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Selection of the most appropriate roadside vehicle restraint system – the SAVeRS project

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Abstract

Run Off Road (ROR) crashes are road accidents that often result in severe injuries or fatalities. To reduce the severity of ROR crashes, "forgiving roadsides" need to be designed and this includes identifying situations where there is a need for a Vehicle Restraint System (VRS) and what appropriate VRS should be selected for a specific location and traffic condition. Whilst there are standards covering testing, evaluation and classification of VRS within Europe (EN1317 parts 1 to 8), their selection, location and installation requirements are typically based upon national guidelines and standards, often produced by National Road Authorities (NRA) and/or overseeing organisations. Due to local conditions, these national guidelines vary across Europe.
The European SAVeRS project, funded within the 2012 CEDR Transnational Research Programme "Safety", has developed a practical and readily understandable VRS guidance document and a user-friendly software tool which allow designers and road administrations to select the most appropriate solution in different road and traffic conditions. This paper describes the main outcomes of the project, the process to select the most appropriate roadside barrier, and the user friendly SAVeRS tool.

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1. Introduction

SAVeRS (Selection of Appropriate Vehicle Restraint Systems) is a Research Project funded within the 2012 Call "Safety" of the Transnational Road Research Programme of CEDR (Conference of European Directors of Roads) by Belgium/Flanders, Germany, Ireland, Norway, Sweden, and the United Kingdom to produce a practical and readily understandable Vehicle Restraint System (VRS) guidance document and a user-friendly software tool that would allow users (designers and road administrations) to select the most appropriate solution in different road configurations and traffic conditions.

The Guideline aims at:

- **identifying the need for a VRS (barrier placement guidance)** and the minimum length of barrier to be placed prior to the hazard ("length of need");
- selecting the most appropriate **VRS performance class for safety barriers** (including bridge parapets);
- selecting the most appropriate **VRS performance class for crash cushions**;
- selecting the most appropriate **VRS performance class for terminals**;
- **identifying the need for motorcycle protection systems (MPS)**.

All the performance classes are given according to EN1317 parts 1 to 3 (CEN (2010a), CEN (2010b) and CEN (2010c)) and ENV1317-4 (CEN (2002)).

This paper describes the roadside barrier selection process (including medians and bridge parapets). More details on the other sections of the Guideline can be found in La Torre et al. (2015).

2. Background

Run Off Road (ROR) crashes are road accidents that often result in severe injuries or fatalities. To reduce the severity of ROR crashes, "forgiving roadsides" need to be designed and this includes identifying situations where there is a need for a Vehicle Restraint System (VRS) and which VRS should be selected for a given location and traffic condition.

Whilst there are standards covering testing, evaluation and classification of VRS within Europe (EN1317 parts 1 to 8), the selection, location and installation requirements are typically based upon national guidelines and standards, produced by National Road Authorities (NRA) and/or overseeing organisations. Due to local conditions, these national guidelines vary across Europe.

Within Work Package 1 of the SAVeRS project, an extensive international review of the current state-of-the-art was undertaken to identify the most influential parameters for the placement and selection of vehicle restraint systems. This was achieved through the examination and detailed analysis of 37 national standards and guidelines, and also from a thorough review of existing literature (Erginbas et al. (2014)).

The analysis of the collected guidelines and standards revealed many similarities among different countries. It is understood that while some countries have their original standards, some others adopt and adapt at least in part the guidelines from other countries. Figure 1 shows the distribution of the national guidelines and standards in the different countries around the world.

It can be observed in Figure 1 that there are some dominant guidelines/standards in different parts of the world. This is most probably due to different VRS testing standards existing in different regions. Since the performance classification is different for each test standard, each country will adopt/adapt a guideline that uses the same performance classification as the testing standard. It can be seen, for example, that guidelines from the US are adopted by countries in America, while Australia and New Zealand have their own.

In Europe, although the German standard stands out as the most widely adopted, the majority of the countries have their own dedicated guidelines and standards. However, many approaches, decision processes, tables and graphs are shared or similar among several countries.

