FINAL REPORT
TO:

Department of Transportation
National Highway Traffic Safety Administration
Office of Acquisition Management (NPO-320)
West Building 51-117
1200 New Jersey Avenue, SE
Washington, DC 20590

for

Contract Number: DTNH2216D00037
Task Order: 693JJ918F000168

Cost and Weight Analysis of Motorcoach Glazing

from:

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August 21, 2019

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Table of Contents

1.0 ABSTRACT

Ricardo has found that changes to motorcoach side window glazing to prevent occupant ejection in a rollover crash have a broad range of costs depending on what type of glazing the manufacturer is presently using. Changes required to meet FMVSS No. 217a were determined for the three motorcoach manufacturers by NHTSA as reported in “Motorcoach Side Glazing Retention Research,” published in November 2013. As a result of this research, NHTSA has found that motorcoach side windows must use laminated glazing for the inner pane in order to withstand impact after having the glass pre-broken before testing. It is also important to note that the changes made to the window latches by NHTSA were not intended to be ready for production by the bus manufacturers but rather were attempts to keep the windows from unlatching when impacted as specified by FMVSS No. 217a. The three manufacturers with the highest sales volumes in the US are MCI, Prevost and Van Hool.

MCI had the lowest cost for modification since it already uses laminated glazing in its side windows. MCI buses had changes to the side window latches that amounted to an incremental manufacturing cost of $5.04 and an end user price increase of $6.47. The latching changes were the addition of steel washers to the top of the striker posts and a thicker, heavier latch plate. These changes prevented the detent lever from sliding over the striker post upon impact to keep the window closed. The modified latching hardware weighed 0.76 kg more than the production hardware for a bus with 8 emergency exit windows.

Prevost buses use tempered glass panes for their double-paned windows and therefore would need to change to laminated glazing of the inner pane to meet the requirements of FMVSS No. 217a. The incremental cost for laminated glazing in 8 emergency exit windows was determined to be $124.08. The modified latch posts and locator tabs were made of steel which made the latching heavier but less costly than the production parts which were aluminum and plastic, respectively. However, a satisfactory solution for the latch bar failures was not found. Overall, the changes made to the Prevost bus windows as recorded by NHTSA incurred an incremental manufacturing cost of $118.77 but weighed 0.13 kg less than the 8 production windows due to a lighter laminated inner pane. The end user price increase for Prevost buses was $154.42.

Van Hool buses also use tempered glass panes in their double-paned windows and would also require a change to advanced laminated glazing. Like the Prevost buses, the laminated glazing cost was $124.18 for 8 side windows. The changes to the latching hardware in the NHTSA research report were more extensive than for Prevost window latching and involved making a thicker, stronger spring clip; a longer, thicker and stronger slider; and adding aluminum angle bars over the sliders to the window frame. The incremental latching costs totaled $44.11 for the Van Hool windows. Overall, the changes to the Van Hool bus side windows would incur an incremental cost penalty of $168.19 and weigh 5.28 kg more. The end user price increase for Van Hool coaches was $217.15.

2.0 SUMMARY OF FINDINGS

The 2013 NHTSA report[1] on motorcoach side glazing retention research noted changes that may need to be made to the inner pane of glass and to the latching to be considered advanced laminated glazing meeting the requirements of FMVSS No. 217a. The incremental manufacturing costs and weights for the three top-selling motorcoach bus makers in the U.S.A. are summarized in Table 1.

Table 1 Incremental manufacturing cost and weight changes for MCI, Prevost and Van Hool motorcoach glazing

Manufacturer	Incremental Glazing Cost	Incremental Latching Cost	Incremental Total Cost	Incremental Total Weight [kg]
MCI	$ -	$ 5.04	$ 5.04	0.8
Prevost	$ 124.08	$ (5.31)	$ 118.77	-0.1
Van Hool	$ 124.08	$ 44.11	$ 168.19	5.3

Overhead burdens, characterized by fixed percentage markups for indirect manufacturing, SG&A, profit, transportation & warranty as well as dealer costs and markup as described in the *Cost and Weight Analysis Approach* section of 3.0 Engineering Analysis, are applied to the total manufacturing costs to determine the end-user price increases as summarized in Table 2.

Table 2 End user price increases as calculated from the total manufacturing costs

		MCI		***Prevost***		***Van Hool***	
		Cost	**Markup**	**Cost**	**Markup**	**Cost**	**Markup**
Variable manufacturing cost		$ 3.79	1.00	$ 116.34	1.00	$ 141.91	1.00
Fixed manufacturing cost		$ 1.24	0.33	$ 2.44	0.02	$ 26.20	0.18
Total manufacturing cost		**$ 5.04**	**1.33**	**$ 118.77**	**1.02**	**$ 168.19**	**1.19**
SG&A (% of variable)	*6%*	$ 0.23	0.06	$ 6.98	0.06	$ 8.51	0.06
Profit (% of total)	*3.75%*	$ 0.19	0.05	$ 4.45	0.04	$ 6.31	0.04
Transportation & warranty (% of total)	*7.5%*	$ 0.38	0.10	$ 8.91	0.08	$ 12.61	0.09
Wholesale price increase		**$ 5.83**	**1.54**	**$ 139.12**	**1.20**	**$ 195.63**	**1.38**
Dealer costs & markup (% of wholesale)	*11%*	$ 0.64	0.17	$ 15.30	0.13	$ 21.52	0.15
End user price increase		**$ 6.47**	**1.71**	**$ 154.42**	**1.33**	**$ 217.15**	**1.53**

Motor Coach Industries (MCI®) already uses laminated glazing for the inner pane of its motorcoaches and therefore does not need to change the glass. The incremental cost for the

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[1] Duffy, S., & Prasad, A. (2013, November). ***Motorcoach side glazing retention research***. (Report no. DOT HS 811 862). Washington, DC: National Highway Traffic Safety Administration.

latching changes that were made, as reported in the NHTSA research report, amount to $5.04 for a motorcoach bus with 8 emergency exit windows. The changes that were made to the MCI windows were to the latch plate and striker post and weighed a total of 0.76 kg for 8 emergency exit windows.

Prevost and Van Hool, on the other hand, use tempered glass for the inner panes of their bus side windows and therefore must change to laminated glass. The incremental cost to switch from tempered to laminated glazing for the inner pane was determined to be $15.51 per pane or $124.08 per bus with 8 emergency exit windows. Because laminated glazing has an interlayer of polyvinyl butyral (PVB) which is less dense than glass, a single inner pane of laminated glazing was found to be 1.35kg less than a tempered pane, or 10.8 kg less for a bus with 8 emergency exit windows.

The total incremental cost for Prevost latching changes were found to be less than the production latch parts that failed NHTSA testing due to the lower processing costs for working with mild steel rather than cast aluminum materials. The use of thicker and more dense steel in place of aluminum meant the weight increased by 1.34 kg per window. The changes that were made by NHTSA to the latching amounted to an incremental cost savings of $5.31 but added 10.7 kg on a bus with 8 emergency exit windows. As noted in the NHTSA research report, however, a satisfactory solution for the latch bar failures was not found.

Prevost bus windows require an inner pane of laminated glazing and changes to the latch posts and locator tabs. When added together, the changes to laminated glazing and thicker steel incrementally cost $118.77 and weighed 0.13 kg less for a bus with 8 emergency exits.

Larger and heavier latching hardware was used in the Van Hool bus windows in attempting to keep the window closed under impact. These changes cost $5.51 and weighed 2.0 kg more per window. The total latching changes for a bus with 8 emergency exits amounted to $44.11 and weighed 16.1 kg. When combined with the advanced laminated glazing changes, a Van Hool motorcoach bus incrementally costs $168.19 and weighs 5.28 kg more than the baseline window components.

3.0 ENGINEERING ANALYSIS

Background

Background was provided by NHTSA in the contract for this study of advanced laminated glazing for motorcoach bus. [2]

> *In 2003, the National Highway Traffic Safety Administration (NHTSA) and Transport Canada entered into a joint research program that was conducted by Martec Limited (subsequently referred to as the Martec study), which focused on preventing unrestrained occupant ejections during motorcoach rollovers by improving standard window glazing and retention. Results from this research established the occupant forces exerted on the motorcoach window during rollover events, which aided in the development of a dynamic*

[2] Contract No. DTHN2216D00037/693JJ918F000168, for the project entitled, "**Cost and Weight Analysis of Advanced Laminated Glazing for Motorcoach Bus**," pp5&6

test device to evaluate the effectiveness of glazing materials and bonding techniques in preventing ejections.

Using a numerical analysis of a motorcoach rollover, the Martec study determined that the impact velocity of an occupant striking the glazing was as much as 21.6 km/h. A 50th percentile adult male U.S. side impact crash test dummy (SID) was used to determine peak loading and duration under this worst-case scenario. The US-SID was seated on the far side and fell with its head making first contact on the glazing, followed closely by its shoulder/torso. The largest load on the glazing came from the torso impact and was subsequently used as the target load/load profile in the dynamic impact test device development.

A NHTSA report on research efforts involving the topic, titled "Motorcoach Side Glazing Retention Research" (November 2013), discussed the above results and expands on them.[3] *A presentation on the report from a public meeting (Society of Automotive Engineers) is also available.*[4]

NHTSA has proposed to establish a new Federal Motor Vehicle Safety Standard (FMVSS) to require the installation of advanced glazing in motorcoach buses in a Notice of Proposed Rulemaking.[5] *The new standard would require impactor testing of glazing material. The proposed standard, FMVSS No. 217a, Anti-Ejection Glazing for Bus Portals, would require a 26-kilogram (57 pound) impactor to be propelled from inside a test vehicle toward the window glazing at 21.6 kilometers per hour (13.4 miles per hour). The proposed FMVSS No. 217a would apply to over-the-road buses of any weight, and buses, other than over-the-road buses, that have a gross vehicle weight-rating (GVWR) of greater than 11,793 kilograms (26,000 pounds). This standard [would] not apply to school buses, transit buses, prison buses, and perimeter-seating buses.*

Purpose

The purpose of this study is to "determine the incremental consumer cost and weight of advanced laminated glazing for bus (motorcoach) windows … as compared to non-advanced glazing types."[6] In the Notice of Proposed Rulemaking (NPRM), NHTSA considers "glass meeting the

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[3] Duffy, S., & Prasad, A. (2013, November). ***Motorcoach side glazing retention research***. (Report no. DOT HS 811 862). Washington, DC: National Highway Traffic Safety Administration.

[4] Prasad, Aloke, NHTSA, Duffy, Stephen, TRC, Inc., "Evaluating Window Retention of Motorcoach Side Windows," SAE Government Industry Meeting, January 2014.

