shown in Figure 1.



**Figure 1: Safe System treatment hierarchy. Source: Woolley et al. (2018)**

The Safe System treatment hierarchy identifies four categories, as shown in Figure 1. Primary Treatments are clearly preferred, as contribute towards the elimination of serious injury and fatal crashes. In the context of road departure crashes, Woolley et al. (2018, p. 68) gives the example of installing “continuous lengths of flexible roadside and median barriers…” to reduce crash severity, as measures such as Wire Rope Safety Barrier, while not changing the likelihood of a crash are expected to reduce impact forces such that serious injury or fatality does not occur. Supporting (step towards) and Supporting Treatments are those that might reduce the likelihood of a serious injury or fatal crash, but not eliminate it. Woolley et al. (2018) gives the examples of audio-tactile centrelines and edgelines, which might alert a driver that they are straying off the road or into oncoming traffic (reducing crash likelihood), but do nothing to reduce the consequences of any crash that does occur.

The question for tram and road authorities, therefore, is should they put their efforts into separating cyclists from tram tracks where possible, but installing rubber inserts when cyclists have to travel close to the tracks as a Supporting (step towards) a Safe System? Or should authorities focus on fully-segregating of tram tracks and cyclists, as a Primary Treatment, such that it is not physically possible for cyclists to interact with tracks other than crossing at right angles? Such segregation might also have the advantage of potentially eliminating the possibility of tram-versus-bike crashes other than at at-grade intersection, but may prove difficult to implement in practice.

Table 2 shows an assessment of how the Safe System treatment hierarchy applies to countermeasures discussed in the research literature. Notably, segregation of cyclists from trams (as identified in Deunk et al. (2014); Teschke et al. (2016); Maempel et al. (2018); Utriainen et al. (2023)) may virtually eliminate the potential for serious injury and fatal tram-related bicycle crashes. Full-separation of the transit Right Of Way (ROW A[[1]](#footnote-1)) might mean that bicycle and tram interactions are grade-separated, making collisions and track-related crashes impossible. Railway-style crossings or longitudinal-separation (ROW B) might not entirely prevent tram versus bicycle or slip/skid crashes were cyclists cross tram tracks, but would appear to be a Primary Treatment for many potential tram-related bicycle crash scenarios. Separation, in contrast, might provide a Step Towards the elimination of serious injury and fatal crashes, but because transit and bicycles would continue to operate in mixed traffic (ROW C) the potential for collisions, slips/skids and wheel wedging might remain.

**Table 2: Applying the Safe System treatment hierarchy to countermeasures identified in the research literature**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Counter-measure** | **Treatment type by crash type** | | | **Reasoning** |
| **Tram vs bike** | **Slip/skid** | **Wedge** |
| **Segregation** | Primary1 | Primary1 | Primary | No interaction = no crash risk |
| **Separation** | Step Towards | Step Towards | Step Towards | May reduce the likelihood of crashes. Step to segregation? |
| **Hook (two-stage) turns** | Supporting Treatment | Supporting Treatment | Primary | May decrease likelihood of some crash types. Eliminates wedging if increased to 90 degree crossings. |
| **Increasing crossing angles** | No impact | Supporting Treatment | Primary |
| **Rubberised inserts** | No impact | Minimal impact | Primary Treatment | Still possible to slip on the metal rail surface. |
| **Public education** | Supporting Treatment | Supporting Treatment | Supporting Treatment | May reduce the likelihood of crashes. |
| **Helmets** | Supporting Treatment | Supporting Treatment | Supporting Treatment | Helmets reduce consequences of head injuries, but do not prevent fractures, dislocations and other potentially serious injury. |

Notes: 1. Longitudinal-segregation (ROW B) may only be a Primary Treatment for tram vs bike and slip/skid crash types involving bicyclists travelling in the same direction as the tram tracks. At-grade intersection crossings may still pose a risk of tram-related bicycle crashes. Source: Authors’ assessment

