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A Safe System-based approach to selection of clear zones, safety barriers and other roadside treatments

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Abstract

On average, 560 fatal run-off-road crashes occur annually in Australia and 135 in New Zealand. In addition, there are more than 14,000 run-off-road crashes causing injuries each year across both countries. In rural areas, run-off-road casualty crashes constitute 50-60% of all casualty crashes. Their severity is particularly high with more than half of those involved sustaining fatal or serious injuries.

This paper reviews the existing approach to roadside hazard risk assessment, selection of clear zones and hazard treatments. It proposes a modified approach to roadside safety evaluation and management. It is a methodology based on statistical modelling of run-off-road casualty crashes, and application of locally developed crash modification factors and severity indices. Clear zones, safety barriers and other roadside design/treatment options are evaluated with a view to minimise fatal and serious injuries – the key Safe System objective. The paper concludes with a practical demonstration of the proposed approach. The paper is based on findings from a four-year Austroads research project into improving roadside safety in the Safe System context.

Key words: roadside, clear zone, safety barrier, hazards, Safe System

1. Introduction

On average, 560 fatal run-off-road crashes occur annually in Australia and 135 in New Zealand. In addition, across both countries there are more than 14,000 run-off-road crashes causing injuries each year. In rural areas, run-off-road casualty crashes constitute 50-60% of all casualty crashes. Their severity is particularly high, with more than half of those involved sustaining fatal or serious injuries. For these reasons, provision of more forgiving roadsides has come into the focus of the National Road Safety Strategy (2011-2020) in Australia and Safer Journeys (2010-2020) in New Zealand (Australian Transport Council 2011, Ministry of Transport 2010).

Under the Safe System, addressing severe run-off-road crashes through safer roads involves providing roads that minimise the risk of vehicles leaving the carriageway (e.g. via delineation), that provide adequate recovery space when vehicles run off the road, and that ensure that any collision that occurs will be with a structure that limits impact forces to levels that will not cause a serious injury.

This paper proposes an approach to roadside safety management focused on the second and third of the above criteria. The approach consists of a roadside evaluation methodology based on statistical modelling of run-off-road casualty crash frequencies, application of locally developed crash modification factors and severity indices. Clear zones and other roadside design options (e.g. barriers) are evaluated with a view to minimise fatal and serious injuries – the key Safe System objective. The paper concludes with a practical demonstration of the proposed method.

This paper draws on findings of a four-year Austroads study researching the fundamental road, roadside and run-off-road crash relationships applicable in improving roadside safety (Roper et al. 2010, Jurewicz et al. 2011, 2012, in-press).

2. Current approach to roadside management

The general guidance to managing roadside hazards in Australia and New Zealand is based on selection of clear zones and provision of safety barriers when clear zones are not achievable. Roadside hazard modification also plays a role, when possible (e.g. use of slip-based or impact absorbent poles, drivable culvert ends, etc.). The current guidance is summarised in part 6 of Austroads road design guidelines (Austroads 2010). Clear zone is defined as a width of the roadside, measured from the edge of through traffic lane, kept free of objects which would be potentially hazardous to errant vehicles. Hazard risk assessment and roadside design begin with selection of a clear zone width and its adjustment for various factors.

Jurewicz and Pyta (2011) provide an overview of the current clear zone selection practice in Australia and New Zealand and its theoretical basis. The existing practice draws on the principles documented in AASHTO (2011), which are based on the probability of a vehicle road departure and the probability of reaching a given lateral encroachment into the roadside. These principles are based on North American research dating back to 1960s and late 1970s (Hutchinson and Kennedy 1966, Cooper 1980). Fundamentally, the current practice accepts that approximately 15% of errant vehicles would encroach deeper into the roadside than the selected clear zone, i.e. crash into hazards beyond it. This approach, based on a trade-off between safety and cost, does not align well with the Safe System objectives. Even very wide clear zones are able to control only part of the run-off-road casualty risk, as shown by analysis of run-off-road casualty crash data (Jurewicz and Pyta 2011).