[5] National Highway Traffic Safety Administration (NHTSA), Department of Transportation (DOT), **Notice of Proposed Rulemaking** for "**Bus Emergency Exits and Window Retention and Release, Anti-Ejection Glazing for Bus Portals**," 49 CFR Part 571, Docket No. NHTSA-2016-0052

[6] Contract No. DTHN2216D00037/693JJ918F000168, for the project entitled, "**Cost and Weight Analysis of Advanced Laminated Glazing for Motorcoach Bus**," p6

requirements [of FMVSS No. 217a] to be "advanced glazing."[7] It also states that "advanced glazing" means "glazing installed in a portal on the side or roof of a motorcoach that is designed to be highly resistant to partial or complete occupant ejection in all types of motor vehicle crashes."[8]

Brief Summary of FMVSS No. 217a Requirements

This section is not intended in any way to state the legal requirements for motorcoach bus side window glazing as proposed by FMVSS No. 217a but does attempt to succinctly summarize those requirements. The first broadly-stated objective of 217a is to prevent unrestrained occupants from being ejected from a motorcoach bus during a rollover event. This objective drives the use of laminated glazing for side windows as opposed to tempered glazing and secondly it requires window latches to remain closed when the window is impacted. A second broadly-stated objective of 217a is to allow occupant egress after a rollover event or other "motor vehicle crash" through designated "emergency exit" windows; this objective requires that window latches remain operable *after* the window has been impacted.

To ensure these two objectives are met, the Martec study developed a dynamic test procedure as shown below in Figure 1.

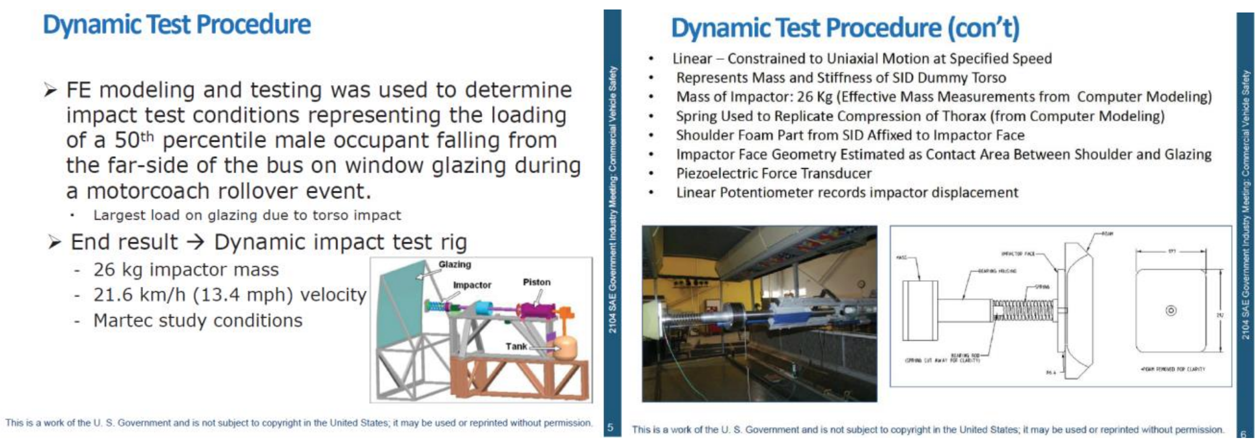

Figure 1 Slides from Prasad[9] showing the impact test rig and the dynamic test procedure that were developed in the Martec study

FMVSS No. 217a would apply to new over-the-road buses (OTRB) of any weight, and buses other than over-the-road buses with gross vehicle weight rating (GVWR) greater than 26,000 pounds. An ORTB is characterized by an elevated passenger deck located over a baggage compartment.[10]

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[7] National Highway Traffic Safety Administration (NHTSA), Department of Transportation (DOT), **Notice of Proposed Rulemaking** for "**Bus Emergency Exits and Window Retention and Release, Anti-Ejection Glazing for Bus Portals**," 49 CFR Part 571, Docket No. NHTSA-2016-0052, p7

[8] Ibid., p6.

[9] Prasad, Aloke, NHTSA, Duffy, Stephen, TRC, Inc., "Evaluating Window Retention of Motorcoach Side Windows," SAE Government Industry Meeting, January 2014.

[10] 6 USC sec. 1151

Motorcoach Bus Sales in the US

Market shares of new motorcoach bus sales in the US and Canada were given for 2008 in NHTSA's motorcoach side glazing retention research report, Figure 2, indicate that bus sales are well-represented by MCI, Prevost and Van Hool buses.

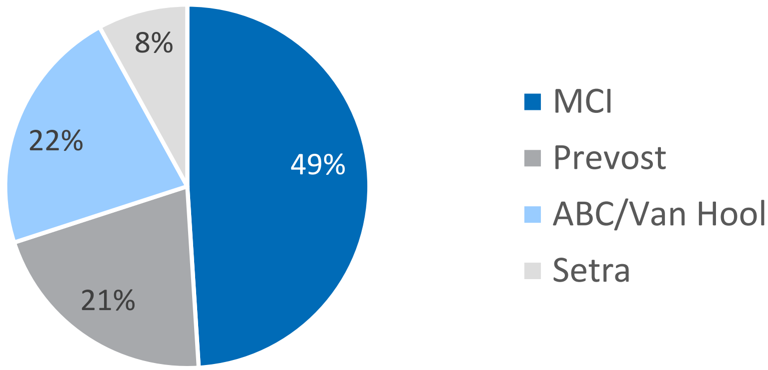

Figure 2 New motorcoach sales percentages from 2008[11]

Specifications for Motor Coach Industries (MCI®) D-series and E/J-series motorcoaches that are being made today (earlier model year versions were studied in the Martec study) are given in Table 3 and examples shown in Figure 3. The Prevost H3-45 (also studied in the Martec study) is still being made today and specifications are listed in Table 4 with a picture in Figure 4. The Martec study tested the Van Hool C2045 which is no longer being produced; however updated versions are being produced as the CX series and the taller TX series. Specifications for the current models are given in Table 5 and pictures in Figure 5.

Table 3 MCI motorcoach current model specifications

Model	Overall Length	Overall Width	Overall Height	Seating capacity
D4505	45 ft	8'-6"	11'-5"	55
J4500	45 ft		11'-9"	56 - 60
J3500	35 ft		11'-9"	up to 44

[11] Duffy, S., & Prasad, A. (2013, November). ***Motorcoach side glazing retention research***. (Report no. DOT HS 811 862). Washington, DC: National Highway Traffic Safety Administration, p.32.

Figure 3 MCI J-series and D-series motorcoaches are being produced today

Table 4 Prevost H3-45 motorcoach specifications

Model	Overall Length	Overall Width	Overall Height	Seating capacity
H3-45	45 ft	8'-6"	12'-2"	56

Figure 4 Prevost H3-45 motorcoach

Table 5 Van Hool motorcoach specifications

<table>
<tr><th>Model</th><th>Overall Length</th><th>Overall Width</th><th>Overall Height</th><th>Seating capacity</th></tr>
<tr><td>CX35</td><td>35 ft</td><td rowspan="4">8'-6"</td><td>11'-6"</td><td>38</td></tr>
<tr><td>CX45</td><td>45 ft</td><td>11'-6"</td><td>56</td></tr>
<tr><td>TX40</td><td>40 ft</td><td>12'-2"</td><td>48</td></tr>
<tr><td>TX45</td><td>45 ft</td><td>12'-2"</td><td>56</td></tr>
</table>

Figure 5 Van Hool motorcoaches being produced today

The market share percentages shown above in Figure 2 were applied to sales data available from the American Bus Association (ABA) Foundation shown in Figure 6 below. Since mid-2018 the ABA has gotten responses to from 3 out of 5 historically-reporting coach builders; these are assumed to be MCI, Prevost and Van Hool given the market shares noted above. The historical data has been edited to account for the three responding companies which made up 89% of previously reported numbers in 2016 (total reported sales for 2016 was 2,407.)

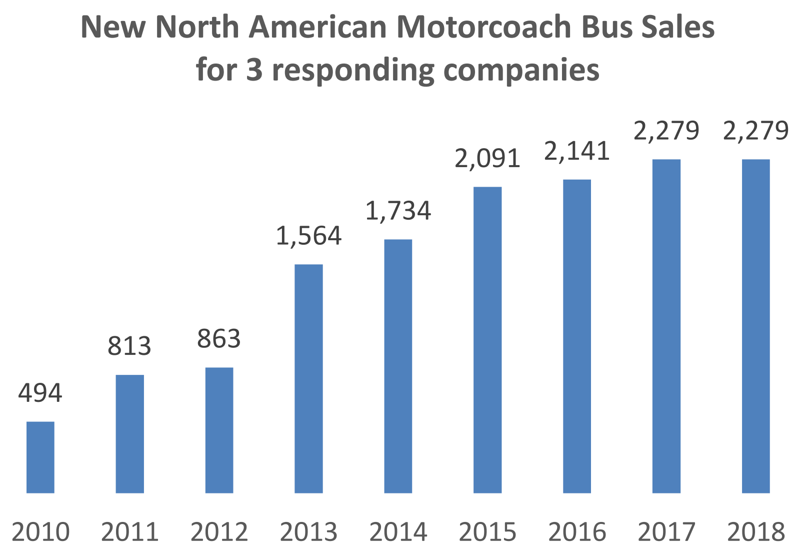

Figure 6 New motorcoach sales from the ABA coach manufacturer survey, Q4 2018

By combining the market shares from the 2008 sales data as illustrated in Figure 2 with the latest motorcoach sales it was estimated that MCI sold around 1200 buses and Prevost and Van Hool between 500 – 600 each in NA in 2018. These annual motorcoach sales volumes were assumed to apply to the manufacturing volumes for side windows with 8 emergency exit windows per coach. As the glazing suppliers for motorcoaches are capable of supplying glass panes for a wide variety of applications, as shown below in Figure 7, at relatively low volumes compared to the passenger car industry, changes to the manufacturing volume assumptions will not significantly impact the cost results presented in this report. Some of the suppliers known to be producing glazing for the motorcoach industry are Custom Glass Solutions, LLC. in the USA, Prelco Inc. in Canada, and VidurGlass, S.L. in Spain.