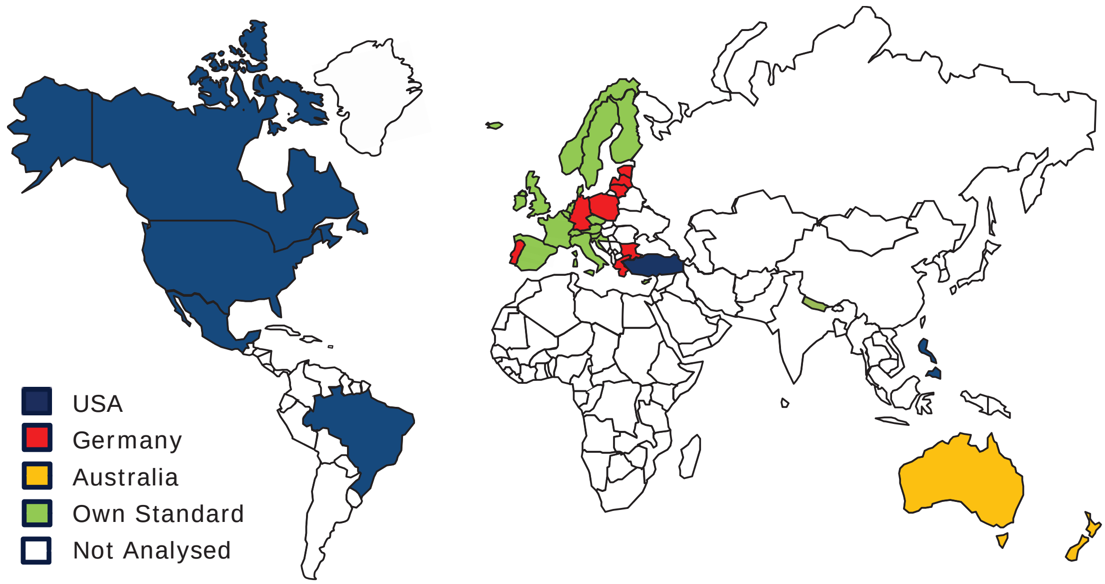

Fig. 1. Distribution of National Guidelines in Other Countries (Worldwide).

Most noticeably a risk based model underlies the decision mechanism in most of the examined standards, as shown in Figure 2, either explicitly or implicitly in diagrams and tables. In these standards the decision upon the installation of a VRS is based on the likelihood of a vehicle reaching a hazard and the consequences of the hazard being hit.

Fig. 2. Risk Model.

Likelihood alone is not enough for the decision concerning a VRS installation, as a VRS would not be necessary if the hazard would not pose any danger to errant motorists. For this reason, it is essential to evaluate also the consequences of hitting a barrier as compared to the consequences of hitting the hazard shielded by the barrier.

The “forgiving roadside” approach is an inherent part of all the standards reviewed within the SAVeRS Project and should always be kept in mind as the main guideline in deciding if a VRS is required or not. The first priority of any designer should be to make the roadside as “forgiving” as reasonably possible. In order to achieve this goal, the following design options should be applied in the following order:

1. **remove the hazard:** if possible, a hazard should be removed to completely eliminate any risk for an errant vehicle reaching it;
2. **redesign the hazard to be safely traversable:** if the hazard cannot be removed, it should be designed flexible enough to be bent by an errant vehicle;
3. **relocate the hazard further away from the road:** if the hazard cannot be made traversable, it should be moved further away from the road, where it is less likely to be reached by errant vehicles;
4. **make the hazard passively safe:** if the hazard cannot be relocated, it should be made passively safe, in accordance with EN12767 (CEN (2007)), to reduce the severity of a possible impact;
5. **install a VRS:** a VRS should only be installed if the options above are not possible or unreasonable from a cost-effectiveness perspective;

6. **delineate the hazard:** if none of the options above are applicable, the hazard should at least be made visible to warn road users of its existence.

It should always be remembered that, although barriers are designed and tested to decrease impact severity, a collision with a VRS can also have undesired consequences. This is the reason why installing a VRS is presented only as the 5th option on a list of decreasing priority. For this reason a VRS should only be used if reaching the hazard is likely to have more severe consequences than a collision with the VRS. Similarly, the selection of a barrier containment level should be made taking into account that higher containment VRS are generally associated with higher crash severity for errant vehicles contained by the VRS as compared to lower containment VRS.

The procedure presented in the following section should be applied considering the overall risk mitigation approach explained above.

