Development of Fit Envelopes to Promote Compatibility among Child Restraints and Vehicles

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ABSTRACT

This project developed fit envelopes representing the space occupied by small, medium, and large rear-facing and forward-facing child restraints that can be used as tools for promoting compatibility between vehicles and child restraints. The approach applies the envelope method used by the International Standards Organization (ISO) to the US market, by considering the range of child restraint sizes in the 2014 US market and the more commonly used method of installation with flexible LATCH.

Thirty-one child restraints representing a range of sizes, manufacturers, and product types were scanned and installed in vehicles (Klinich et al. 2015). The installed positions of the child restraints were measured in ten late model vehicles. A comparison of the installed positions of the child restraints in vehicles was done virtually using Hypermesh. Starting with the envelope geometries used by the ISO, envelope shapes were modified to represent small, medium, and large rear-facing and forward-facing child restraints. When possible, envelope dimensions were harmonized with the ISO envelopes. To promote compatibility, child restraints should be able to fit in one or more applicable envelopes at an acceptable orientation when the envelope is rotated 15 degrees relative to horizontal (to represent installed orientations on a typical vehicle seat cushion angle.) To promote compatibility from the vehicle side, at least one rear-facing and one forward-facing envelope should be able to be installed in each vehicle rear seating position. Although the evaluation of fit can be performed virtually using computer-aided design, physical representations of the envelopes were also constructed. Test procedures have been drafted to describe setup of vehicles, child restraints, and the evaluation process.

INTRODUCTION

Motivation

Caregivers often struggle to correctly install child restraints in their vehicles. Child restraint installation errors occur frequently, as documented in laboratory studies and observational field studies (Decina and Lococo 2005, Decina and Lococo 2007, Dukehart et al. 2007, Greenwell 2015, Jermakian et al. 2014, Klinich et al. 2013a, Klinich et al. 2013b, Klinich et al. 2010, Koppel and Charlton 2009, Mirman et al. 2014, Tsai and Perel 2009). In some cases, difficulties arise because some combinations of child restraints and vehicles are incompatible. Examples of incompatibilities include:

- Interference between the head restraint and forward-facing child restraint systems (FF CRS)
- Highly contoured vehicle seat cushions that do not permit the CRS to have firm contact with the seat
- Gaps between the back or base of the CRS and vehicle seat cushion or seatback because of incompatible geometries
- Rear-facing (RF) CRS cannot be installed at correct angle because of interference with the vehicle front seat
- Seatbelt or LATCH belt cannot be adequately tightened because of geometric incompatibilities between the CRS belt path and the vehicle anchor geometry
- CRS cannot be installed in adjacent vehicle seating positions.

These issues are not likely to subside, particularly in light of the trend to keep children seated in child restraints longer. In 2011, the National Highway Traffic Safety Administration recommended that children remain rear-facing as long as possible, and the American Academy of Pediatrics recommended that children remain rear-facing at least through their 2nd birthday. They also recommend keeping a child in a forward-facing harnessed restraint as long as possible before switching to a belt-positioning booster seat. In response, child restraint manufacturers have redesigned RF CRS to accommodate larger children; maximum RF weight limits frequently reach 16 or 18 kg. Many FF CRS 29ow have upper weight limits of 20 kg or more. Another factor that could potentially increase the size of CRS is the proposal to modify FMVSS No. 213 to add side impact testing procedures. At the same time, fuel economy requirements are motivating vehicle manufacturers to reduce vehicle size and mass. As a result, rear seat compartment space can become smaller.

ISO Fit Envelopes

The International Standards Organization has developed procedures to try and match the size of CRS with the available interior volume of vehicle seats to help inform consumers' purchasing choices and to aid in vehicle and CRS design decisions. TC22/SC36/WG2 (formerly TC22/SC12/WG1) issued ISO 13216-3:2006(E) (ISO 2006) to define a classification system for child restraints and vehicles that helps consumers choose CRS and vehicles that are dimensionally compatible. The standard defines eight envelopes: three for rear-facing CRSs, three for forward-facing CRSs and two for car beds. Modifications to the standard to add three envelopes for booster seats have been recently proposed (ISO, 2017).