Figure 7 Window glazing is produced for a range of applications including motorcoach buses

Results of the Martec Study Impact Testing (Selection of Sample Hardware)

The proposed requirements for motorcoach side window glazing have been broadly summarized above as preventing occupant ejection during a rollover event and allowing emergency egress after a rollover or vehicle crash. FMVSS No. 217a proposes 3 specific tests that were developed in the Martec study to ensure these requirements are met. All 3 tests involve the dynamic test procedure noted above in Figure 1 utilizing a specifically-designed impactor striking the test window at a velocity of 21.6 km/h (13.4 mph). The differences between the 3 impact tests relate to the location at which the window is struck and the condition of the glazing prior to impact. Noting that order of testing is not important, the first test strikes at the center of daylight opening on an intact (unbroken) window and the second test also uses an intact window but strikes near the edge of the window (or near-latch.) The third test impacts a window at the center of daylight opening in which the glazing has been pre-broken (by means of staple gun striking the window in a specified pattern across the window opening.) In the Martec study, the third series of tests were performed only on laminated glazing samples from MCI E/J-series coaches to test the strength of glazing after it has been pre-broken (for example due to a rollover event) and prior to being impacted by an occupant.[12]

The third test specifically drives the requirement for laminated glazing as tempered glazing will shatter upon initial impact and thus not be able to retain an occupant after the rollover. This was found to be the case in the Martec study for the tempered outer pane of the MCI double-paned window; only the inner laminated pane remained to be pre-broken and then impacted by the SID impactor. Even after pre-breaking and impacting the laminated glazing at Martec study

[12] Ibid. p.73.

conditions, no tearing of the PVB interlayer was observed post impact,[13] indicating that laminated glazing is strong enough to retain occupants after a rollover event which may break tempered glazing. Therefore, the NPRM states: "We believe that laminated glass could meet the requirements proposed in this NPRM. We consider glass meeting the requirements to be "advanced glazing.""[14]

Whereas the third test was designed to test the strength of laminated glazing, the first two tests with intact window glazing were designed to test the integrity of the window framing and latching systems. The first of the tests strikes the window at the "center of daylight opening" and therefore distributes the load more-or-less equally to both latches. After impacting the window, the amount of force necessary to unlatch the window and the force to push the window open were also measured. This test, therefore, primarily ensures the latching system remains operable to allow emergency egress after a rollover event as the existing standard FMVSS No. 217 (not the *proposed* standard FMVSS No. 217a) specifies.

Production Latching Mechanisms

The second of the tests, however, strikes an intact window within an inch of the edge of the window and centered directly over one of the two window latches. This test was developed primarily to ensure the integrity of the window frame and latching mechanism to withstand the impact loading and prevent occupant ejection. For this NHTSA designed test frames that represented the side passenger window frame for each of the three manufacturers as described in the Motorcoach Bus Sales in the US section of this report. Specifically, windows from the MCI E/J-series coach, the Prevost model H3-45, and the Van Hool model C2045 were tested with near-latch impact tests. The test frame and the latching mechanisms for these three bus models are shown in Figure 8, Figure 9 and Figure 10, respectively.

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[13] Ibid. pp 72, 76, 77.

[14] National Highway Traffic Safety Administration (NHTSA), Department of Transportation (DOT), **Notice of Proposed Rulemaking** for "**Bus Emergency Exits and Window Retention and Release, Anti-Ejection Glazing for Bus Portals**," 49 CFR Part 571, Docket No. NHTSA-2016-0052, p7

Figure 8 MCI E/J-series test frame and latching mechanism (latch bar not shown) (Fig. 5.1 and Fig. 5.3 of reference 1)

Figure 9 Prevost H3-45 test frame and latching mechanism (Fig. 5.5 and Fig. 5.6 of reference 1)

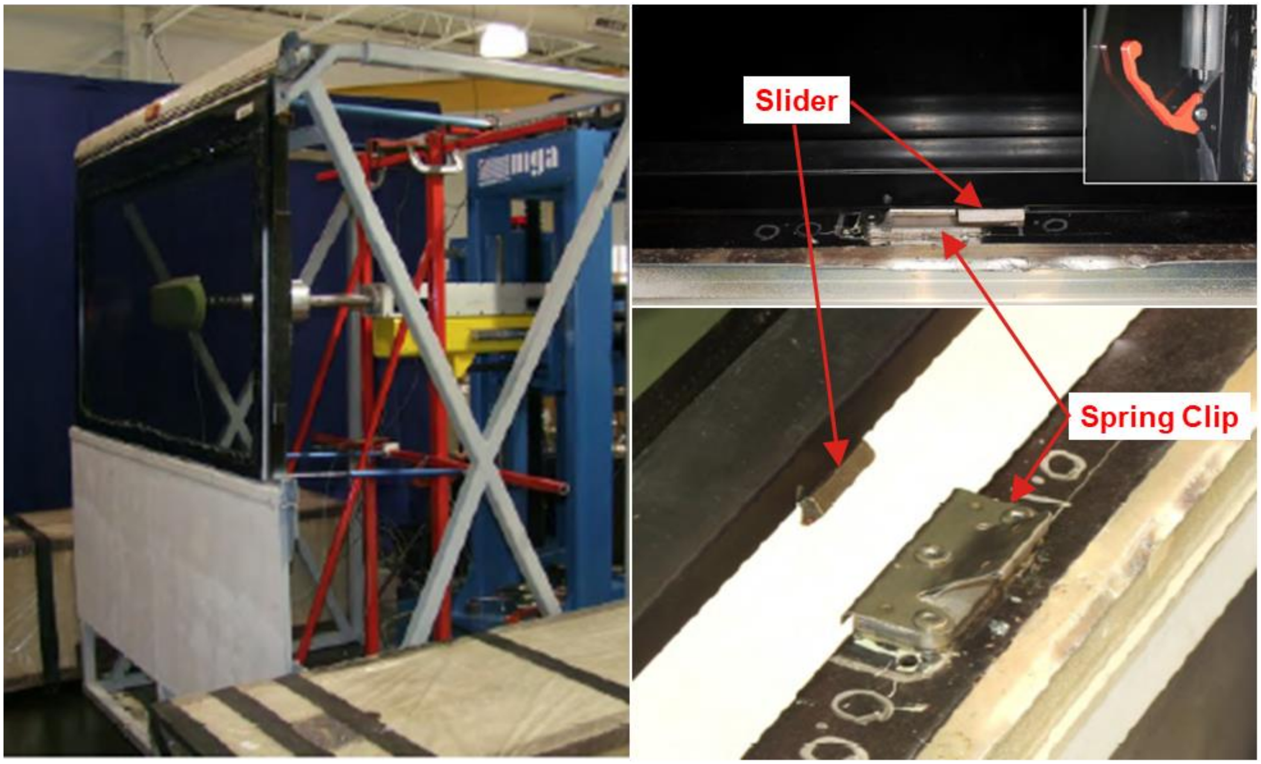

Figure 10 Van Hool C2045 test frame and latching mechanism. (Fig. 5.7, Fig. 5.8 and Fig. 5.9 of reference 1)

Production Latching Mechanism Failure Modes

Under testing at the near-latch impact location, the primary latches on all three bus models failed to keep the window latched (closed) for impact velocities lower than 21.6 km/h with a 22.7 kg impactor. High-speed videography was used to record the dynamics of the unlatching events. For the MCI coach, Figure 11 shows the latch plate bending over under impact and allowing the detent lever to slide over the striker post. The Prevost bus experienced two latching failure modes, latch post shear at the primary latch post, as shown on the left in Figure 12, and tearing of the latch bar as shown on the R in Figure 12. The Van Hool bus used an emergency handle to move two sliders out of the way of the spring clips so the window could be opened, as shown in Figure 10. The spring clips are designed and made from flexible stainless steel so that the window can return to the latched position with the slider bending the spring clip downward as the window closes. It was the spring clip at the primary latch location on the Van Hool motorcoach that bent to allow the window to become unlatched on impact, as Figure 13 shows.

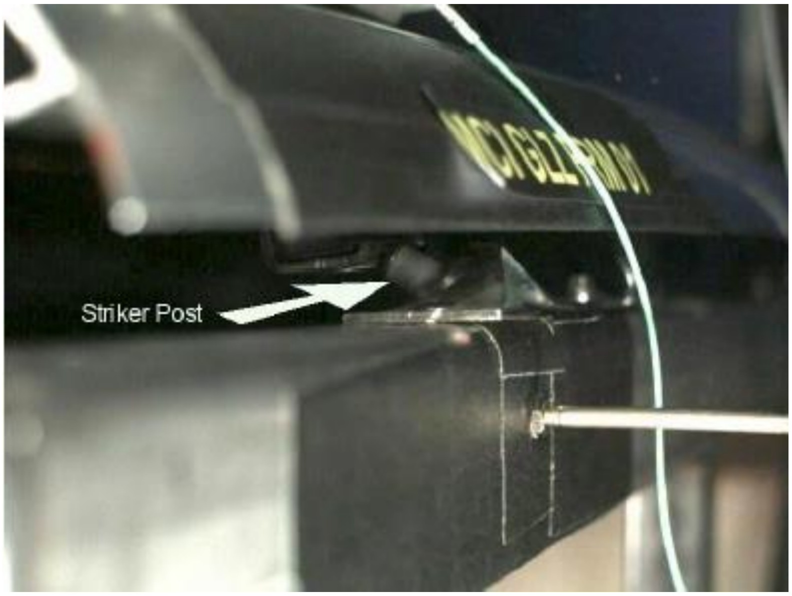

Figure 11 MCI E/J-series unlatching event at primary latch (Fig. 5.14 of reference 1)

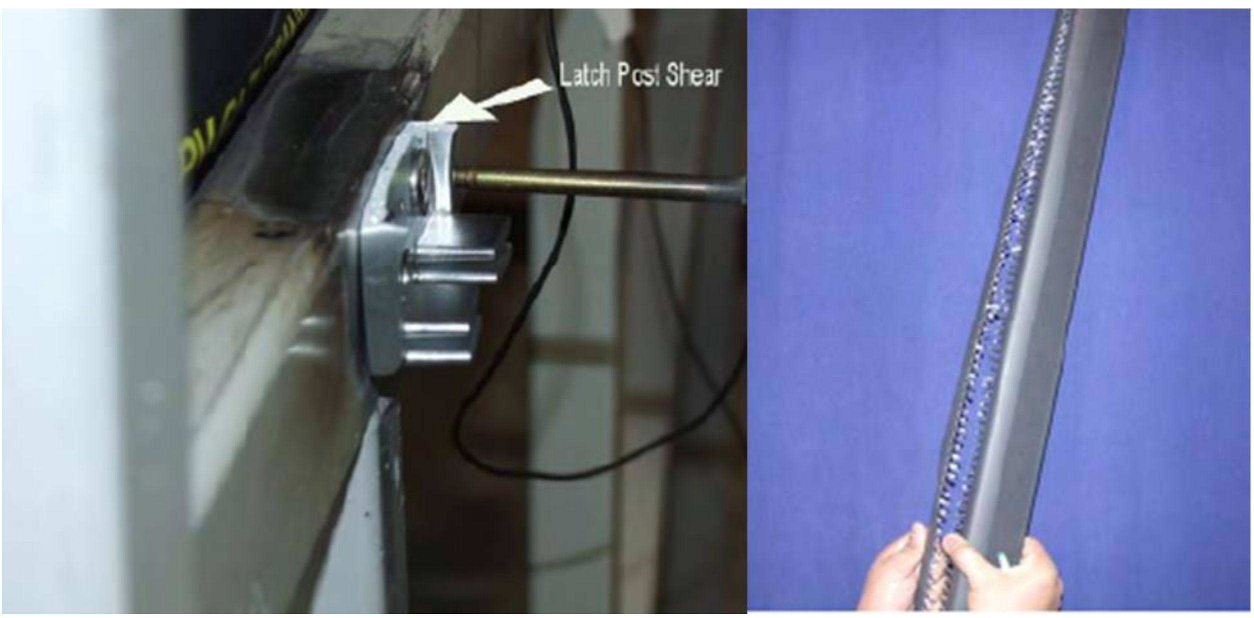

Figure 12 Prevost H3-45 primary latch post shear failure (L) and latch bar failure (R) (Fig. 5.16 and Fig. 5.17 of reference 1)

Figure 13 Van Hool primary latch spring clip bending failure (Fig. 5.18 of reference 1)

Modified Latching Mechanisms

In attempts to alleviate the failure of the latching mechanism to keep the window latched, NHTSA evaluated modified parts for each of the three motorcoach bus models. It should be noted that these modifications were not done in consultation with the bus manufacturers and were not intended to be production-feasible solutions, rather they were simply attempts to see if each latch could be modified and the window remain latched during impact testing under Martec study conditions.