3. The safety barriers performance and type class selection process

Based on the risk assessment principle described earlier, the procedure developed in the SAVeRS project to select the most appropriate safety barrier performance class and type consists of the following steps, as shown in Figure 3:

- define the likelihood of having an impact with a barrier for both a passenger car or a Heavy Goods Vehicle (HGV) by developing a set of Run Off Road (ROR) models;
- define the probability that the crash will be contained by the given barrier by comparing the specific crash impact energy (IKE) with the barrier containment lever (VRSCL);
- evaluate the potential consequences of a crash for road users depending on weather the vehicle is contained or not and depending on the hazard the barrier is shielding or protecting from;
- a suitable VRS and conduct a Whole Life Cost (WLC) analysis;
- evaluate third party risk (based on the chart included in the Guideline).

As different countries, as well as different designers within a country, have different levels of expertise and data availability, the SAVeRS procedure has been structured for different application levels, as shown in Table 1.

Table 1. SAVeRS Multilevel approach.

LEVEL	DATA AVAILABILITY	SAVeRS APPROACH
1	Very detailed data available	Full SAVeRS selection procedure
2	Limited data available	Reduced SAVeRS Selection procedure
3	No data available	Default selection criteria

Each model in the SAVeRS procedure is designed to allow the user to change the calculation parameters. Where possible, different default parameter sets are given for different conditions in order to allow the user to select the one that best fits the specific case being analysed.

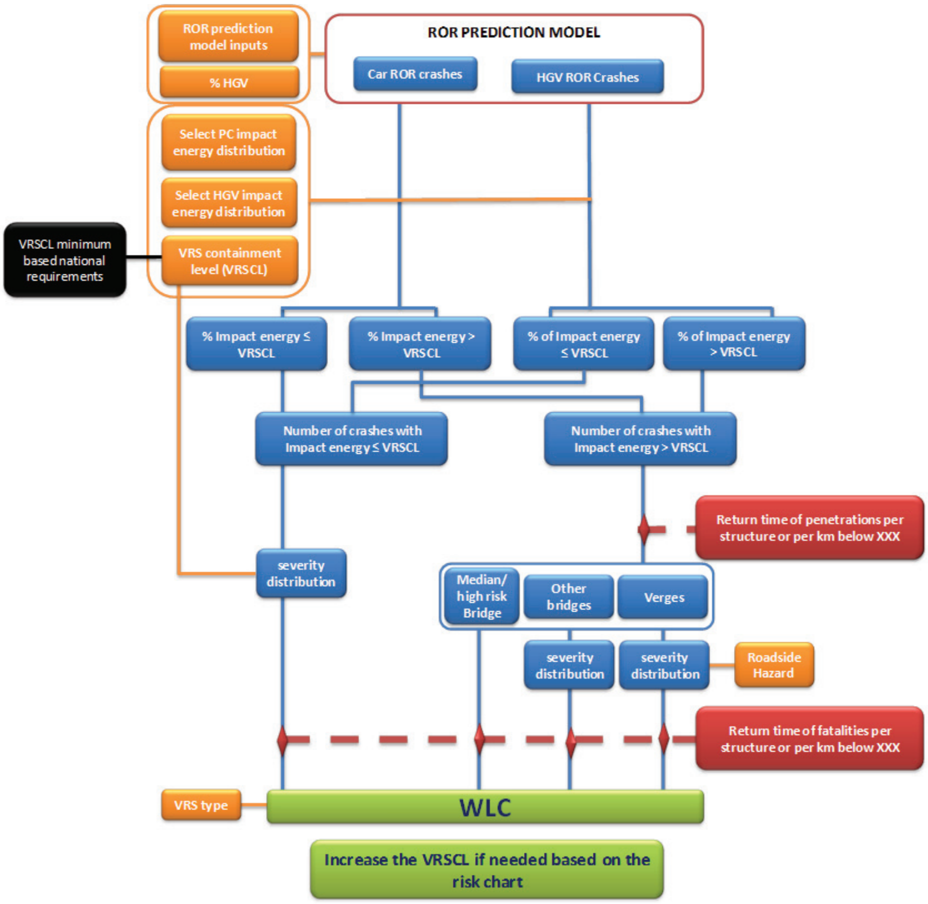

Fig. 3. SAVeRS procedure for selecting the most appropriate VRS (for safety barriers and bridge parapets).