Hook turns for cyclists and other treatments that increase crossing angles up at 90 degrees may provide a Primary Treatments for wedge-type crashes. However, the possibility of a serious injury or fatal crash from a collision or slip/skid might remain, even if such treatments reduce the likelihood of such crashes. Similarly, rubberised inserts that fill the track groove would appear to be a Primary Treatment that eliminates wedge-type crashes, yet are unlikely to have much impact on reducing the severity or likelihood of collisions or slip/skid-type crashes. Public education and the use of bicycle helmets, in contrast, appear to be measures the reduce the likelihood of serious injury or fatal crashes, but not eliminate the potential for such crashes to occur. Helmets, in particular, appear (slightly counter-intuitively) in Table 1 as a Supporting Treatment because they do not entirely eliminate the potential for serious and fatal crashes. While obviously helmets greatly reduce the likelihood of head-injury crash types (which might be the consequence of some types of falls and collisions) they do not prevent fractures, dislocations or other serious outcomes in collisions or loss-of-control incidents that do not involve the head.

Slipping or skidding on the tram track’s metal surface is identified as a crash mechanism by many authors, with (Teschke et al. 2016; Maempel et al. 2018; Leune et al. 2021) discussing how this can be more likely in wet conditions. Leune et al. (2021) finds a statistically significant (p<0.001) overrepresentation of crashes occurring during autumn (43% of cases), although it is unclear whether this might be because of more leaves on the track, wet days, cycling or other factors.

Wedging of a bicycle wheel in the groove of a tram track is discussed by much of the research literature, including by Deunk et al. (2014); Vandenbulcke et al. (2014); Naznin et al. (2016); Teschke et al. (2016); Vandenbulcke et al. (2017); Maempel et al. (2018); Gerber et al. (2021); Leune et al. (2021); Smith et al. (2023); Utriainen et al. (2023). This appears to occur when bicyclists cross tracks at a low angle, such as when changing lanes or turning across tracks at an intersection, especially for opposed turns (a right-turn in left-hand drive jurisdictions) (Teschke et al. 2016; Maempel et al. 2018; Beck et al. 2019; Utriainen et al. 2023). Restricting crossing angles to more than 45 degrees or as close to 90 degrees is one way to prevent wedging either through public education or detailed design of crossings (Novales et al. 2014; Beck et al. 2016; Teschke et al. 2016; Gildea et al. 2021; Smith et al. 2023), or even the use of hook (two-stage) turns (Currie & Reynolds 2011; Teschke et al. 2016; Maempel et al. 2018).

In general, therefore, the context for this study is that tram-related bicycle crashes is an area that has been closely studied in a small number of papers (namely Maempel et al. (2018); Gerber et al. (2021); Leune et al. (2021); Smith et al. (2023) and Teschke et al. (2016)). However, it is an area in need for further research (Teschke et al. 2016; Gerber et al. 2021; Smith et al. 2023), as tram-related bicycle crashes are a public health issue (Teschke et al. 2016; Smith et al. 2023) that tend to have consequences such as head injuries, fractures and dislocations that are medically complicated (Maempel et al. 2018; Leune et al. 2021; Smith et al. 2023). Unfortunately, it does not appear that the previous research literature on tram-related bicycle crashes has engaged with the Safe System framework or Vision Zero principles, although this is not especially surprising given that that this approach is a relatively recent development in road safety engineering. That said, however, some of the countermeasures for tram-related bicycle crashes appear to be Primary Treatments that might virtually eliminate the potential for serious injury or fatal outcomes for tram versus bike or slip/skid crash types (segregation), or for tyre-wedge-type crashes (segregation, hook turns, increased crossing angles, rubberised inserts).

1. See Vuchic (1981, pp. 62-3; 2005, pp. 5-6) definitions of ROW A (fully-separated, where transit operates in its own alignment and road crossings are grade-separated or controlled by railway-style crossings), ROW B (longitudinally-separated, but where crossings are at-grade and potentially controlled by traffic signals or road rule) and ROW C (mixed traffic, where transit and other road users share the same space). [↑](#footnote-ref-1)