A previous study (Hu, et al 2015) used computer simulation to evaluate the FF and RF ISO 13216-3:2006(E) envelopes relative to rear seat compartments from vehicles and CRS in the U.S. market. Three-dimensional geometry models for 26 vehicles and 16 convertible CRS developed previously were used. Geometric models of three forward-facing and three rear-facing CRS envelopes prescribed by the ISO were constructed. A virtual fit process was developed that followed the physical procedures described in the ISO standards. The results showed that most of the RF CRS could fit in at least one of the current ISO RF envelopes, but that half of the FF CRS evaluated could not fit in any of the FF envelopes. From the vehicle perspective, vehicles could usually accommodate most of the FF envelopes. However, most vehicles evaluated could accommodate the smallest RF ISO envelope, but not the largest.

These results indicate that the current ISO envelopes could not be used to assess the range of vehicle and child restraint products available in the US due to differences in product shapes. While the FF ISO envelopes fit in the vehicles, FF US child restraints often do not fit in the envelopes. The smallest RF ISO envelope fit in most vehicles, but very few RF CRS fit in this envelope.

This previous project concluded that the ISO fit envelopes are not entirely compatible with the range of child restraint products available in the US. As a result, the current project was conducted to determine how to adapt the ISO envelope method for the US market.

Objectives and Approach

The objective of this project is to develop CRS fit envelopes that would allow improved compatibility between US vehicles and CRS using a procedure modeled after the ISO envelope strategy. The following steps were taken to achieve this goal:

1) A total of 31 CRS contours were digitized.
2) Ten 2012-2014 vehicle rear seats were digitized to capture seat contours and key reference points in rear seats.
3) Multiple CRS restraints were installed in the rear outboard positions of the scanned vehicles using LATCH and the location of key landmarks was recorded to provide information on realistic positioning of CRS and envelopes within vehicle seats.
4) A set of CRS fit envelopes representing the range of typical US CRS was developed, with an effort to harmonize with some dimensions of the ISO fit envelopes.
5) Features on the envelopes were included that allow physical and virtual installation into a vehicle using flexible LATCH.
6) Physical versions of the CRS fit envelopes were constructed.
7) A procedure for installing the fit envelopes into vehicles was developed that allows both physical and virtual installation in vehicles and considered the installed orientation and position of the child restraints installed in step 3.
8) The envelopes and procedures were used to assess fit of CRS within the envelope and the fit of the envelopes within the vehicle.

METHODS

CRS Installations

The first part of the project involved documenting the position and orientation of child restraint systems (CRS) installed in the second rows of vehicles. Klinich et al. (2015) describe the methods and results for initial part of the study that resulted in a database of 486 installations. Thirty-one different CRS were evaluated, selected to provide a range of manufacturers, sizes, types, and weight limits. Eleven CRS were rear-facing only, fourteen were convertibles, five were combination restraints, and one was a booster. Ten top-selling vehicles were selected to provide a range of manufacturers and body styles: four sedans, four SUVS, one minivan, and one wagon. CRS were marked with three reference points on each moving component. The contours and landmarks of each CRS were first measured in the laboratory. Vehicle interior contours, belt anchors, and LATCH anchors were measured using a similar process. Then each CRS was installed in a vehicle using LATCH according to manufacturers' directions, and the reference points of each CRS component were measured to document the installed orientation. Seven CRS were installed in all vehicles, while the remaining twenty-four CRS were divided into three groups, each tested in three or four vehicles.

Envelope Design Process

The geometric data for each vehicle and CRS were imported into Hypermesh software for processing. The measured coordinates of the CRS reference points were used to orient the CRS geometry appropriately in each vehicle. The H-point of the 2L seating position was used as the origin for each vehicle. The reference points measured on each installed CRS were used to position the CRS scan relative to each vehicle seat contour; this process accounts for deformation of the vehicle seat during the installation process. An example is shown in Figure 1.

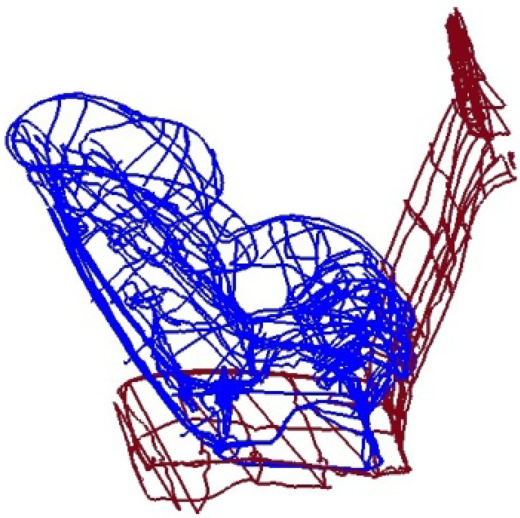

Figure 1. Example of CRS geometry positioned relative to seating position using reference coordinates.