4. The Run Off Road models

The Run Off Road model implemented in the SAVeRS procedure, developed in Work Package 2 of the project (see Stefan et al. (2014) for more details), provides maximum flexibility and adaptability to local conditions. The crash prediction model has the following form:

$$N_{pred,i} = N_{SPF,i} \times (CMF_{1,i} \times CMF_{2,i} \times ......\times iCMFv,i) \times C \qquad (1)$$

where:

$N_{pred,i}$ is the predicted average single vehicle ROR crash frequency for a specific year for a site i;

$N_{SPF,i}$ is the predicted average single vehicle ROR crash frequency determined for base conditions for site i (base model);

$CMF_{y,i}$ are the Crash Modification factors specific to site i;

C is the calibration coefficient to adjust the prediction for local conditions (national, regional, by network etc).

This structure has the advantage to allow for a very high degree of flexibility and adaptability to different conditions. The SAVeRS tool user can:

- select one of the models already available in the SAVeRS tool;
- select one of the base models already available in the SAVeRS tool and perform an overall calibration to the local network as described in Annex 3 of the Guideline (for motorways) and Annex 4 of the Guideline (for two-lane two-ways rural roads);
- fit the base model functional form to local data as described in Annex 2 of the Guideline and then perform an overall calibration to the local network as described above;
- replace the number of crashes estimated by the SAVeRS ROR model with locally derived crash values (typically based on an Empirical-Bayes evaluation). The statistical methods to derive local crash data are not discussed in the Guideline. More details can be found in the AASHTO Highway Safety Manual (AASHTO (2010) and AASHTO (2014)).

The ROR models have been developed for the road networks shown in Table 2:

Table 2. Run Off Road models developed in the SAVeRS Project.

COUNTRY	NETWORK TYPE
Austria	Motorway
Italy	Motorway
Sweden	Motorway
	Two-lane two-way rural roads
Ireland	Motorway
	Two-lane two-way rural roads
UK	Motorway

The models are calibrated considering the total single vehicle ROR crashes. To complete a full analysis, the SAVeRS procedure requires that the total number of ROR crashes is divided into passenger car and HGV (trucks and buses) crashes. A common assumption is that the accident risk is the same and therefore the number of crashes with HGV (N_{HGV}) would be given by:

$$N_{HGV} = N \times \%HGV \tag{2}$$

where %HGV is the percentage of HGVs in the traffic mix.

Recent studies show that this assumption is not valid for ROR crashes. In the NCHRP 22-27 project (Ray et al. (2012)) a correction factor (C_{HGV}) of 0.3 has been introduced to account for the reduced ROR risk of HGVs.

This means that the number of ROR crashes involving a HGV should be calculated as:

$$N_{HGV} = C_{HGV} \times N \times \%HGV \tag{3}$$

Using the Italian, UK and Irish fatal+injury single vehicle ROR crash dataset the following statistics have been derived for motorways:

- in UK a C_{HGV} value of 0.5 was estimated;
- in Italy a C_{HGV} value of 0.61 was estimated;
- in Ireland a C_{HGV} value of 0.51 was estimated.

This extensive evaluation confirms that there is a need for a correction factor to estimate HGV crashes and therefore an HGV correction factor is included in the procedure by using Eq. 3 and the percentage of HGV in the mix should not be used directly to calculate the expected number of HGV ROR crashes.

5. The impact energy distribution models

The selection of a VRS is based on several variables, however one of the most critical parameter to be defined is the required structural capacity, or containment level, of a VRS. To compare the demand for a specific crash with a given VRS containment level, the Impact Kinetic Energy (IKE) is considered, as described in Figure 3.

To identify the distribution of IKE values, only very limited datasets have been published and they mostly contain information on passenger cars. For this type of vehicles the IKE distributions available in the SAVeRS tool are:

- the US RSAP3 distributions (RSAP (2013)) for single carriageways and dual carriageways;
- the German GIDAS distributions (German In Depth Accident Survey) for Motorway – Dual carriageways, Highway – Dual carriageways and Rural – Single carriageway roads.