Overview of clear zone research documented in Jurewicz et al. (2012) also showed that a majority of run-off-road casualty crashes occurred at significant road departure angles. The mean was about 15° according to Mak, Sicking & Coon (2010). Jurewicz and Pyta (2011) demonstrated that when roadside entry occurs at more than several degrees, even excessively wide and well maintained clear zones would not provide sufficient space to decelerate safely. Findings by Doecke and Woolley (2011) also showed that 100% of errant vehicles in their casualty crash sample, which did not hit a hazard, travelled more than 10 m deep into the roadside. They demonstrated that such errant vehicles had a low potential for recovery back onto the road. Jurewicz and Pyta (2011) also showed that the proportion of rollover crashes increased with clear zone width.

Nevertheless, analysis by Jurewicz et al. (in press) showed evidence that increasing very narrow or nil clear zones to over 4 m offered potential for reduction in the risk of a run-off-road casualty crashes into the treated side on rural roads (49%). This reduction improved to 54% for clear zones over 8 m.

Overall, the review of literature and data analysis showed that wide clear zones typically achievable on most Australian and New Zealand rural roads could not be relied on to provide Safe System outcomes. It was reasonable to conclude that provision of clear zones over 4 m wide was effective in recovery of many errant vehicles, especially those departing the road at low angles. Clear zones over 8 m wide provided an incremental improvement in roadside safety.

In this light, there was a need to review the role of clear zones as the starting point in roadside hazard risk assessment and roadside design. The scope of the Austroads project called for practitioner guidance which focuses on minimising fatal and serious injuries in roadsides (i.e. a Safe System relevant approach) through a methodical evaluation of a variety of road and roadside factors, including clear zones (Jurewicz et al. in-press).

3. The proposed approach

The aim of roadside safety management in Safe System context is to provide a forgiving area on both sides of the carriageway that will minimise the likelihood and severity of run-off-road crashes.

Safe System requirements indicate that the highest survivable impact speed for a car into a tree or pole (side impact) is about 40 km/h (Australian Transport Council 2011). At such impact speed, the probability of death is very low[1], although severe injuries are likely (Jurewicz and Pyta 2011). Therefore, in a Safe System roadside, forgiving safety barriers would be placed along road corridors to deflect an errant vehicle or to dissipate its kinetic energy to a safe level. Any necessary unshielded roadside objects would be selected or engineered to be frangible in a case of a vehicle collision. Clear zones could only play a supporting role in providing a traversable recovery zone.

Arguably, none of these scenarios existed at the time of the Austroads investigation. Fatal and serious injury run-off-road crashes still occurred in the presence of the highest available roadside design standards, although in much reduced frequency and severity, especially in the presence of flexible barriers (Jurewicz et al. 2012).

Hence, the proposed approach should be seen as a stepping stone towards the Safe System. It is a tool for making design choices likely to result in significant reduction in the risk of severe injuries. Research and development efforts should continue to improve the design choices (e.g. even more forgiving safety barriers than currently available). The long-term achievement of Safe System aims will depend on the combined contribution of Safer Roads, Safer Vehicles, Safe Speeds and Safer Road Users.

3.1 Roadside safety evaluation approach

The scope of Austroads study called for drawing together the key project findings and providing general guidance for practitioners on when clear zones, hazard modifications, and safety barriers are the most fit-for-purpose treatments. Jurewicz et al. (in-press) proposes an evaluation approach which allows this to be carried out at different levels:

- Strategic – drawing on the elements of the approach may suggest design policy choices based on the potential for reductions in fatal and serious injuries due to run-off-road casualty crashes. These can be then evaluated economically and environmentally on a network-wide basis.
- Route/corridor – broad effects of different improvements can be assessed by modelling safety effects of significant roadside design changes along a route, e.g. an incremental widening of shoulder vs. widening of clear zones vs. application of barriers.
- Localised – detailed application of the approach to design-level choices based on agreed economic evaluation model.

Figure 1 illustrates the proposed approach.