MCI Modifications

Figure 14 shows the first modification attempt, modification "A," of the MCI latch plate/striker post assembly with a bent production latch plate in the background. This modification still prevented the detent lever from sliding over the striker post so a second attempt was made, modification "A1," by adding washers to the top of the modified striker post as shown in Figure 15. In addition, NHTSA tested an original (production) latch plate with washers added as they were to the modified latch plate/striker post. Both modification A and the production latch plates with washers added to the top of the striker post were able to prevent the window from opening under 21.6 km/h impact testing including with an impactor mass of 26 kg.

Figure 14 MCI E/J-series latch plate modification "A" shown in foreground (Fig. 5.19 of reference 1)

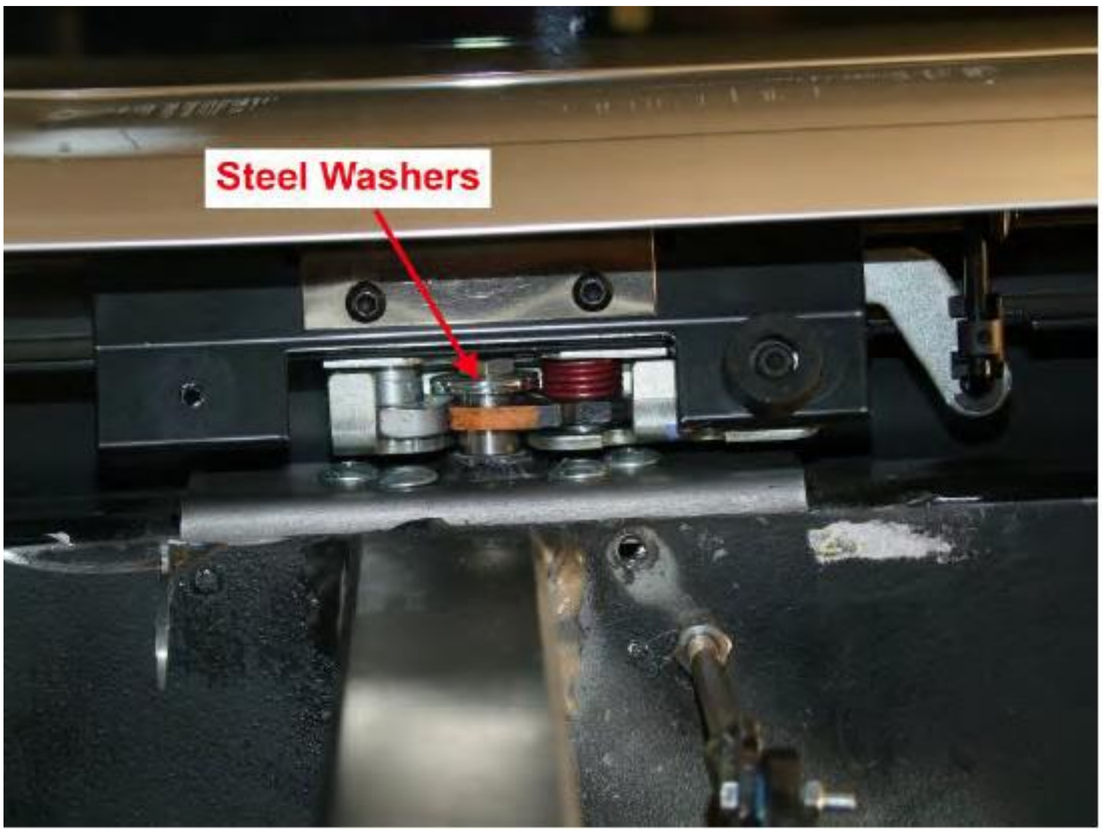

Figure 15 MCI modification A1 with window latched. (The tip of the detent lever is painted orange.) (Fig. 5.21 of reference 1)

Prevost Modifications

The countermeasures that were developed for the Prevost H3-45 bus latching system are shown to the right of their production counterparts in the right-hand photograph of Figure 16; the image on the left shows the modified latching system installed on the Prevost test frame. The production locator tab was made from plastic and sheared under impact, although this failure mode was not pictured in the report. The production striker post, an aluminum die-casting, also failed in shear.

The modified striker post and locator tabs were both modified by fabricating parts out of thicker steel and with additional material added to further increase the shear resistance. As noted in the report, “VRTC did not have the in-house capability to fabricate a suitable latch bar countermeasure” to keep the window latched in the near-latch impact tests. However, in center of daylight opening test, which evenly distributed the load to the two striker posts, the production composite latch bar was able to hold the window closed.

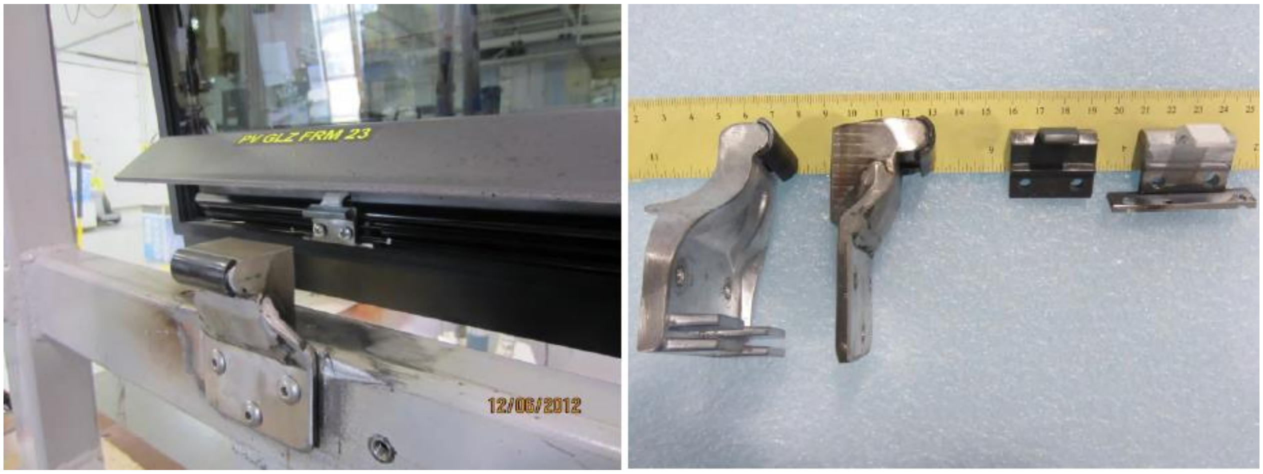

Figure 16 Prevost striker post and locator tab countermeasures (Fig. 8.4 of reference 1)

Van Hool Modifications

A thicker spring clip was fabricated for the Van Hool bus as a countermeasure to the production spring clip bending backwards as shown on the left of Figure 17.

Figure 17 Van Hool modified spring clip (L) versus production spring clip (R) (Fig. 8.1 of reference 1)

However, when tested with near-latch impact, the sliders partially pulled out of the track and rotated allowing them to slide over the spring clips and the window to open. Therefore, an aluminum angle bar was fastened to the window track containing the sliders to stiffen the window frame as shown on the right of Figure 18. When the window was tested this time, again with near-latch impact, the sliders came out of the window track and allowed the window to open again. The next step was to modify the slider mechanism by replacing the brass production slider with a fabricated steel version that was screwed to a steel reinforcing bar as shown on the left of Figure 18. Under near-latch impact testing, however the two screws holding the steel slider to the reinforcing bar both sheared and allowed the window to partially open; the secondary latch prevented the window from opening further. Finally, a new set of spring clips were fabricated and installed along with the modified slider and reinforcing bar. This was tested with impact at the center of daylight opening and both latches held this time, but the tempered glass panes both shattered.

This series of tests with countermeasure latches on the Van Hool window shows that both the latches and the glazing must be strong enough to survive impact testing at near-edge and center-of-daylight-opening positions.

Figure 18 Van Hool latch countermeasure system (Fig. 8.2 of reference 1)

Manufacture of Laminated and Tempered Glazing

The laminated glass manufacturing process is illustrated below in Figure 19. Starting at the top left, raw glass (also called flat glass or “float” glass because it has been floated out of the furnace onto a pool of molten metal) is first marked or scored and the excess material is broken off along the scored lines. Following the cutting to final shape the edges are ground, the glass piece is washed, and then printed (to put black edging around the perimeter where it will be sealed into the window frame, for example.) After printing, two glass pieces enter the furnace as a pair to be heated and bent to shape. Then the pair of bent glass pieces are cooled down at a carefully controlled rate to below the annealing point (470-540ºC) to relieve internal stresses. This is called annealed glass at this point and is used for making a laminated glass pane.