The design of fit envelopes began using rear-facing installations. Of the ten vehicles, installations in four vehicles, which allowed inclusion of all rear-facing products, were considered for designing the fit envelopes. The two vehicles with the highest and lowest cushion and seatback angles, plus two vehicles with intermediate angles, were chosen to evaluate the installed RF CRS conditions. For these installations, only installations with the correct angle were used, and no particular RF CRS was an "outlier" in terms of its installed position.

The first step was to compare the installed CRS profiles and orientations to the ISO R1, R2, and R3 envelopes while positioning the envelope in an "installed" configuration. Figure 2 shows a comparison of installed CRS profiles with the R3 ISO envelope. For the 25 RF CRS measured, none fit in R1, one fit in R2, and seven would fit in R3 if the envelope was about 1 cm wider.

The next step was to "stretch" the R3 box until it encompassed all of the installed RF child restraints, excluding any carry handles. An example of this envelope is shown in Figure 3. After considering various envelope iterations, three RF envelopes were established. RS consists of the ISO R1 dimensions plus 1.5 cm wider, and generally fits RF CRS without the base. RM consists of ISO R3 dimensions plus 1.5 cm wider, while RL is designed to encompass the larger CRS currently being sold in the US.

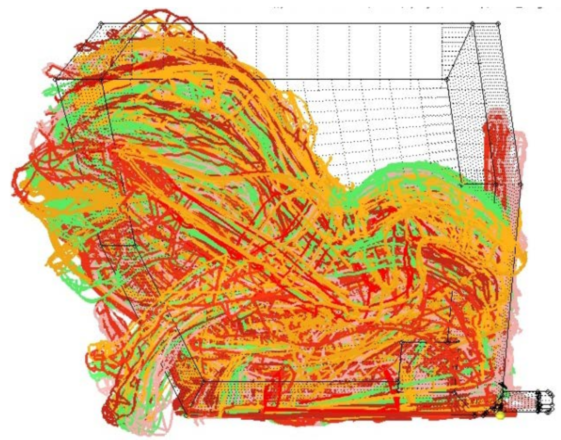

Figure 2. Installed RF CRS positions in four vehicles compared to the ISO R3 envelope.

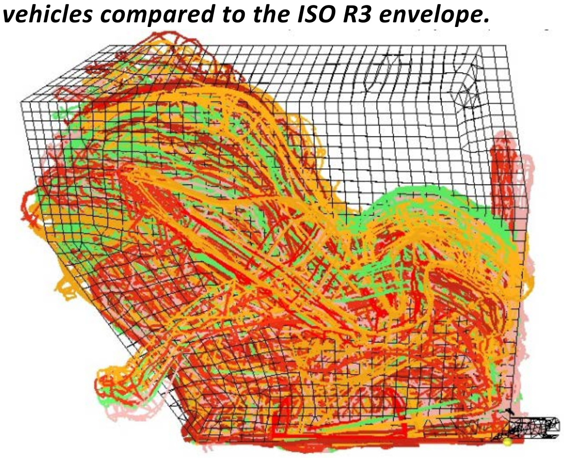

Figure 3. Envelope design that fits around RF CRS

For the forward-facing installations, all of the CRS could be installed tightly in the vehicle. However, in some cases, there was a gap between the CRS and vehicle seatback, most often because of a reclined CRS position or a protruding vehicle head restraint. When choosing which FF installations to use to develop the FF envelopes, installations with a substantial gap were not included. Although a gap is allowable, it is not desirable. For each vehicle, reference points representing a 50 mm gap 10 cm below the top of the vehicle seatback and a 100 mm gap 10 cm above the H-point were virtually marked. Figure 4 and Figure 5 illustrate unacceptable gap levels when determining whether particular installations should be included in the envelope development, while Figure 6 shows installations where the lower gap is considered acceptable.