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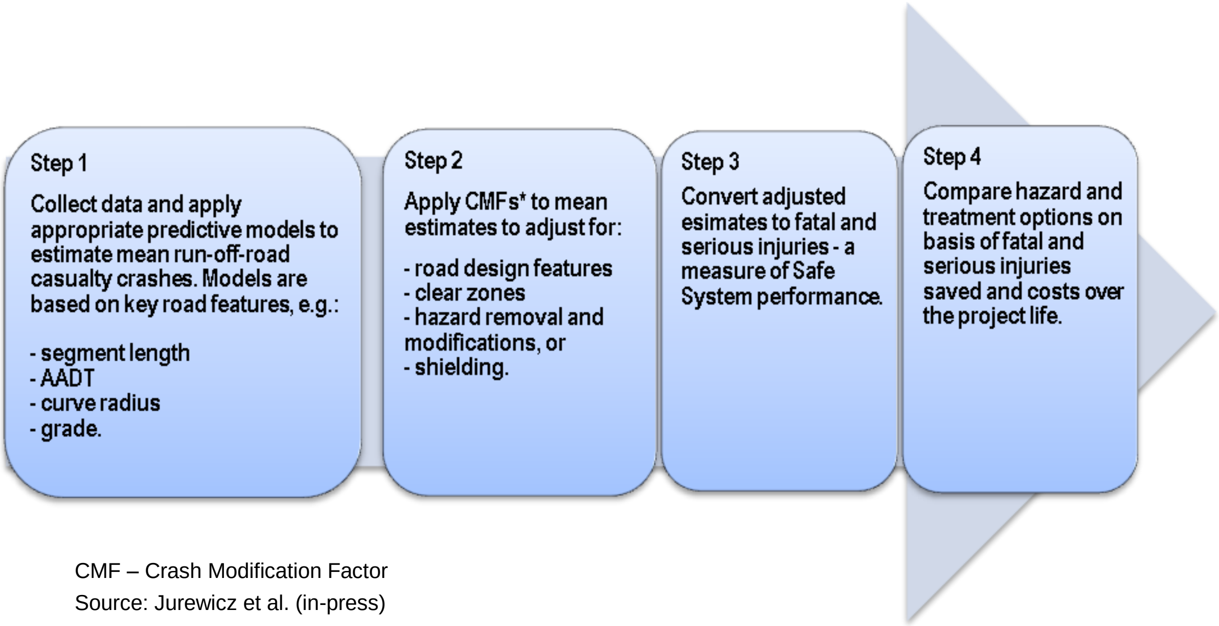
[1] The accepted 'survivable' impact speed for a car-tree/pole impact carries a 10% risk of a fatality outcome.



CMF – Crash Modification Factor

Source: Jurewicz et al. (in-press)

Figure 1: Approach for roadside safety management

The proposed approach has been developed for rural undivided roads and rural freeways. For economy of space only rural undivided road aspects are presented in this paper. The reader is referred to the forthcoming Austroads report for full details (Jurewicz et al. in-press).

3.1.1 Step 1

Step 1 of the proposed approach requires collection of the key geometric design and roadside hazard data, including the available clear zone width. The data is used in crash prediction models to estimate the mean number of run-off-road casualty crashes in each direction of travel. Four crash predictive statistical models have been developed as part of the Austroads project for 100 km/h rural undivided roads and for 110 km/h rural freeways. The form of the two 100 km/h rural undivided road models is presented in Equation 1.

$$\text{ROR2L}_{100} \text{ or } \text{ROR2R}_{100} = \text{Constant} \times \text{Length} \times \text{AADT}_{\text{one-way}} \times \text{Curve radius} \times \text{Grade} \tag{1}$$

where

ROR2L_{100} ROR2R_{100} = The expected mean number of run-off-road casualty crashes to one side (left or right), in one direction of travel, for a given road segment over a period of 5 years.

Constant = Model constant.

Length = Segment length in kilometres.

$\text{AADT}_{\text{one-way}}$ = Parameter representing one-way annual average daily traffic category.

Curve radius = Parameter representing the curve radius category.

Grade = Parameter representing the grade category.

The model parameters are given by Table 1:

Table 1: Model parameter values for the run-off-road casualty crash to one side model for 100 km/h rural undivided roads

Variables	Categories	To the left	p-value	To the right	p-value
Model constant		0.050		0.046	
AADT (one-way)	≤ 1200 vpd	0.55	≤ 0.001	0.71	≤ 0.05
	>1200 vpd	1.00	–	1.00	–
Curve radius	≤ 600	2.44	≤ 0.001	2.75	≤ 0.001
	600 – 1500 m	1.42	≤ 0.1	1.66	≤ 0.05
	> 1500 m	1.00	–	1.00	–
Grade	Negative	1.30	≤ 0.05	*1.21*	*> 0.10*
	Positive or zero	1.00	–	1.00	–

Source: Jurewicz et al. (in-press)

The models were based on Victorian road feature information, traffic volumes and crash data. At strategic or route/corridor levels, run-off-road casualty crash history can be used instead of the models to provide the baseline for estimation of safety benefits of different options. The models are reported in full in Jurewicz et al. (in-press).