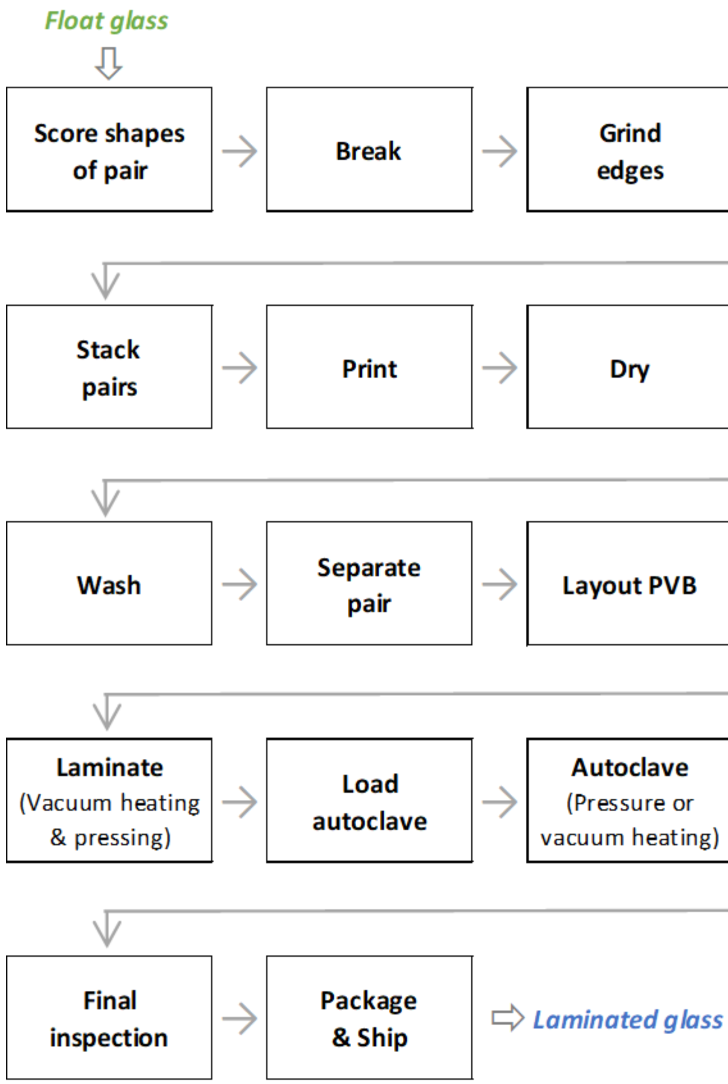

Figure 19 Laminated glass manufacturing process

The next stage of laminated glass making is the assembly phase where, after washing the pair of shaped tempered glass pieces, a layer of plastic film (usually polyvinyl butyral, or PVB) is inserted between the layers of glass. This assembly of glass-PVB-glass is then heated with a vacuum applied and pressed together to squeeze out air. This process softens the PVB interlayer and securely bonds it to the glass outer layers. To improve optical clarity, however, the fully-assembled glass lite is put into an autoclave. The autoclave is a pressure vessel where the laminated pane is heated (usually under pressure, can also be under vacuum) for a period of time (approximately an hour or two depending on size of the glass and pressure and temperature in the autoclave) to ensure that the laminated glass has good optical clarity, or appears as a single layer of glass.

Finally, the PVB is trimmed around the edge and the laminated glazing is inspected for shape and for optical characteristics and then packaged and shipped.

Tempered glass is much simpler as show in Figure 20. The processes of cutting, grinding the edges, printing and bending to shape are the same as for laminated but are done for a single piece of glass instead of a pair. As the glass exits the high temperature furnace, it is cooled down at a faster rate to induce stresses in the glass that make it stronger. Thus, tempered glass is also referred to as heat treated or heat strengthened glass. There is no assembly that needs to be done to a monolithic pane of tempered glass, unlike the laminated glass processing, and after tempering the glass pane is inspected and packaged for shipment.

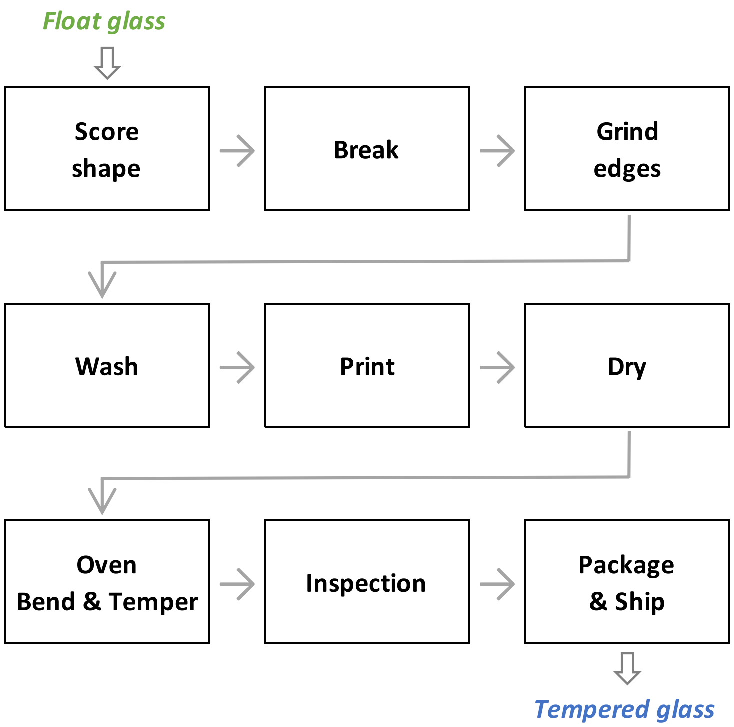

Figure 20 Tempered glass manufacturing process

Assembly and sealing of the glass pane into the window frame (along with an outer pane for double-paned glazing) was not considered as the same processes and sealing materials are used for either laminated or tempered glazing.

Motorcoach Window Inner Pane Sizes

Side window assemblies were purchased for MCI, Prevost and Van Hool motorcoaches and the inner pane sizes were measured. While the three manufacturers use different heights and widths, the projected areas of the inner pane on the three windows is nearly the same (±3% from MCI) as Table 6 illustrates. Because Prevost and Van Hool use tempered inner panes that are nearly the same as MCI's inner pane thickness, also shown in Table 6, it was assumed that a transition to advanced glazing would involve the use of laminated glazing with the same thicknesses for the glass and the PVB layers as the MCI windows. This was important in allowing a single cost and weight model to be used for the laminated glazing on the three motorcoach windows studied.

Table 6 Inner pane sizes for the MCI, Prevost and Van Hool motorcoach windows

	MCI E/J3500		Prevost H3-45		Van Hool C2045	
	Value	Variance from MCI	Value	Variance from MCI	Value	Variance from MCI
Width [mm]	1600	-	1560	-2.5%	1660	3.8%
Height [mm]	940	-	990	5.3%	890	-5.3%
Thickness [mm]	4.75	-	4.67	-1.7%	4.90	3.2%
Projected area [m^2]	1.50	**-**	1.54	**2.7%**	1.48	**-1.8%**

Cost and Weight Analysis Approach

Ricardo engaged automotive system and vehicle integration experts, cost modeling teams, and procurement professionals to support the cost and weight analysis of motorcoach glazing. In high volume automotive applications, OEMs usually launch several vehicle platforms with the technology required to be compliant with proposed rulemaking well in advance of the rule being finalized. As a result, the hardware required for compliance with the proposed rule is often available commercially well in advance of the proposed date for the rule to come into effect. In the case of FMVSS No. 217a, there is no motorcoach OEM or Tier 1 glazing supplier known to be currently making hardware (either commercially or in the prototype stage) that has been validated as compliant. Thus, there was no commercially available hardware with known compliance to FMVSS No. 217a.

In order to develop an appropriate surrogate and to understand the potential cost impact of FMVSS No. 217a, a two-pronged approach was proposed and approved by NHTSA:

1) A cost model was developed for laminated and tempered glazing to understand the cost impact of the glass type required for compliance
2) The existing latch hardware cost would be compared to the hardware that was modified for the Martec study, as this is the only hardware that has been tested in the Martec study. Some of the modified hardware was shown to be compliant with all Martec study tests (specifically, the MCI modifications) and other modified hardware had improved test results but still did not pass all the Martec study tests (specifically, the Prevost and Van Hool modifications.)

Side window assemblies were selected for current generation bus models as were tested in the Martec study. These current model bus windows have the same glazing types, framing and latching mechanisms as the ones tested by Martec. Further, only the specific latch parts which failed under impact testing by NHTSA and were subsequently modified, as noted above in the Engineering Analysis section, were selected for cost and weight analysis. It is important to note that NHTSA was not trying to make production-intent hardware and as such the costs and weights identified here may not be representative of the true costs to manufacture.

Following acquisition of the window assemblies, the latching parts were then disassembled and evaluated to determine materials used, weighed, and analyzed by Ricardo's subcontractor MeC S.r.l. For the glazing itself, Ricardo visited the manufacturing facilities of Custom Glass Solutions, LLC who make side windows for MCI coaches to confirm manufacturing processes as described above were being used. In addition, online research confirmed that suppliers for

Prevost and Van Hool windows also supply glazing for a range of vehicles and other uses similar to Custom Glass Solutions.

Costs were developed for each manufacturing step and captured those costs along with material costs in the component costs. Standard parts such as fasteners were accounted for as procured parts in the analysis. Detailed manufacturing process operation worksheets are provided in the appendix for each of the analyzed components that illustrate how variable manufacturing costs, fixed burden, and weights were accumulated. These were then reconciled, each part to its subassembly, and from subassembly to the total incremental system.

An Asset Center Costing (ACC) methodology was used to identify cost drivers in terms of:

- Direct labor minutes per cycle
- Direct material costs per cycle
- Machine occupancy or station times per cycle
- Machinery, equipment, and tooling utilized and allocated per cycle.

The total manufacturing cost was built up from the following elements:

- Direct labor cost per unit (based on US rates for appropriate trades by manufacturing process)
- Direct material costs including scrap allowance and inbound freight per unit
- Variable burden/overhead costs, including indirect labor, energy, and other costs that vary with production volume
    - Indirect plant staff
    - Material handlers
    - 1st line supervision
    - Tool & equipment maintenance
    - Facilities maintenance
    - Non-production plant supplies
    - Energy
    - Process fluids & gases
    - Fringe on Direct labor
- Fixed burden / overhead per unit, including capital depreciation and other fixed costs
    - Capital equipment requiring investment and amortized at the stated annual sales volumes including property, plant machinery, equipment and primary tooling
        - Capital depreciation schedules for property, plant, and equipment
        - Special tooling depreciation schedules
    - Floor space for manufacturing and offices
    - Taxes – local and property
    - Insurance – property and liability

The following assumptions were utilized in applying the ACC methodology to the systems and components analyzed:

- Annual vehicle production volumes as noted above for each of the three bus manufacturers

- Burdened labor rate: labor rates were determined for specific manufacturing processes and applied to the cost analysis. For example, the labor rate associated with glass making operations located in the Midwest was assumed to be $33.66/hour.
- Capital equipment depreciation schedule of 12 years straight line with no residual value consistent with IRS depreciation schedules
- Special tooling depreciation schedule of 5 years straight line with no residual value consistent with IRS depreciation schedules
- Scrap rate of 10% of direct material cost for motorcoach glazing (higher than other materials due to the frangibility of float glass)
- Scrap rate of 1% of direct material cost for latching components

In addition, overhead burdens for glazing and components suppliers and motorcoach manufacturers were assumed to be similar to automotive component suppliers and manufacturers and were applied to get a more complete estimate of the end-user costs. The following corporate overhead rates were used as being typical for in-house made components by an original equipment manufacturer (OEM) in the light-duty automotive industry after reviewing Spinney et al[15], Rogozhin et al[16], National Academy of Sciences (NAS)[17], and Vyas et al[18]:

- SG&A of 8% applied to total manufacturing costs, including
  - Sales
  - Research & Development
  - General administration
  - Human resources
  - Supplier quality
  - Senior plant management
- Profit of 5% applied to total manufacturing cost
- Transportation and warranty costs of 10% applied to total manufacturing cost.