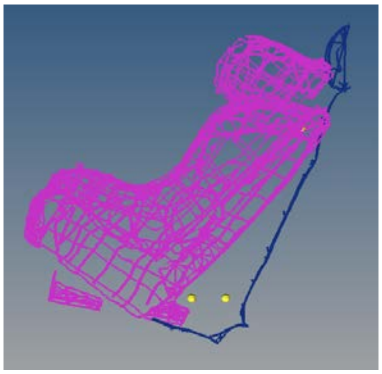

Figure 4. Lower gap too large (greater than 100 mm)

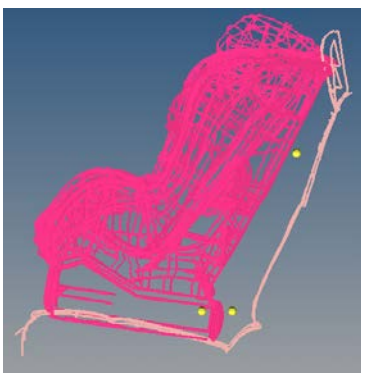

Figure 5. Upper gap too large (greater than 50 mm)

Figure 6. Lower gap acceptable (less than 100 mm).

For the design of the forward-facing envelopes, installations from the same four vehicles with acceptable gaps were considered. The installed positions of the FF CRS were compared to the profiles of the ISO F1, F2, and F3 envelopes. Figure 7 compares the installations to the ISO F3 profile. For the 21 FF CRS measured, one fit in F2 and F2X, and five fit in F3 if the envelope was about 1 cm wider. Therefore, the design of the smallest FF envelope uses the dimensions of the ISO F3 profile, but is 1.5 cm wider (FS). Two other FF envelopes were developed to have a similar wider width than the FS envelope, but different heights to span the range of FF US product sizes.

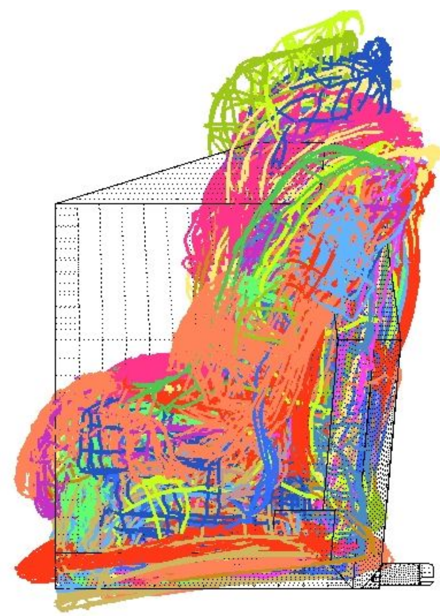

Figure 7. CRS installations in four vehicles compared to the ISO F3 envelope.

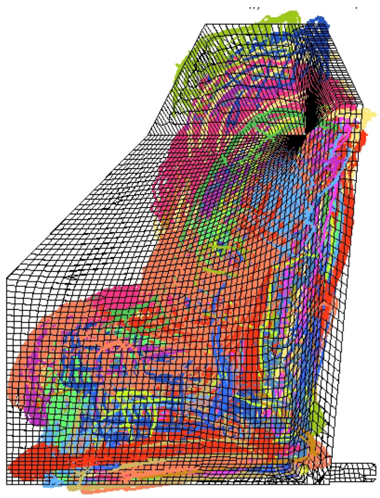

Figure 8. IISO F3 envelope "stretched" to fit around acceptable FF CRS installations in four vehicles.

Belt Path and Tether Zones

While the main goal of the envelopes is to promote compatibility between shapes of CRS and vehicles, achieving compatibility between LATCH belt paths and the vehicle lower anchors can also be considered. In addition, a means of securing the physical envelopes in the vehicle using flexible LATCH is needed, as the rigid LATCH anchors used with the ISO envelopes are not common in the US.

When the CRS were installed in the vehicles, the locations of the lower anchors and the point on the CRS where the LATCH belt first contacted the child restraint were measured. The distance between the lower anchors and the belt path contact point, as well as the angle relative to horizontal, were calculated for each installation. Klinich et al. (2015) report details on how the distance and angle between lower anchor and belt path contact point vary with CRS and vehicle. Based on these reported values, attachment points for flexible LATCH anchors on the envelopes were chosen to be near the center of the angle range on the belt path zone, but also close to the frame support of the envelope so they could be physically mounted to a rigid component. For the RF envelopes, the point produces an angle of 48 degrees and a distance of 136 mm, while for the FF envelopes, the point produces an angle of 62 degrees and a distance of 175 mm. The attachment points consider a vehicle cushion angle of 15°. In addition, a target zone for belt path contact point is included on each envelope, spanning angles from 37° to 57° on the RF envelopes and 50° to 70° on the FF envelopes. To improve compatibility, the belt path or flexible LATCH attachment point should fall within these target zones.

