and the severity of injuries. The data has shown that the most common CMFs that need to be developed or recalibrated to fit into the local contest deal with safety barrier and signage. However, care should be taken in determining whether these CMFs are targeting level 1, 2 or 3 risk rated items. Substantial resources can be saved if only level 1 and 2 risk rated items are dealt with as a priority. Any support TII invests into developing CMFs locally may be beneficial, at least in terms of furthering the understanding of the principles underlying CMFs.

The reuse of existing CMFs, despite their origins from other road networks, appears to have yielded a reliable picture of where the main hazards are within the Irish motorway network. They have also indicated how much more safety can be embedded, long term, into the network if TII fund and implement the recommendation for the RSI reports.

Author Contribution Statement

The authors confirm contribution to the paper as follows: study conception and design: O'Connor, D; data collection: Maguire, S, Staunton, C; analysis and interpretation of results: O'Connor, D, Maguire, S; draft manuscript preparation: O'Connor, D. All authors reviewed the results and approved the final version of the manuscript.

References

Adminaite, D, Calinescu, T, Jost, G, Stipdonk, H & Ward, H 2018, '*Ranking EU Progress on - Road Safety*', 12th Road Safety Performance Index Report, European Transport Safety Council, viewed 18th October 2019, < https://etsc.eu/wp-content/uploads/PIN_AR_2018_final.pdf>

Cardoso, J, Roque, C, Connell, T, Hall, G & Krkinbas, C 2016, '*Provision of Guidelines for Road Side Safety (PROGReSS) – Road Safety Elements',* State of the Art Report, Work Package 1 Tech Review, CEDR Call 2016 Safety

Curtis, B 2018, Opinion of the European Economic and Social Committee on '*Proposal for a Directive of the European Parliament and of the Council amending Directive 2008/96/EC on road infrastructure safety management*', viewed 18th October 2019, < https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1571507438942&uri=CELEX:52018AE2974>

de Beer A, O'Connor D, Cullen H, Vigors F & Leahy, M 2016 '*Ireland: Implementing research outputs on safety management from CEDR (Conference of European Road Directors) research programme'*, paper presented at Roads Safety on Five Continents, Rio, 17-19 May

Directive 2008/96/EC of the European Parliament and of the Council of 19 November 2008 on road infrastructure safety management, viewed 18th October 2019, < https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32008L0096 >

McCarthy, T 2011, '*Risk Assessment Review'*, Research deliverable 3.2 from European Road Safety Inspections, CEDR Call 2009 Safety under ERANET Road, viewed 18th October 2019, <https://www.cedr.eu/download/other_public_files/research_programme/eranet_road/call_2009_safety/eursi/02_EuRSI_D3.2_Final_August_2011.pdf>

O'Connor D, Cullen H, Vigors F, de Beer A & Leahy, M 2016, '*Implementing road safety inspections in Ireland and initial results*', paper presented at Roads Safety on Five Continents, Rio, 17-19 May

Road Safety Foundation, 2008, '*Ireland Eurorap Results 2008: Risk & Star Rating of Ireland's Major Roads*', viewed 18th October 2019,< https://roadsafetyfoundation.org/ireland-eurorap-results-2008-risk-star-rating-irelands-major-roads/>

Santacreu, A, Meynier, L & Crist, P 2019, '*New Directions for Data-Driven TRANSPORT Safety*', OECD/ITF, viewed 18th October 2019, < https://www.itf-oecd.org/new-directions-data-driven-transport-safety-0>

Short, J 2017,*'Traffic Injuries in Ireland: a neglected problem'*, paper presented at the Statistical and Social Inquiry Society of Ireland, Dublin, 12th October

Thomson, W (Lord Kelvin) 1883, '*Lecture on Electrical Units of Measurement'*, Popular Lectures, vol. I, p. 73, viewed 18th October 2019, <https://en.wikiquote.org/wiki/William_Thomson>

Transport Infrastructure Ireland, 2014, '*Road Safety Inspection Guidelines - AM-STY-06043'*, Guideline documentation, viewed 18th October 2019 < https://www.tiipublications.ie/library/AM-STY-06043-02.pdf>

Transport Infrastructure Ireland, 2016, '*Introduction to the Guidance on Measuring and Pricing - CC-GMP-00010'*, Guideline documentation, viewed 18th October 2019 < https://www.tiipublications.ie/library/CC-GMP-00010-02.pdf>

Transport Infrastructure Ireland, 2017. '*Road Safety Inspection - AM-STY-06044'*, Guideline documentation, viewed 18th October 2019, < https://www.tiipublications.ie/document/?id=1587>

Transport Research Centre 2008, '*Towards Zero – Ambitious Road Safety Targets and the Safe System Approach'*, Policy Brief, OCED Publishing, viewed 18th October 2019, <https://www.itf-oecd.org/sites/default/files/docs/08targetssummary.pdf>

Woolsgrove , C n.d., '*How the EU can improve its road infrastructure safety management'*, viewed 18th October 2019, <https://ecf.com/what-we-do/road-safety/safer-infrastructure>

Yannis, G, Dragomanovits, D, Laiou, A, La Torre, T, Domenichini, L, Richter, T, Ruhl, S, Grahamd, D & Karathodoroud, N 2016, '*Development of an online Repository of Accident Prediction Models and Crash Modification Factors'*, paper presented at 1st European Road Infrastructure Congress, Leeds, 18-20 October