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[15] Spinney, B.C., Faigin, B., Bowie, N., & St. Kratzke. 1999, Advanced Air Bag Systems Cost, Weight, and Lead Time analysis Summary Report, Contract NO. DTNH22-96-0-12003, Task Orders – 001, 003, and 005. Washington, D.C., U.S. Department of Transportation

[16] Rogozhin, A., Gallaher, M., & McManus, W. 2009, Automobile Industry Retail Price Equivalent and Indirect Cost Multipliers. Report by RTI International to Office of Transportation Air Quality. U.S. Environmental Protection Agency, RTI Project Number 0211577.002.004, February, Research Triangle Park, N.C.

[17] National Academy of Sciences, Committee on the Assessment of Technologies for Improving Light-Duty Vehicle Fuel Economy, "Assessment of Fuel Economy Technologies for Light-Duty Vehicles," The National Academies Press, Washington D.C., 2011

[18] Vyas, A., Santini, D., And Cuenca, R., "Comparison of Indirect Cost Multipliers for Vehicle Manufacturing," Technical Memorandum of the Center for Transportation Research, Argonne National Laboratory, April 2000

For outsourced components made by a Tier 1 supplier, however, the NAS found that outsourced components had a markup factor of only on average 75% of that for in-house components as their Table 3.5 shows[19].

TABLE 3.5 Comparison of Markup Factors

Markup Factor for	ANL	Borroni-Bird	EEA
In-house components	2.00	2.05	2.14
Outsourced components	1.50	1.56	1.56

SOURCE: Vyas et al. (2000).

Therefore, the following corporate overhead rates for outsourced components, at 75% of the OEM in-house component rates, were used:

- SG&A of 6% applied to total manufacturing costs
- Profit of 3.75% applied to total manufacturing cost
- Transportation and warranty costs of 7.5% applied to total manufacturing cost.

These overhead burdens applied to direct labor, variable and fixed manufacturing costs equate to a wholesale price from the manufacturer. Dealer costs and markup were estimated to be 11% of the wholesale price, consistent with Spinney et al, to arrive at a final cost to the end-user.

4.0 COST AND WEIGHT ANALYSIS

Components related specifically to the motorcoach side window latching were identified from the NHTSA report as described in the *Production Latching Mechanisms* and *Modified Latching Mechanisms* sections of this report; the *Manufacture of Tempered and Laminated Glazing* section describes the manufacturing processes for both tempered and laminated side window glazing. The identified latching and glazing components were analyzed for cost and weight as outlined in the *Cost and Weight Analysis Approach* section of 3.0 Engineering Analysis.

Cost and Weight Results

The following pages give a summary of the cost and weight results associated with the key latching and glazing hardware components for the three selected motorcoach bus side window systems. The full detail of the incremental cost and weight analysis results are given in the appendix.

MCI E/J-series Coaches

MCI production motorcoach side window assemblies use laminated glazing for the inner pane, therefore, only the latch plate/striker post assemblies need to be modified. One potential solution is to modify the latching as described above in the *Modified Latching Mechanisms* section of 3.0 Engineering Analysis for the MCI windows. The cost of the modified latching mechanism as described above has been determined as it is the only potential solution known to have been

[19] See p. 33 of National Academy of Sciences, Committee on the Assessment of Technologies for Improving Light-Duty Vehicle Fuel Economy, "Assessment of Fuel Economy Technologies for Light-Duty Vehicles," The National Academies Press, Washington D.C., 2011

tested to the Martec Study impact conditions. Table 7 provides a summary of the incremental cost and weight differences for the MCI motorcoach side windows assuming 8 emergency egress windows per bus. Table 7 also gives a tabular breakdown of manufacturing costs into direct labor, material, other variable, and fixed costs as described above in the *Cost and Weight Analysis Approach* section of 3.0 Engineering Analysis. Details of the MCI incremental manufacturing costs and weights for side window latching can be found in the appendix.

Table 7 Incremental cost and weight summary for MCI motorcoach windows

Description	Cost per coach	Quantity per coach	Cost per window	Labor	Material	Variable	Fixed	Weight per coach [kg]
MCI incremental	***$ 5.04***	***8***	***$ 0.63***	***$ 0.07***	***$ 0.32***	***$ 0.09***	***$ 0.16***	***0.8***
Incremental Glazing	**$ -**	***0***	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	***0.0***
Incremental MCI Latching	**$ 5.04**	***8***	**$ 0.63**	**$ 0.07**	**$ 0.32**	**$ 0.09**	**$ 0.16**	***0.8***
MCI baseline latch parts	$ 13.27	8	$ 1.66	$ 0.45	$ 0.35	$ 0.40	$ 0.45	1.8
MCI modified latch parts	$ 18.31	8	$ 2.29	$ 0.52	$ 0.67	$ 0.49	$ 0.61	2.6

Prevost H-Series Coaches

Prevost uses tempered glazing for its production motorcoach side window assemblies and therefore would require changing the inner pane to laminated glazing in order to meet the requirements of FMVSS No. 217a. In addition, the striker posts, locator tabs, and latch bars need to be modified, as described above in the *Production Latching Mechanism Failure Modes* and *Modified Latching Mechanisms* sections of 3.0 Engineering Analysis for the Prevost latches. Table 8 provides a summary of the incremental cost and weight differences for the Prevost motorcoach side windows assuming 8 emergency egress windows per bus. Table 8 also gives a tabular breakdown of manufacturing costs into direct labor, material, other variable, and fixed costs. Details of the Prevost incremental manufacturing costs and weights for side window latching can be found in the appendix. The appendix also includes detail on the manufacturing costs and weights of laminated and tempered glazing.

Table 8 Incremental cost and weight summary for Prevost motorcoach windows

Description	Cost per coach	Quantity per coach	Cost per window	Labor	Material	Variable	Fixed	Weight per coach [kg]
Prevost incremental	***$ 118.77***	***8***	***$ 14.85***	***$ 1.67***	***$ 9.11***	***$ 3.76***	***$ 0.30***	***-0.1***
Incremental Glazing	**$ 124.08**	**8**	**$ 15.51**	**$ 1.75**	**$ 8.75**	**$ 3.50**	**$ 1.52**	**-10.8**
Tempered Glazing	$ 266.04	8	$ 33.25	$ 1.57	$ 8.47	$ 21.12	$ 2.10	143.2
Laminated Glazing	$ 390.12	8	$ 48.77	$ 3.31	$ 17.22	$ 24.62	$ 3.61	132.3
Incremental Prevost Latching	**$ -5.31**	**8**	**$ -0.66**	**$ -0.08**	**$ 0.37**	**$ 0.26**	**$ -1.21**	**10.7**
Prevost baseline latch parts	$ 140.39	8	$ 17.55	$ 1.78	$ 8.94	$ 2.02	$ 4.82	25.3
Prevost modified latch parts	$ 135.08	8	$ 16.89	$ 1.70	$ 9.30	$ 2.28	$ 3.60	36.0

Van Hool CX-Series Coaches

Van Hool also uses tempered glazing for its production motorcoach side window assemblies and therefore would require changing the inner pane to laminated glazing in order to meet the requirements of FMVSS No. 217a. In addition, the sliders and spring clips would need to be modified along with changes to strengthen the window framing, such as described above in the *Production Latching Mechanism Failure Modes* and *Modified Latching Mechanisms* sections of 3.0 Engineering Analysis for the Van Hool latches. Table 9 provides a summary of the incremental cost and weight differences for the Van Hool motorcoach side windows assuming 8 emergency egress windows per bus as well as a tabular breakdown of manufacturing costs into direct labor, material, other variable, and fixed costs. Details of the Van Hool incremental manufacturing costs and weights for side window latching can be found in the appendix. The appendix also includes detail on the manufacturing costs and weights of laminated and tempered glazing.

Table 9 Incremental cost and weight summary for Van Hool motorcoach windows

Description	Cost per coach	Quantity per coach	Cost per window	Labor	Material	Variable	Fixed	Weight per coach [kg]
Van Hool incremental	***$ 168.19***	***8***	***$ 21.02***	***$ 2.02***	***$ 11.87***	***$ 3.84***	***$ 3.28***	***5.3***
Incremental Glazing	**$ 124.08**	**8**	**$ 15.51**	**$ 1.75**	**$ 8.75**	**$ 3.50**	**$ 1.52**	**-10.8**
Tempered Glazing	$ 266.04	8	$ 33.25	$ 1.57	$ 8.47	$ 21.12	$ 2.10	143
Laminated Glazing	$ 390.12	8	$ 48.77	$ 3.31	$ 17.22	$ 24.62	$ 3.61	132
Incremental Van Hool Latching	**$ 44.11**	**8**	**$ 5.51**	**$ 0.27**	**$ 3.13**	**$ 0.34**	**$ 1.76**	**16.1**
Van Hool baseline latch parts	$ 20.26	8	$ 2.53	$ 0.86	$ 0.31	$ 0.50	$ 0.88	0.7
Van Hool modified latch parts	$ 64.37	8	$ 8.05	$ 1.13	$ 3.43	$ 0.84	$ 2.64	16.8

5.0 ACRONYMS, ABBREVIATIONS, & REGISTERED TRADEMARK

ABA	American Bus Association
ACC	Asset Center Costing
ºC	Degrees Centigrade
CFR	Code of Federal Regulations
DOT	Department of Transportation
FMVSS	Federal Motor Vehicle Safety Standard
GVWR	Gross Vehicle Weight Rating
Inc.	Incorporated
IRS	Internal Revenue Service
kg	kilogram
km/h	kilometers per hour
L	Left
LLC	Limited Liability Company
MCI®	Motor Coach Industries
mph	miles per hour
NAS	National Academy of Sciences
NA	North America
NHTSA	National Highway Traffic Safety Administration
No.	Number
NPRM	Notice of Proposed Rulemaking
OEM	Original Equipment Manufacturer
OTRB	Over-The-Road-Bus
PVB	Poly-Vinyl Butyral
R	Right
®	Registered trademark
SAE	Society of Automotive Engineers
sec	seconds
SG&A	Selling, General & Administration
S.L.	Sociedad Limitada (Spanish limited liability company designation)
SID	Side Impact Dummy
S.r.l.	Società a responsabilità limitata (Italian limited liability company designation)

TRC	Transportation Research Center
US	United States
USA	United States of America
USC	United States Code
US-SID	SID representing an average (50^{th} percentile) male adult living in the USA

6.0 APPENDIX

Manufacturing cost and weight breakdowns for laminated and tempered glazing

The manufacturing processes for a single pane of laminated glass and tempered glass to fit a motorcoach bus window were studied and broken into labor, material, variable and fixed cost elements. The costs for each process step are recorded in Table A-1; process cycle time and man power requirements are also provided, as are weights, where appropriate.