3.1.2 Step 2

Ideally, the crash predication models in step 1 would recognise the effect of the main existing or proposed roadside safety features. Unfortunately, observational statistical models do not account well for features applied predominantly as safety treatments in response to high crash frequency. Therefore, step 2 of the approach proposes to apply crash modification factors (CMFs) associated with run-off-road casualty crash changes in response to key roadside safety treatments, and also with design features not included in the models. These factors are applied as adjustments to the estimated mean run-off-road casualty crashes estimated in step 1.

CMFs were developed from comparative run-off-road casualty crash rate analysis based on project data, and from research literature reviews (Jurewicz et al. in-press) CMFs for the undivided rural roads are presented in in Table 2. The CMFs were divided into three groups: road design or standard related (likelihood of running off the road), hazard removal, relocation or modification, and hazard shielding. The last two groups were mutually exclusive.

The estimated mean run-off-road casualty crashes to the left (ROR2L) and to the right (ROR2R) are multiplied by applicable CMFs from the table to obtain the adjusted estimate of the run-off-road crashes in one direction. This has to be done for the existing, or baselines, scenario and for the treatment option being evaluated. The process is performed for the whole carriageway and in both directions of travel (if applicable). This way the full relative effects of the treatment may be captured.

Multiple versions of the same treatment can be compared by changing one or more CMF values, e.g. adjusting clear zone width.

Table 2: CMFs for 100 km/h rural undivided roads

Variable	Category	CMF ROR2L	CMF ROR2R
Road design/standard related			
Mean speed (km/h)	100	1.00	1.00
	90	1.24	1.24
	80	1.55	1.55
	≤ 70	1.95	1.95
Traffic lane + LHS sealed shoulder, LHS unsealed shoulder	<3.5 m, ≤ 0.5 m	3.61	2.81
	<3.5 m, > 0.5 m	1.66	1.21
	≥ 3.5 m, ≤ 0.5 m	1.28	1.16
	≥ 3.5 m, > 0.5 m	0.86	0.74
Hazard removal/relocation/modification			
Clear Zone LHS	0 - 2 m	2.19	na
	2 - 4 m	1.60	na
	4 - 8 m	1.27	na
	> 8 m	1.00	na
Clear Zone RHS	0 - 2 m	na	1.57
	2 - 4 m	na	1.56
	4 - 8 m	na	1.03
	> 8 m	na	1.00
LHS batter slope	<1:6 (flat)	1.00	na
	1:6 - 1:3.5	1.67	na
	1:3.5 - 1:2	1.97	na
	>1:2	3.35	na
RHS batter slope	<1:6 (flat)	na	1.00
	1:6 - 1:3.5	na	1.40
	1:3.5 - 1:2	na	1.81
	>1:2	na	2.45
Density of hazards (per 100m of roadside)	< 10	1.00	1.00
	10 to 25	0.98	0.98
	25 to 50	1.08	1.08
	> 50 or continuous	1.57	1.57
Replace rigid with frangible	Frangible pole	0.60	0.60
Hazard shielding			
Barriers	Change semi-rigid to flexible	0.68	0.68
	Semi-rigid	0.53	0.53
	Flexible	TBA	TBA
	Flexible 2+1	0.76	1.76
Barrier offset factor	≤ 0.5 m	5.39	5.39
	1.0 m	2.11	2.11
	≥ 1.5 m	1.00	1.00

Source: Jurewicz et al. (in-press)

3.1.3 Step 3

The adjusted estimate of the mean number of run-off-road casualty crashes is then converted to fatal and serious injuries. This is done by multiplying the estimate by FSI ratios which are severity indices for the predominant roadside hazards or treatments potentially hit by errant vehicles. FSI ratios were developed from Victorian crash data analysis (Jurewicz et al in-press). They are a rate of fatal and serious injuries per run-off-road casualty crash into a hazard of a given type. This may include the 'no object' option often applicable in flat, cleared roadside areas with no trees. The full list of FSI ratios for different road stereotypes is reported in Jurewicz et al. (in-press). Table 3 provides a selection of these ratios for 100 km/h undivided roads .