Because flexible LATCH is being used to secure the envelopes in vehicles to evaluate compatibility, the forward-facing envelopes should also include a tether strap. Figure 9 shows the profiles of the three FF envelopes, overlaid with the tether attachment points from each CRS install. A tether location marked with an X was selected to represent a common location that could be used with all three envelopes.

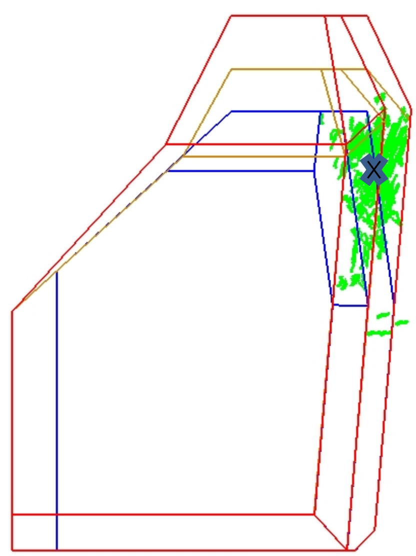

Figure 9. Tether location that can be used with all three envelopes representing common attachment location marked with X.

RESULTS

Diagrams of the final envelope designs are shown in Figure 10 for the FF designs and Figure 11 for the RF designs. Drawings for the designs can be downloaded from deepblue.lib.umich.edu.