Table A-1 Manufacturing costs and weights for laminated and tempered glazing

Item #	Description	Total cost to manu-facture	Cycle time [sec]	Man power	Labor	Material	Variable	Fixed	Total weight [kg]
1	*Laminated glazing*	*$ 48.77*			*$ 3.31*	*$ 17.22*	*$ 24.62*	*$ 3.61*	*16.54*
1.1	**Pre-processing**	**$ 12.66**	**30**	**1**	**$ 0.57**	**$ 11.73**	**$ 0.11**	**$ 0.26**	**15.49**
1.1.1	Load pair	$ 11.81			$ 0.01	$ 11.73	$ 0.02	$ 0.05	15.49
1.1.2	Cut	$ 0.31		0.33	$ 0.19	$ -	$ 0.03	$ 0.09	
1.1.3	Break	$ 0.24		0.33	$ 0.19	$ -	$ 0.02	$ 0.03	
1.1.4	Grind	$ 0.31		0.33	$ 0.19	$ -	$ 0.03	$ 0.09	
1.2	**Print**	**$ 2.33**	**30**	**1**	**$ 0.34**	**$ -**	**$ 1.83**	**$ 0.16**	
1.2.1	Wash	$ 0.53		0.20	$ 0.11	$ -	$ 0.42	$ 0.00	
1.2.2	Spray powder	$ 0.61		0.20	$ 0.06	$ -	$ 0.55	$ -	
1.2.3	Stack pairs	$ 0.13		0.20	$ 0.06	$ -	$ 0.02	$ 0.05	
1.2.4	Print	$ 0.08		0.20	$ 0.06	$ -	$ 0.01	$ 0.02	
1.2.5	Dry	$ 0.98		0.20	$ 0.06	$ -	$ 0.83	$ 0.09	
1.3	**Bend / Anneal**	**$ 23.55**	**72**	**2**	**$ 0.72**	**$ -**	**$ 20.00**	**$ 2.83**	
1.3.1	Bend & Anneal	$ 21.51		1	$ 0.67	$ -	$ 20.00	$ 0.83	
1.3.2	Check	$ 2.04		1	$ 0.04	$ -	$ -	$ 2.00	
1.4	**Laminate**	**$ 7.95**	**30**	**3**	**$ 0.96**	**$ 5.49**	**$ 1.30**	**$ 0.20**	**1.05**
1.4.1	Wash	$ 0.66		0.43	$ 0.24	$ -	$ 0.42	$ 0.00	
1.4.2	Separate pair	$ 0.19		0.43	$ 0.12	$ -	$ 0.02	$ 0.05	
1.4.3	Layout PVB	$ 5.61		0.43	$ 0.12	$ 5.49	$ -	$ -	1.05
1.4.4	Re-unite pair	$ 0.19		0.43	$ 0.12	$ -	$ 0.02	$ 0.05	
1.4.5	Trim PVB	$ 0.12		0.43	$ 0.12	$ -	$ -	$ -	
1.4.6	Laminate	$ 1.04		0.43	$ 0.12	$ -	$ 0.83	$ 0.09	
1.4.7	Stack carts	$ 0.13		0.43	$ 0.12	$ -	$ 0.00	$ 0.01	
1.5	**Autoclave**	**$ 1.87**	**36**	**1**	**$ 0.34**	**$ -**	**$ 1.38**	**$ 0.16**	
1.5.1	Load autoclave	$ 0.20		0.33	$ 0.11	$ -	$ 0.03	$ 0.06	
1.5.2	Autoclave	$ 1.56		0.33	$ 0.11	$ -	$ 1.35	$ 0.09	
1.5.3	Unload autoclave	$ 0.12		0.33	$ 0.11	$ -	$ 0.01	$ 0.00	
1.6	**Finish**	**$ 0.40**	**30**	**2**	**$ 0.39**	**$ -**	**$ 0.00**	**$ 0.00**	
1.6.1	Final trim	$ 0.19		0.67	$ 0.19	$ -	$ -	$ -	
1.6.2	Final inspection	$ 0.02		0.67	$ 0.01	$ -	$ -	$ 0.00	
1.6.3	Pack for shipment	$ 0.20		0.67	$ 0.19	$ -	$ 0.00	$ 0.00	
2	*Tempered glazing*	*$ 33.25*			*$ 1.57*	*$ 8.47*	*$ 21.12*	*$ 2.10*	*17.90*
2.1	**Pre-processing**	**$ 8.98**	**30**	**1**	**$ 0.28**	**$ 8.47**	**$ 0.06**	**$ 0.16**	**17.90**
2.1.1	Load	$ 8.55			$ 0.00	$ 8.47	$ 0.02	$ 0.05	17.90
2.1.2	Cut	$ 0.15		0.33	$ 0.09	$ -	$ 0.02	$ 0.04	
2.1.3	Break	$ 0.12		0.33	$ 0.09	$ -	$ 0.01	$ 0.02	
2.1.4	Grind	$ 0.15		0.33	$ 0.09	$ -	$ 0.02	$ 0.04	
2.2	**Print**	**$ 1.44**	**30**	**1**	**$ 0.28**	**$ -**	**$ 1.05**	**$ 0.11**	
2.2.1	Wash	$ 0.30		0.33	$ 0.09	$ -	$ 0.21	$ 0.00	
2.2.2	Print	$ 0.12		0.33	$ 0.09	$ -	$ 0.01	$ 0.02	
2.2.3	Dry	$ 1.01		0.33	$ 0.09	$ -	$ 0.83	$ 0.09	
2.3	**Bend / Temper**	**$ 22.53**	**72**	**2**	**$ 0.70**	**$ -**	**$ 20.00**	**$ 1.83**	
2.3.1	Bend & Temper	$ 21.51		1	$ 0.67	$ -	$ 20.00	$ 0.83	
2.3.2	Check	$ 1.02		1	$ 0.02	$ -	$ -	$ 1.00	
2.4	**Finish**	**$ 0.31**	**30**	**2**	**$ 0.31**	**$ -**	**$ 0.00**	**$ 0.00**	
2.4.1	Final inspection	$ 0.02		1	$ 0.02	$ -	$ -	$ 0.00	
2.4.2	Pack for shipment	$ 0.29		1	$ 0.28	$ -	$ 0.00	$ 0.00	

Detailed Cost and Weight Breakdowns for MCI, Prevost and Van Hool latching changes

Detailed cost and weight information is given below on the manufacturing processes for the latching parts that failed initial impact testing (baseline latching, described more fully above in the *Production Latching Mechanisms* and *Production Latching Mechanism Failure Modes* sections of 3.0 Engineering Analysis) and were modified as countermeasures to the failure modes (modified latching, described more fully above in the *Modified Latching Mechanisms* section of 3.0 Engineering Analysis.) Table A-2 shows the incremental costs and weights for MCI side window latching, Table A-3 for Prevost latching, and Table A-4 for Van Hool latching.

Table A-2 MCI incremental costs and weights for baseline and modified latching

Item #	Description	Mfg'g Cost per window	Quantity per window	Mfg'g Cost per latch	Cycle time [sec]	Man power	Labor	Material	Variable	Fixed	Weight per window [kg]
1	**Incremental MCI Latching**	**$ 0.63**	**2**	**$ 0.32**			**$ 0.03**	**$ 0.16**	**$ 0.04**	**$ 0.08**	**0.09**
1.1	Processing	$ 0.25	2	$ 0.13			$ -	$ 0.12	$ -	$ 0.00	
1.1.1	Washers	$ 0.25	4	$ 0.06				$ 0.06			
1.1.2	Bolt	$ 0.12	2	$ 0.06				$ 0.06			
1.2	Latch plate	$ 0.07	2	$ 0.03			$ -	$ 0.03	$ -	$ 0.00	
1.3	Bushing	$ 0.31	2	$ 0.16			$ 0.03	$ 0.00	$ 0.04	$ 0.07	
1.4	Striker post	$ -	2	$ -			$ -	$ -	$ -	$ -	
2	**MCI Baseline Latching**	**$ 1.66**	**2**	**$ 0.83**			**$ 0.23**	**$ 0.18**	**$ 0.20**	**$ 0.23**	**0.22**
2.1	Processing	$ 0.67	2	$ 0.34	27	1.5	$ 0.11	$ 0.06	$ 0.08	$ 0.08	
2.2	Latch plate	$ 0.26	2	$ 0.13	2	1	$ 0.01	$ 0.05	$ 0.04	$ 0.02	
2.3	Bushing (plastic)	$ 0.07	2	$ 0.03	7.2	0.5	$ 0.01	$ 0.00	$ 0.01	$ 0.01	
2.4	Striker post	$ 0.66	2	$ 0.33	16	1.5	$ 0.09	$ 0.06	$ 0.06	$ 0.11	
3	**MCI Modified Latching**	**$ 2.29**	**2**	**$ 1.15**			**$ 0.26**	**$ 0.34**	**$ 0.24**	**$ 0.30**	**0.32**
3.1	Processing	$ 0.92	2	$ 0.46	27	1.5	$ 0.11	$ 0.18	$ 0.08	$ 0.08	
3.1.1	Washers	$ 0.25	4	$ 0.06				$ 0.06			
3.1.2	Bolt	$ 0.12	2	$ 0.06				$ 0.06			
3.2	Latch plate	$ 0.33	2	$ 0.17	2	1	$ 0.01	$ 0.09	$ 0.04	$ 0.02	
3.3	Bushing (steel)	$ 0.38	2	$ 0.19	15	0.5	$ 0.04	$ 0.01	$ 0.06	$ 0.08	
3.4	Striker post	$ 0.66	2	$ 0.33	16	1.5	$ 0.09	$ 0.06	$ 0.06	$ 0.11	

Table A-3 Prevost incremental costs and weights for baseline and modified latching