Table 3: Selection of FSI ratios used in the proposed approach

Roadside hazard/treatment type	**Rural 100 km/h undivided**	
	FSI ratio	**95CL:low, high; sample size n**
Non-frangible poles	0.78	0.42, 1.14; 23
Guide posts	0.77	0.56, 0.98; 35
Trees	0.75	0.70, 0.79; 3,653
Bridges (when not on path)	0.72	0.49, 0.96; 28
Semi-rigid safety barriers	0.60	0.42, 0.77; 42
Frangible poles	0.57*	0.18, 0.97; 14
Roadside clear of objects	0.55	0.51, 0.60; 2,522
Fences and walls (incl. gates)	0.55	0.48, 0.62; 533
Embankments	0.53	0.48, 0.58; 1,107
Rigid safety barriers	0.50**	0.33, 0.68; 90
Traffic signs	0.43	0.29, 0.57; 57
Flexible safety barriers	0.33**	0.07, 0.58; 19

Source: Jurewicz et al. (in-press)

* Based on a sample from 80 km/h urban roads

** Based on a sample from 100 km/h urban freeways.

There was some indication that FSI ratio increased with barrier offset from the edgeline at about 5% per metre. This trend was only demonstrated for semi-rigid and flexible barriers on high-speed roads. The evidence was not consistent for all barrier types in all speed environments due to small crash data samples. A relevant scaling factor could be applied to a barrier FSI ratio if it was to be placed significantly further away than its typical application range (2 - 4 m usually).

When a given roadside has multiple roadside hazard types, the FSI ratio may be composed by using proportions of different hazard types. This may include a proportion of roadside clear of any hazards.

After carrying out the step 3, the resulting estimated fatal and serious injuries for a given section of carriageway are a measure of Safe System performance.

3.1.3 Step 4

Various scenario options can be compared in step 4, e.g. between an existing scenario and various design/treatment options at the strategic, route/corridor and localised levels. The difference between a baseline scenario and a given treatment option represents the safety benefit, which can be monetised. Alternative options may be then ranked using benefit-cost ratio. Preferably an alternative Safe System option ranking method could be developed. One proposed approach could be to rank treatment options by fatal and serious injuries saved per $1m.

4. Example of application

This section seeks to demonstrate how the proposed approach could be applied in a real situation, e.g. treatment proposed for a curve on a rural undivided road. Figure 2 shows an example of such a location.

Source: Google Earth (2012)

Figure 2: A rural road curve

According to the information collected on site, the existing conditions were:

- curve length 0.3 km
- 100 km/h speed limit rural undivided
- curve radius ~400 m radius
- AADT 500 vpd one way
- slight downhill grade in forward direction (uphill in reverse)
- narrow pavement no sealed shoulder on both sides (< 3.5 m category)
- unsealed shoulder: left-hand-side 0 m, right-hand-side 1.3 m
- <2 m clear zones on left- and right-hand side
- left-hand-side hazard was a cutting embankment, right-hand-side – trees.

The proposed treatment involved installation of a semi-rigid barrier along the outer edge of the curve and sealing the shoulder up to the barrier. Table 4 presents an evaluation of the crashes to the left and to the right in both travel directions, and then of the fatal and serious injuries for the existing and treatment scenarios. The table shows that the barrier treatment would have reduced fatal and serious injuries to an estimated mean of 0.22 per 5 years, a saving of 31%.

Closer observation of the CMF values and estimated fatal and serious injuries on the left-hand-side of the forward direction suggests where the greatest potential for safety improvement may be. Instead of the barrier, it would have been potentially more effective to address proximity of the embankment, e.g. through provision of a wider lane and a sealed shoulder on the inside the curve.

This is how the proposed approach can be used to generate, evaluate and rank alternative roadside treatment options.