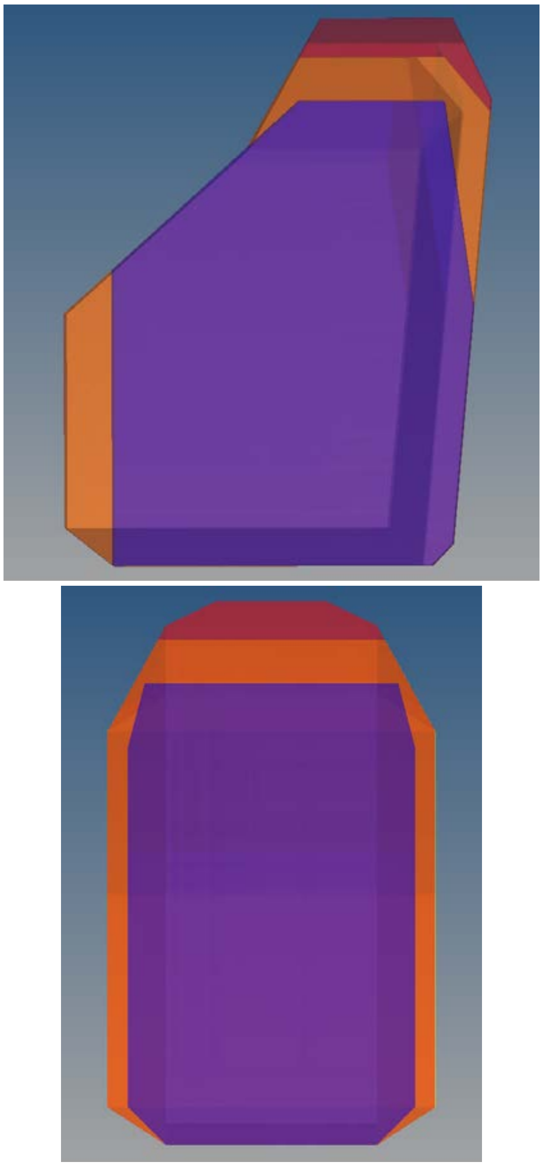

Figure 10. Final dimensions of FF envelopes

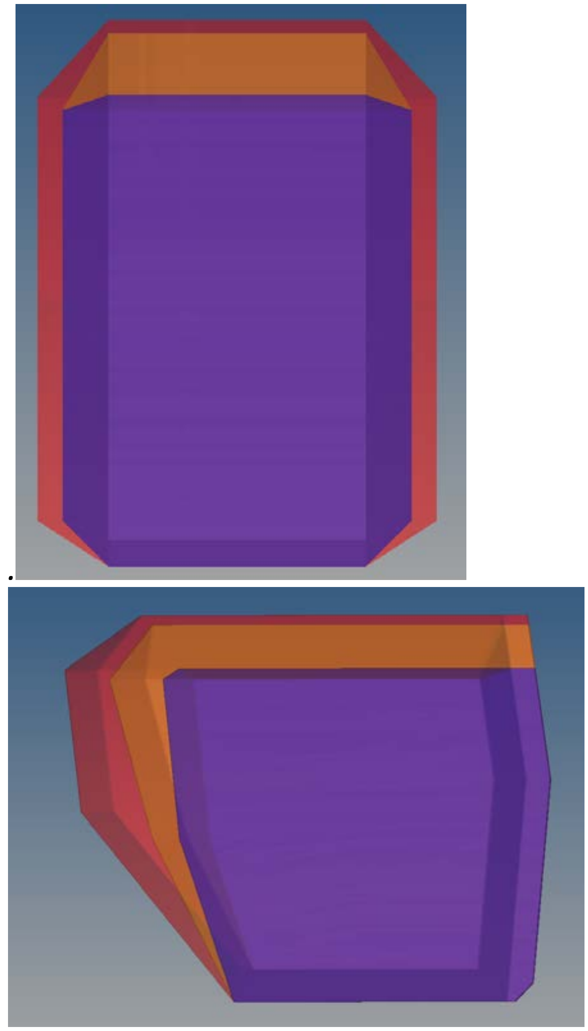

Figure 11. Final dimensions of RF envelopes.

Compatibility Assessment

Checking for CRS fit into the envelopes or fit of the envelope volume shape into vehicle seating positions can be done virtually using CAD or physically using the sets of modular fixtures developed to represent the envelopes and described by Klinich et al. (2015). Results below are based on testing with the physical envelopes.

Twenty-six RF CRS were evaluated in the RS, RM, and RL envelopes. Key criteria for assessing fit in RF envelopes were that:

- The CRS could be placed in the envelope.
- CRS was at an acceptable angle. Tolerance of +/-5 degrees was used if angle was judged using a horizontal line.

- The bottom surface of the CRS did not extend past the edge of the envelope base.
- The bottom surface of the CRS contacted the envelope base.
- Handle fit in at least one position usable for travel, but not all.
- RF belt path aligns with target belt path zone.

Results are shown in Table 1. The main reasons for not fitting were that the CRS was too big to fit in the envelope, the CRS could not fit in the envelope at an acceptable angle, the CRS had insufficient contact with the bottom of the envelope, or the CRS was too wide to fit.

Twelve CRS did not fit in any of the envelopes. One CRS fit in the small envelope under all configurations. Four others fit in the small envelope without the base, but in the RM envelope when the base was used. Five CRS fit in the RM envelope and four others fit in the RL under all configurations.

Twenty-one FF CRS were evaluated in the FF_{CRS} envelopes. Criteria for assessing fit include:

- The CRS could be placed in the envelope.
- CRS was at an acceptable angle.
- The bottom surface of the CRS did not extend more than 4 cm past the lateral open edge of the envelope base.
- The bottom surface of the CRS contacted the envelope base. In addition, the bottom structure of the CRS did not extend past the bottom angled portion of the envelope
- Gap less than 50 mm at upper location and less than 100 mm at lower location.
- FF belt path aligns with target belt path zone

Results are summarized in Table 2. If a cell contains a number, that is the amount (in cm) that the CRS overhangs the edge of the envelope. Reasons why CRS did not fit were too big to fit in envelope, insufficient bottom contact (IBC), a lower gap greater than 100 mm (LG>100), or an upper gap greater than 50 mm (UG>50).

Two FF CRS fit in the FS envelope and three others fit in the FM envelope. Four more CRS fit in the FL envelope. Eleven CRS did not fit into any envelopes under all configurations. One CRS (equipped with rigid LATCH) fit in the envelopes but its belt path did not overlap with the targeted corridors.

Results from assessing vehicle rear seats are shown in Table 3 for the RF envelopes and Table 4 for the FF envelopes. Key criteria for assessing fit were:

- Front seat placed at mid track position with a seat back angle of 23 degrees.
- Envelope base could be installed in vehicle and move less than 25 mm when a 40 lb lateral force is applied at the point where the flexible LATCH is anchored.
- Envelope tips laterally less than 5 degrees from vertical.
- Has no interference with front seat.
- Has no interference with lateral components (and rear door can be closed.)
- For RF_{veh}, bottom of envelope must be 10-20 degrees from horizontal about the lateral vehicle axis.
- For FF_{veh}, gap of less than 50 mm at top edge of base module.

All vehicles evaluated could fit the RS and FS envelopes in the rear seat. All but the Chevrolet Cruze could fit the RM and FM envelopes. For the RL_{veh} envelope, only the Ford F150, Subaru Outback and Toyota Sienna could accommodate it. All of the other vehicles had interference with the front seat, while the Hyundai Elantra also had interference with the B-pillar. For FL, all vehicles could accommodate it except for the Cruze and the Ford Focus.

