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Measuring driving workload of heavy vehicles at roundabouts

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ABSTRACT

Correctly designed roundabouts proved to have positive safety and functional performances. However, they are also affected by peculiar disadvantages. In particular, they are difficult to manoeuvre, especially for heavy vehicle drivers. Despite these concerns, there are currently no driving workload metrics devoted to roundabouts.

A novel methodological approach is proposed for trying to quantify workload impinging on heavy vehicle drivers when manoeuvring through complex at-grade intersections. Proper acquisition of input data constitutes the starting point for future research about ascertainment of workload for these particular road scenarios. The described procedure enables recording steering wheel angles performed by a driver when manoeuvring an articulated lorry through a complex at-grade intersection. A field trial was carried out for verifying the practical feasibility of proposed method in capturing driver's steering behaviour. Dynamic data acquired via global navigation satellite system instrumentation were related to actual driver's steering wheel behaviour captured by camera frames. As a complement to the experiment, selected steering behaviour metrics were calculated. Steering Entropy attributed a high difficulty level to the manoeuvres performed through the roundabout, whereas High Frequency Component and Steering Reversal Rate showed intensity and occurrences of driver's corrections needed for controlling position of the semitrailer at the ring. It appears that even a single roundabout may represent an arduous task for drivers. The study concludes with recommendations for further research about workload imposed by roundabouts to heavy vehicle drivers, with special attention to successions of closely spaced roundabouts.

1. Background

1.1. Challenges posed by roundabouts to heavy vehicle drivers

Properly designed roundabouts often guarantee better results in terms of safety and operational performances as compared to signalised intersections (AASHTO & Transportation Officials, 2010; Guichet, 1997). They decrease the number of conflict points, as well as vehicle speed and crash severity (Elvik, 2003). The reduction of traffic flow congestion, experienced by numerous case studies, is equally relevant.

However, there are still certain disadvantages. Roundabouts may represent a challenging task for drivers (Hels & Orozova - Bekkevold, 2007). As an example, signalised intersections are easier to cross because traffic stream movements are rigidly

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regulated, while traffic operations at roundabouts strictly rely on a complex mutual interaction between multiple vehicular flows approaching to the ring simultaneously (Rodegerts et al., 2010).

Therefore, in light of beneficial aspects and potential concerns posed by roundabouts, their adoption should be a case-by-case decision (Isebrands, Hallmark, Fitzsimmons, & Stroda, 2008). The design process should require a considerable amount of iterations among geometric layout, operational analyses and safety evaluations. Transit of large goods vehicle (LGV) poses additional challenges to the designers (Harwood, Torbic, Richard, Glauz, & Elefteriadou, 2003). Turning manoeuvres of LGV require wider entries and circulating lanes. A trade-off must be reached between space requirements imposed by heavy vehicles and needs for adequate deflections of smaller vehicles' trajectories. Prevention of LGV overturning events is an essential concern too. United Kingdom reports nearly 60 injury crashes per year involving truck overturns at roundabouts (Kennedy, 2007). In a French study, 39 roll-over crashes occurred on 27 roundabouts were analysed. In 95% of cases, the vehicle was an articulated lorry rolled over outside the ring, on its right side (CETE & Normandy Centre, 1997).

Most of these crashes are not reported in statistical crash records because they are usually not serious, given that speed of involved vehicles is usually low. Nevertheless, these events have economic consequences due to road damage, lorries damage and subsequent traffic disruptions (Cerezo & Gothiè, 2006).

Geometric layout of roundabouts is usually decisive for the occurrence of overturning events involving heavy vehicles. Succession of reverse curves imposed by roundabouts to vehicles' trajectories can induce critical oscillatory motions on suspensions that can lead to roll-over (Waddel, Lenters, & Gingrich, 2009). Likelihood of overturning events may even increase with a circulatory roadway sloping outward the central island, a solution usually adopted for making water drainage easier.

In this case, the lateral gravity force acting on the semitrailer could be greater than one experienced by the driver on the tractor. As a result, drivers could not notice an eventual dangerous lean of the semitrailer (Kennedy, 2007; Waddel et al., 2009). Misperception of forces acting on the semitrailer is due to the so-called "low speed off-tracking" phenomenon, which causes the rear of the vehicle to follow a path that is inside the trajectory taken by the front of the tractor during a steering manoeuvre (National Transport Commission Australia, 2007).

At multilane roundabouts, lorry drivers have to carefully monitor the other vehicles, especially the lighter ones, for preventing possible collisions. Situations are not rare when cars circulate next to LGV within the circulatory roadway before abruptly changing lanes to exit the roundabout (Kennedy, 2005; Waddel et al., 2009).

All of these considerations highlight how dangerous guiding though a roundabout could result for LGV drivers, who must cope with small turning radii and adverse cross slope, as well as taking into account movements of interfering traffic flows. Heavy vehicles drivers could take benefit from proper geometric design conceived on the base of aforementioned criticalities. However, these topics are still far from being accurately addressed by all of the national guidelines. For example, prevention of overturning crashes, when provoked by successive reverse curves imposed by roundabout to vehicles' trajectories, is not contemplated by national guidelines, even if this kind of crash may occur at very low speeds. Possible countermeasures, which lie in making roundabout approaches more tangent for avoiding harmonic motions of suspensions, are proposed by only technical Literature (Waddel et al., 2009). Briefly, accommodation of heavy vehicles at roundabouts is usually managed at a geometrical level only, without any further consideration about actual efforts sustained by the drivers.

The problem arises of investigating whether roundabouts along heavy vehicle corridors could dangerously stress LGV drivers performances with consequent safety potential concerns. This assumes more relevance in light of the fact that successions of roundabouts separated by only a few hundred metres are a recurrent situation for different road networks, such as the rural ones, as well as industrial areas and logistic platforms (Isebrands, 2011; Rodegerts, Jenior, Bugg, & Ray, 2014; Russell, Landman, & Godavarthy, 2012). LGV drivers must travel collector links continuously interrupted by difficult-to-manoeuvre roundabouts imposing the above-mentioned difficult tasks.

Currently, there are no design consistency evaluation methods specifically devoted to series of roundabouts, in spite of their increasing diffusion. Even more important, a rigorous ascertainment of stresses induced by crossing roundabouts is still far from being implemented.

1.2. Driving workload

Drivers continuously gather new information from surrounding environment and their vehicle before comparing it to information previously elaborated like a sort of space-time continuum process (Hancock & Verwey, 1997). Successively, decisions are made and actions performed. The concept of driving workload is directly related to portion of operator's limited capacity required to successfully accomplish a specific task which can refer to both the vehicle control, i.e. the primary task, and to other secondary activities such as conversation, listening to the radio, making a cellular phone call, and checking a navigation map display.

Driving workload focuses on driver's personal reaction to task demand, given that it involves specific operator factors like his driving skills, driving experience and even applied strategy for crossing difficult sites, such as complex at-grade intersections.

Briefly, exposition of control, guidance and navigation issues, as well as driver's individual capabilities, determines the total amount of workload (Ba & Zhang, 2011).

Problems arise when efforts induced by surrounding stimuli exceed the processing data capacity of drivers. They may quickly become unable to manage all the difficulties posed by the road context, with potentially harmful consequences (Fitzpatrick et al., 2010).