However, to evaluate the performance of a VRS in real world conditions, also the expected departure conditions for heavy trucks should be included. Unfortunately there are no databases for HGV crashes available to create similar exit condition plots as for passenger cars. The HGV impact angle distribution is expected to be lower than the passenger car distribution and therefore the approach used in the RSAP3 model (RSAP3 (2013)) is to select all the trajectories that are compatible with the sliding conditions of a single unit truck or with a tractor-trailer/multiple units truck.

A study conducted for the high speed rail risk assessment in Italy (Domenichini et al. (2004)), developed a predictive model based on the handling performance of vehicles, position in a travel lane, observed vehicle speed distributions by vehicle type and vehicle type distribution in the mix. This model allows to estimate the distribution of the upper threshold of IKE values assuming that all the crashes will occur at the maximum sliding equilibrium condition for a given vehicle and speed. This assumption is extremely conservative, it has been applied only for very critical risk evaluations and these distributions should be adjusted for VRS design.

Based on the trajectory data given by RSAP3, a set of HGV distributions have been defined excluding from each subset any record where the combination of speed and angle was not compatible with the equilibrium of a single unit truck (or bus) or with a tractor-trailer/multiple unit truck. The equilibrium evaluation criterion is defined in Annex 5 of La Torre et al. (2015) where the original procedure has been adjusted to be applied to the SAVeRS procedure. Different limiting conditions are defined depending on the number of lanes (2 or 3), the position on the lane (lane 1 is the outer, lane 3 is the closest to the median) and the edge to be considered (roadside or median). In all the evaluations a 3 m wide outside shoulder and a 0.70 m wide inside shoulder have been considered. The full procedure defined in Annex 5 of La Torre et al. (2015) has been applied using 2 different datasets from 2 sections on the Italian motorway network: one for a 3 lane section and one for a 2 lane section. Based on the observed mix, lane occupancy for the different vehicle types and speed distribution per lane and per vehicle type, the probability of having a vehicle running off with a given combination of speed, mass and maximum impact angle is calculated.

As an example the different HGV distribution curves for roadsides are shown in Figure 4.

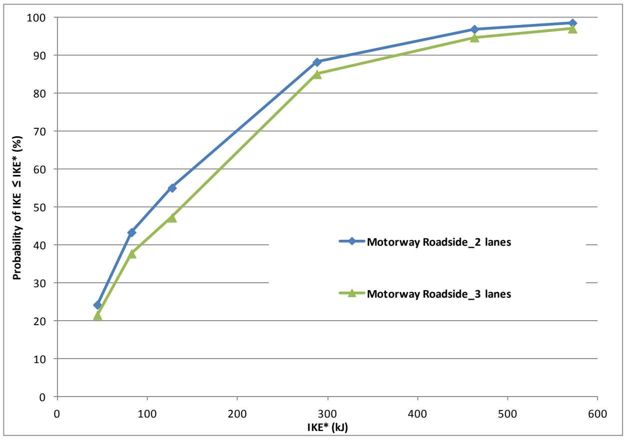

Fig. 4. Distribution of HGV Impact Kinetic Energy for roadsides (outer edge).

6. The Severity Distribution Functions

The Severity Distribution Functions (SDF) are used in the SAVeRS tool to split the total injury+fatal crashes different severity crashes, where the severity is defined in the KABC scale as shown in Table 3.

Table 3. Injury Severity Classification used in SAVeRS.

SEVERITY CODE	INJURY SEVERITY
K	Fatal crash
A	Incapacitating injury crash
B	Non incapacitating injury crash
C	Possible injury crash

In the SAVeRS tool the following criteria have been applied to define the severity distribution functions:

- vehicle potentially penetrating the VRS (IKE above the containment level of a VRS, VRSCL):
  - for medians or high risk bridges (tall bridges – with a drop of 10 m or more, important water streams, highly traffic roads, structures behind) a 100% fatality rate is assumed as a safe estimate;
  - for non-high risk bridges the data from NCHRP 12-22(03) (Ray and Carrigan (2014)) have been applied showing that out of 38 fatal+injury crashes involving a VRS penetration 5 were fatal (17.2%), 13 where A injuries (44.8%), 5 where B injuries (20.7%), and only 6 (20% resulted in C injuries);
  - for verges the Highway Safety Manual (HSM) freeway model distributions without a safety barrier have been applied (AASHTO (2014)). A correction factor to K, A, B crashes has then been applied based on the UK RRRAP model to account for the different risk related to the hazards shielded by the VRS (http://www.standardsforhighways.co.uk/tech_info/rrrap.htm). Moreover, the user can adopt the default hazard risk factors included in the SAVeRS tool or introduce a “user defined” value;
- vehicle potentially contained by the VRS (IKE below or equal to the VRSCL):
  - the HSM freeway model SDF has been applied with a correction factor to account for the different VRS containment levels (defined according to EN1317). Due to a lack of experimental data this factor is based on the work conducted in 2010 by U. Ehlers (2010) regarding potential severity of impacts with N2, H1 and H2 barriers. Increasing the VRSCL leads to an increase of severe crashes, K and A, compared to the less severe crashes, B and C. The values for H3 and H4 have been extrapolated from the H2 to H1 ratio. A specific study to evaluate the severity of impacts with different classes of barriers, including H3 and H4, is deemed necessary.

As no direct correlation has been found between the distribution of injury crashes and the EN1317 severity class (based on ASI and THIV indices) in the current version of the SAVeRS tool there are no correction coefficients to account for this. This differentiation could be added in future releases of the tool when different severity distributions will be available.

7. The whole life cost model

The evaluation of the economic impact of a selected VRS is based on different cost components and benefits that can be grouped into several categories. These different financial elements depend on construction and operational costs and on the estimated injury and societal cost.

The following cost categories are considered in the SAVeRS procedure:

- societal costs (obtained multiplying the number of expected crashes per each injury severity category for the unit cost of accidents for a given severity). As the unit cost per crash severity can vary considerably amongst the different countries, different default values are given in the tool. For countries not included in the SAVeRS tool the unit costs for injuries can be user defined;
- equipment cost. This is dependent on the specific VRS used and accounts for the following costs items:

- construction costs;
- reconstruction cost after the expected design life (that needs to be defined for each specific barrier);
- maintenance cost per year;
- repair cost based on the repair cost per unit length (m), estimated length of barrier (m) to be repaired, type of impacting vehicle (passenger car or HGV), type of crash (contained or penetrated), and number of expected crashes.

8. The SAVeRS tool and potential applications

The SAVeRS tool (Figure 5) is a free of charge public tool developed as an Excel Spreadsheet (downloadable at www.saversproject.com) that can be used by National Road Authorities, designers road administrations directly involved in road management and researchers for setting VRS requirements, or for site specific risk assessments.

Fig. 5. Introductory screen of the SAVeRS tool.

The SAVeRS tool can be applied at a national level in the definition of national standards allowing the different National Road Authorities to identify:

- the minimum return time of a penetration per km that can be deemed acceptable in the design phase;
- the minimum return time of a fatal crash per km that can be deemed acceptable in the design phase;
- the default parameters that should be used in the design phase;
- the minimum VRS class for different traffic conditions and infrastructure layouts to be included in the national standard. This would be used in preliminary design phases and where a site specific analysis is not conducted;
- the situations where a maximum VRS class should be set unless special circumstances justify a higher VRS class.

Examples of applications in UK and Italy are given in La Torre et al. (2015).

Designers can use the tool to conduct a risk assessment of specific project and to identify the most appropriate solution for a given traffic, infrastructure ad hazard combination.

Finally road administrations directly involved in road management can use the tool for assessing possible upgrades of vehicle restraint systems already in place by comparing the potential risk associated with a given situation with that of the upgraded situations obtained by increasing the performance class of the barrier.

9. Conclusions

Within the SAVeRS project a guideline for the selection of the most appropriate vehicle restraint system class and type has been developed and a public tool has been made available. This tool will allow designers to conduct risk assessments of specific situations and road administration directly involved in road management to set priorities in upgrade programmes. It will also support National Road Authorities to set new standards for minimum performance requirements.

The main innovation of the SAVeRS tool is that the likelihood of having a ROR crash can be calculated based on several models implemented in the tool as well as with locally derived models.

The tool allows the user to select predefined values as well as locally derived values for all the variables used in the different models (e.g. the impact energy distributions, the type of hazards and aggressiveness etc). User-defined values can be set at a national level by the National Road Authority to adapt the models to represent more accurately specific conditions.

The implementation of the SAVeRS Guideline and tool will provide a more sound risk based selection of vehicle restraint system.

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