Table 4: Example of application of the roadside safety management approach

Steps	**EXISTING Forward direction**	**EXISTING Reverse direction**	**TREATMENT Forward direction**	**TREATMENT Reverse direction**
1. Model: run-off-road to the left*	0.026	0.020	0.026	0.020
2. CMFs for run-off-road to the left (multiplicative)				
CMF Speed limit	1.00	1.00	1.00	1.00
CMF Traffic lane + LHS sealed shoulder, LHS unsealed shoulder	3.61	1.66	3.61	1.28
CMF Clear zone$_{\text{LHS}}$	2.19	2.19	2.19	
CMF Batter slope$_{\text{LHS}}$	3.35		3.35	
CMF Hazard density$_{\text{LHS}}$		1.57		
CMF Rigid to frangible$_{\text{LHS}}$				
CMF Barrier$_{\text{LHS}}$				0.53
2. Adjusted run-off-road to the left	0.69	0.12	0.69	0.01
3. FSI ratio$_{\text{LHS}}$ (multiplicative)	0.55	0.73	0.55	0.55
3. Fatal & serious injuries on LHS	**0.38**	**0.08**	**0.38**	**0.01**
1. Model: run-off-road to the right	0.033	0.028	0.033	0.028
2. CMFs for run-off-road to the right (multiplicative)				
CMF Speed limit	1.00	1.00	1.00	1.00
CMF Traffic lane + LHS sealed shoulder, LHS unsealed shoulder	2.81	1.21	2.81	1.16
CMF Clear zone$_{\text{RHS}}$	1.57	1.57		1.57
CMF Batter slope$_{\text{RHS}}$		2.45		2.45
CMF Hazard density$_{\text{RHS}}$	1.57			
CMF Rigid to frangible$_{\text{RHS}}$				
CMF Barrier$_{\text{RHS}}$			0.53	
2. Adjusted run-off-road to the right	0.23	0.13	0.05	0.12
3. FSI ratio$_{\text{RHS}}$ (multiplicative)	0.73	0.55	0.55	0.55
3. Fatal & serious injuries on RHS	**0.17**	**0.07**	**0.03**	**0.07**
4. Fatal and serious injuries both sides	**0.550**	**0.154**	**0.409**	**0.075**
4. Sub-total existing & treatment		**0.704**		**0.484**
4. Compare existing vs. treatment, i.e. the safety benefit expressed in fatal and serious injuries:				**0.220**

Source: Jurewicz et al. (in-press)

* left and right are based on the direction of travel, i.e. forward or reverse. Thus, forward left-hand-side is reverse right-hand-side.

5. Discussion

The proposed approach is ready for trialling but is still open to further development. Over time, new research is likely to provide refinements of individual run-off-road risk components (CMFs). New CMF categories could be added, e.g. those related to run-off-road likelihood such as delineation, audio-tactile edgelines, or pavement skid resistance.

Also the approach is based mostly on Victorian data. While the relationships and values should be broadly applicable across jurisdictions, just as the North American ones have been, the approach should be tested and calibrated across a range of different environments. For example, roadside safety issues in remote areas of Western Australia or Queensland may need to be reflected by additional factors or adjustments. This would also apply to the unique characteristics of the New Zealand rural road network.

The approach has been developed for rural undivided roads and rural freeways. Future research may see extension of this approach to urban freeways and major arterials. Indications from reviewed literature suggest that a different approach may need to be taken in lower-speed urban environments, where space is restricted but run-off-road casualty crash severities were shown to exceed Safe System expectations (Jurewicz et al 2012, in-press).

The proposed approach is very repetitive and tedious in manual application. It would lend itself to conversion to a spreadsheet or a formal software tool. This would assist in easy application by practitioners.

6. Conclusions

Based on the findings of a four-year Austroads study, the paper recognised the limitations of the fundamental principles behind the current approach to evaluating roadside hazards, selection clear zones and roadside treatment options. A Safe System focussed approach to roadside safety management was proposed. It provides an evidence-based methodology for evaluating roadside hazards and treatment options. The estimated mean numbers of fatal and serious injuries can be compared between scenarios and ranked according economic viability (e.g. BCR ratio), or preferably, according to a Safe System effectiveness based ranking (e.g. severe injuries saved per $1m). An example of practical application of the proposed approach was provided.

Note:

The findings of the study have not been endorsed by Austroads at the time of writing. Hence the proposed approach in this paper should be treated as preliminary until publication of the final project report.

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