Table 1. Evaluation of RF CRS in envelopes.

Brand	Model	RS	RM	RL
Baby Trend	Flex-Loc, with base (min and max)	Too big	√	√
Baby Trend	Flex-Loc, without base (min and max)	√	√	√
Britax	Boulevard CS	Too big	Wide	IBC
Britax	B-SAFE, with base	Too big	√	√
Britax	B-SAFE, without base	Angle	√	√
Chicco	KeyFit 30, with base	Angle	√	√
Chicco	KeyFit 30, without base	Angle	√	√
Chicco	KeyFit, with base	Too big	√	√
Chicco	KeyFit, without base	Angle	√	√
Compass	True Fit, R1 (min)	Angle	Angle	IBC
Compass	True Fit, R2 (max)	Too big	Angle	IBC
Cosco	Comfy Carry, with base	Too big	√	√
Cosco	Comfy Carry, without base	√	√	√
Eddie Bauer	Deluxe 3-in-1	width	Width	IBC, width
Evenflo	Nurture, with base	Too big	√	√
Evenflo	Nurture, without base	IBC	√	√
Evenflo	Symphony, R1 (min)	Too big	Angle	√
Evenflo	Symphony, R2 (max)	Too big	Too big	√
Evenflo	Tribute LX	Angle	Angle	IBC
Evenflo	Triumph Advance	Too Big	Angle	Width
Graco	Comfort Sport	Too big	Angle	Angle
Graco	My Ride 65	Too big	√	√
Graco	SnugRide Classic Connect 35, base	Too big	√	√
Graco	SnugRide Classic Connect 35, no base	√	√	√
Graco	SnugRide Classic Connect, base	Too big	√	√
Graco	SnugRide Classic Connect, no base	√	√	√
Maxi-Cosi	Mico, with base	Too big	Too big	√
Maxi-Cosi	Mico, without base	Angle	√	√
Maxi-Cosi	Prezi, R1, with base (min)	Too big	IBC	√
Maxi-Cosi	Prezi, R1, without base (min)	IBC	Angle	√
Maxi-Cosi	Prezi, R2, with base (max)	Too big	IBC	√
Maxi-Cosi	Prezi, R2, without base (max)	IBC	Angle	√
Maxi-Cosi	Pria, R1 (min)	Angle	IBC	√
Maxi-Cosi	Pria, R2 (max)	Too big	√	√
Orbit Baby	Toddler Car Seat	Too big	Too big	Width
Peg Perego	Primo Viaggio SIP, with base	Too big	Width	Width
Peg Perego	Primo Viaggio SIP, without base	Too big	IBC	IBC
Recaro	ProRIDE	Width	Width	IBC
Safety 1st	Alpha Omega Elite	Too big	Angle	IBC, width

Brand	Model	RS	RM	RL
Safety 1st	Guide 65 Sport, R1	√	√	√
Safety 1st	Guide 65 Sport, R2	√	√	√
Safety 1st	Scenera	Angle	Angle	Angle
Sunshine Kids	Radian 80SL	IBC	IBC	IBC

Table 2. Evaluation of FF CRS in envelopes.

Brand	Model	FS	FM	FL
Eddie Bauer	Summit, R1 (min)	Too Big	15.5	15.5
	Summit, R3 (max)	Too Big	Too Big	Too Big
Britax	Frontier 85, R1 (min)	IBC	2	2
	Frontier 85, R2 (max)	Too big	Too Big	LG>100
Orbit Baby	Toddler Car Seat	Too big	Too big	3
Sunshine Kids	Radian 80SL	LG> 100	UG>50	√
Compass	True Fit	Too big	√	√
Britax	Boulevard CS, R1 (min)	Too big	Too big	LG>100
	Boulevard CS, R2 (max)	Too big	Too big	IBC
Evenflo	Triumph Advance, R1 (min)	Too big	LG>100	LG>100
	Triumph Advance, R2 (max)	Too big	LG>100	LG>100
Evenflo	Symphony, R1 (min)	Too big	5.5	4.5
	Symphony, R3 (max)	Too big	IBC	√
Graco	Comfort Sport	Too big	4	4
Safety 1st	Alpha Omega Elite, R1 (min)	IBC	6.5	5.5
	Alpha Omega Elite, R2 (max)	Too big	IBC	LG>100
Eddie Bauer	Deluxe 3-in-1, R1 (min)	Too big	7.5	6
	Deluxe 3-in-1, R2 (max)	Too big	IBC	LG>100
Safety 1st	Scenera	1.25	1.25	1.25
Maxi-Cosi	Rodi Fix, R1 (min)	LG> 100	√	√
	Rodi Fix, R4 (max)	Too big	Too big	LG>100, UPUG UG>50
Baby Trend	Trendz FastBack 3-in-1	Belt path	Belt path	Belt path
Graco	Argos 70, R1 (min)	5.5	5.5	5
	Argos 70, R3 (max)	Too big	Too big	IBC
Maxi-Cosi	Pria, R1 (min)	IBC	Belt path	Belt path
	Pria, R2 (max)	Too big	IBC	LG>100
Safety 1st	Guide 65 Sport	Too big	Too big	√
Evenflo	Tribute LX	4	4	4
Graco	My Ride 65	Too big	Too big	√
Recaro	ProRIDE	Too big	Too big	LG>100
The First Years	True Fit SI	Too big	Too big	LG>100