Item #	Description	Mfg'g Cost per window	Quantity per window	Mfg'g Cost per latch	Cycle time [sec]	Man power	Labor	Material	Variable	Fixed	Weight per window [kg]
1	**Incremental Prevost Latching**	**$ -0.66**	**1**	**$ -0.66**			**$ -0.08**	**$ 0.37**	**$ 0.26**	**$ -1.21**	**1.34**
1.1	Latch post	$ -1.85	2	$ -0.92			$ -0.14	$ 0.38	$ 0.15	$ -1.31	1.6
1.2	Locator tab	$ 0.63	2	$ 0.26			$ 0.06	$ -0.02	$ 0.11	$ 0.10	0.08
1.3	Latch bar	$ -	1	$ -			$ -	$ -	$ -	$ -	0.00
2	**Prevost Baseline Latching**	**$ 17.55**	**1**	**$ 17.55**			**$ 1.78**	**$ 8.94**	**$ 2.02**	**$ 4.82**	**3.16**
2.1	Latch post	$ 5.44	2	$ 2.72	120	3	$ 0.41	$ 0.44	$ 0.23	$ 1.64	0.36
2.2	Locator tab	$ 0.50	2	$ 0.25	101	1.5	$ 0.10	$ 0.04	$ 0.06	$ 0.05	0.017
2.3	Latch bar	$ 14.58	1	$ 14.58	120	3	$ 1.27	$ 8.45	$ 1.73	$ 3.13	2.4
3	**Prevost Modified Latching**	**$ 16.89**	**1**	**$ 16.89**			**$ 1.70**	**$ 9.30**	**$ 2.28**	**$ 3.60**	**4.50**
3.1	Latch post	$ 3.60	2	$ 1.80			$ 0.27	$ 0.83	$ 0.38	$ 0.32	2.0
3.1.1	Latch post assembly	$ 1.12	2	$ 0.56	43	1.5	$ 0.23	$ -	$ 0.14	$ 0.19	
3.1.2	Latch post stamped part 1	$ 1.12	2	$ 0.56	6	0.5	$ 0.02	$ 0.35	$ 0.12	$ 0.07	
3.1.3	Latch post stamped part 2	$ 1.35	2	$ 0.68	6	0.5	$ 0.02	$ 0.47	$ 0.12	$ 0.07	
3.2	Locator tab	$ 1.02	2	$ 0.51			$ 0.16	$ 0.02	$ 0.18	$ 0.15	0.10
3.2.1	Locator tab assembly	$ 0.63	2	$ 0.32	28	1.5	$ 0.14	$ -	$ 0.09	$ 0.08	
3.2.2	Loc tab mod stamped 1	$ 0.19	2	$ 0.09	3	0.5	$ 0.01	$ 0.01	$ 0.04	$ 0.04	
3.2.3	Loc tab mod stamped 2	$ 0.20	2	$ 0.10	3	0.5	$ 0.01	$ 0.01	$ 0.04	$ 0.04	
3.3	Latch bar	$ 14.58	1	$ 14.58	120	3	$ 1.27	$ 8.45	$ 1.73	$ 3.13	2.4

Table A-4 Van Hool incremental costs and weights for baseline and modified latching

Item #	Description	Mfg'g Cost per window	Quantity per window	Mfg'g Cost per latch	Cycle time [sec]	Man power	Labor	Material	Variable	Fixed	Weight per window [kg]
1	**Incremental Van Hool Latching**	**$ 5.51**	**2**	**$ 2.76**			**$ 0.14**	**$ 1.56**	**$ 0.17**	**$ 0.88**	**2.02**
1.1	Slider	$ 2.20	2	$ 1.10	50	1.5	$ 0.19	$ 0.64	$ 0.10	$ 0.18	1.55
1.2	Spring Clip	$ -0.41	2	$ -0.20	1	1	$ -0.08	$ -0.07	$ -0.01	$ -0.05	-0.017
2.3	Aluminum Angle bar	$ 3.72	2	$ 1.86	10	0.5	$ 0.03	$ 0.99	$ 0.09	$ 0.75	0.48
2	**Van Hool Baseline Latching**	**$ 2.53**	**2**	**$ 1.27**			**$ 0.43**	**$ 0.15**	**$ 0.25**	**$ 0.44**	**0.085**
2.1	Slider	$ 1.88	2	$ 0.94	30	1	$ 0.35	$ 0.01	$ 0.20	$ 0.38	0.048
2.2	Spring Clip	$ 0.65	2	$ 0.33	15	1	$ 0.08	$ 0.14	$ 0.05	$ 0.06	0.037
3	**Van Hool Modified Latching**	**$ 8.05**	**2**	**$ 4.02**			**$ 0.57**	**$ 1.72**	**$ 0.42**	**$ 1.32**	**2.10**
3.1	Slider	$ 4.08	2	$ 2.04	50	1.5	$ 0.54	$ 0.65	$ 0.30	$ 0.56	1.60
3.2	Spring Clip	$ 0.25	2	$ 0.12	1	1	$ 0.00	$ 0.07	$ 0.04	$ 0.01	0.020
3.3	Aluminum Angle bar	$ 3.72	2	$ 1.86	10	0.5	$ 0.03	$ 0.99	$ 0.09	$ 0.75	0.48

Cost Accounting Methodology Development

NHTSA has traditionally broken costs into ‘variable costs’ and ‘contribution margin’ with the variable cost portion forming the basis for the ‘wholesale price’ as shown in Table A-5a. A ‘dealer margin’ is then applied to the wholesale cost to arrive at the ‘MSRP’ or manufacturer-suggested retail price to the end-user. The markup factors that resulted from the study of advanced airbag systems as made by a Tier 1 automotive supplier for each of these cost elements is also shown in the table. The NHTSA contract for cost and weight analysis further specifies that manufacturing costs are to include all the variable manufacturing costs plus a ‘fixed’ burden cost to account for depreciation of property, plant, equipment and special tooling associated with making the system. In addition, variable costs are broken down into: ‘material’ costs for materials used directly in the manufacture of the system plus inbound freight costs; ‘labor’ costs for direct labor to make a part of the system; ‘variable’ costs which include other variable costs that vary with production volume. The ‘fixed burden’ is further broken down into: ‘fixed’ costs for the fixed cost portion of manufacturing a unit; ‘SG&A’ costs, which was set to a fixed percentage markup of the variable manufacturing costs; ‘profit’ which is the profit margin for the manufacturer and was fixed at a percentage of total manufacturing costs; and ‘transportation and warranty’ costs which was a fixed percentage of total manufacturing costs. Summing these variable and fixed costs leads to a wholesale cost. To the ‘wholesale price’ a ‘dealer margin’ is applied as a fixed percentage of wholesale to get an end-user cost.

Table A-5a Manufacturing cost breakdown with overhead and dealer margins results in the end-user cost

NHTSA Air Bag Report[2]			NHTSA Contract	Ricardo System Analysis (from Tier 1 supplier)							
							System				
NHTSA Air Bag report terminology	% Net Sales	Markup Factor	NHTSA contract terminology	Ricardo category		Description	% Net Sales		Markup Factor	Example Values	
Variable Costs	72.5%	1.00	Variable manu-facturing costs	Material	Material	Direct material costs & scrap allowance per unit	74.6%	80.6%	1.00	$104.91	$113.44
					Freight	Inbound direct material & scrap costs per unit (Note: Scrap = 1% of material costs)	0.8%			$1.06	
				Labor		Direct labor dollars per unit (Note: based on US union shop labor for machining/assembly)	3.6%			$5.02	
				Variable		Variable burden cost per unit, including indirect labor and other costs that vary with production volume	1.7%			$2.45	
Contribution Margin	27.5%	0.38	Fixed burden	Fixed		Fixed burden per unit (Note: Includes depreciation for property, plant, equipment & special tooling)	4.9%	19.4%	0.24	$6.92	$27.27
				SG&A		6.0% of variable manufacturing costs for T1 supplier	4.8%			$6.81	
				Profit		3.75% of total manufacturing costs for T1 supplier	3.2%			$4.51	
				Transportation & warranty		7.5% of total manufacturing costs for T1 supplier	6.4%			$9.03	
Wholesale Price	100.0%	1.38		Wholesale Price				100%	1.24	$140.71	
Dealer Margin	11.0%	1.11		Dealer margin		Dealer costs and markup (11.0% of wholesale price)		11.0%	0.11	$15.48	
MSRP	111.0%	1.52	End user cost	End user cost				111%	1.38	$156.18	
				Total manufacturing cost		= Variable manufacturing costs + Fixed				$120.36	

2) Source: p. 3.8 of Spinney, B.C., Faigin, B., Bowie, N., & St. Kratzke. 1999, Advanced Air Bag Systems Cost, Weight, and Lead Time analysis Summary Report, Contract NO. DTNH22-96-0-12003, Task Orders – 001, 003, and 005. Washington, D.C., U.S. Department of Transportation.

Table A-5b Comparison of cost factors to ANL, Borroni-Bird, and EEA methodologies

ANL Method[4]

NRC/Vyas reports terminology	% Net Sales	Markup Factor: Individual	Markup Factor: Sub-total	Markup Factor: Cumulative Total
Cost to manufacture	68%		1.00	1.00
Warranty	32%	0.10	0.48	1.48
R&D engineering		0.13		
Depreciation & amortization		0.11		
Corp. overhead, retirement, health		0.14		
	100%			1.48
Distribution, marketing, dealers			0.47	1.95
Profit			0.05	2.00

Borroni-Bird[4, 5]

NRC/Vyas reports terminology	% Net Sales	Markup Factor: Individual	Markup Factor: Sub-total	Markup Factor: Cumulative Total
Materials	61%	0.87	1.00	1.00
Labor, other mfg'g costs		0.13		
Transportation & warranty	39%	0.09	0.63	1.63
Depreciation & amortization, engineering R&D, pension, health care, advertising and overhead		0.44		
Price discounts		0.1		
	100%			1.63
Dealer markup			0.36	1.99
Profit			0.06	2.05

EEA[4]

NRC/Vyas reports terminology	% Net Sales	Markup Factor: Individual	Markup Factor: Sub-total	Markup Factor: Cumulative Total
Division costs	68%	0.72	1.00	1.00
Division overhead		0.14		
Assembly labor & overhead		0.14		
Manufacturing O/H	32%	0.22	0.48	1.48
Amortized eng'g, tooling, facilities		0.26		
	100%			1.48
Dealer margin			0.49	1.97
Profit			0.17	2.14

4) Sources: National Research Council, "Assessment of Fuel Economy Technologies for Light-Duty Vehicles," Appendix F - Review of Estimate of Retail Price Equivalent Markup Factors & Chapter 3 - Cost Estimation, 2011; Vyas, A., Santini, D., And Cuenca, R., "Comparison of Indirect Cost Multipliers for Vehicle Manufacturing," Technical Memorandum of the Center for Transportation Research, Argonne National Laboratory, April 2000.

5) Borroni-Bird Price discounts (0.1) and Transportation (<0.09) are included in Contribution Margin which NTHSA & some others group with Dealers selling costs

Table A-5c Comparison of cost factors to RTI/EPA methodology

RTI/EPA report[3]				
		RPE Multiplier		
EPA report terminology	% Net Sales	Individual	Sub-total	Cumulative Total
Cost of sales	75%		1.00	1.00
Production O/H	25%	0.18	0.34	1.34
Corporate O/H		0.08		
Selling (Transportation, marketing)		0.08		
	100%			1.34
Dealers			0.06	1.40
Profit			0.06	1.46

3) Source: Rogozhin, A., Gallaher, M., & McManus, W. 2009, Automobile Industry Retail Price Equivalent and Indirect Cost Multipliers. Report by RTI International to Office of Transportation Air Quality. U.S. Environmental Protection Agency, RTI Project Number 0211577.002.004, February, Research Triangle Park, N.C.