Table 3. Vehicle assessments with RF_{veh} envelopes

	Front seat at mid track, seatback at 23 degrees		
	RS	RM	RL
Chevrolet Cruze	√	FSI	FSI
Ford Escape	√	√	FSI
Ford F150	√	√	√
Honda Pilot	√	√	FSI
Hyundai Elantra	√	√	FSI, LCI
Nissan Sentra	√	√	FSI
Subaru Outback	√	√	√
Toyota Camry	√	√	FSI
Toyota Sienna	√	√	√

FSI: front seat interference LCI: lateral component interference

Table 4. Vehicle assessments with FF_{veh} envelopes

	Front seat at mid track, seatback at 23 degrees		
Vehicle	FS	FM	FL
Chevrolet Cruze	√	LCI	LCI
Ford Escape	√	√	√
Ford F150	√	√	√
Ford Focus	√	√	LCI
Honda Accord	√	√	√
Hyundai Elantra	√	√	√
Nissan Sentra	√	√	√
Subaru Outback	√	√	√
Toyota Sienna	√	√	√

FSI: front seat interference LCI: lateral component interference

DISCUSSION

In Europe, child restraint fit envelopes are used to check that vehicle rear seats can accommodate particular volumes representing small, medium, and large RF and FF child restraints. The same envelope dimensions are used to check the sizes of child restraints. Information is provided to consumers regarding the size their child restraint fits in and the size their vehicle accommodates so they can choose products with greater likelihood of installation compatibility.

The same approach was adopted with consideration for the US market. Child restraints meeting requirements of the February 2014 FMVSS 213 requirements were selected and measured to provide a range of child restraint sizes, types, and manufacturers. Their positions in ten late model US vehicles were recorded. These data were used to design fit envelopes representing the space occupied by small, medium, and large rear-facing and forward-facing child restraints that can be used as tools for promoting compatibility between vehicles and child restraints.

When envelopes were designed, the installed position of the CRS was considered. As described in more detail in a companion paper to this report (Klinich et al. 2015), the orientation of different CRS can vary substantially across vehicles. The design of the RF envelopes only included products that could be installed at an acceptable angle. The design of the FF envelopes did not include products that had an excessive gap between the seatback and CRS.

Once the installed position of the CRS was considered, the US CRS did not fit within the ISO envelopes that were evaluated relative to the US market in a previous study (Hu et al. 2015). It is not sufficient to align the base of the child restraint with the base of the envelopes, because the CRS might need to be shifted to be in a position that is at an angle acceptable for use.

Instead, new envelopes were designed that included efforts to harmonize dimensions between the US and ISO envelopes. The RS, RM, and FS envelopes share most of the side profile dimensions with the ISO R1, R3, and F3 envelopes. However, the RS and FS envelopes are about 1.5 cm wider, while the RM envelope is about 4 cm wider. All of the ISO envelopes have the same lateral width, while the RS and RS US envelopes have narrower widths than the larger sizes. Many of the FF CRS still were too wide relative to the final design of the FL envelope.

One of the limitations of this analysis is that it did not assess the entire range of available child restraints and vehicles. However, the child restraints were selected to provide a range of manufacturers and dimensions. Vehicles selected are commonly used by families, and provided a range of seat characteristics.

CONCLUSIONS

This project adopted the ISO approach of using fit envelopes to promote compatibility between US child restraint systems and vehicles. Six envelope geometries were developed: RS, RM, RL, FS, FM, and FL. Products can be evaluated using virtual or physical representations of the envelopes.

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