LAMINATED GLAZING: SECURITY AND SAFETY ASPECTS

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EXECUTIVE SUMMARY

This project was undertaken on behalf of the Vehicle Standards and Engineering Division of the Department of Environment, Transport and the Regions. The objective of this research programme was to examine the security of various glazing types against the specification of the published British Standard relating to vehicle security, with a specific view to assessing laminated glazing and the applicability of the tests contained within BS AU 209 Part 4. In addition, the implications for safety for different types of glazing tested were investigated by examining injury and entrapment data. The research carried out under this programme included work in accordance with the published standard and also work which was considered in the previous draft standard.

Tests to the specification of the resistance to impact test in BS AU 209 Part 4: 1995 clearly showed that laminated glazing was superior to both toughened and toughened glazing with the addition of a plastic coating. The impact test was found to be objective and the test easy to undertake, with the pendulum impact force being comparable to that of a hand-held hammer. The framing of the glazing proved to be important, since fully-framed glazing resulted in less extensive damage. However, in some cases the current test did not always adequately distinguish between the resistance to breakage of toughened and laminated glazing. This was because the geometry of the impactor was not as aggressive as some of the potential tools that a thief might employ. It is suggested that the tip of the impactor be fitted with a small point to improve the realism of the test. However further investigation into the exact dimensions of this addition and also into the types of tool commonly used to gain illegal access to vehicles is required.

The resistance to removal test as described in the 1987 draft of BS AU 209 Part 4 was also used to test the glass samples. The subjectivity of the test was confirmed, since the test procedure was not adequately specified and the results depended greatly on the force and effort exerted by the researcher. As a result, TRL devised a 'force/lever' test which was proposed to be used after a sample has been subjected to the resistance to impact test. This procedure is described in Appendix 3 and may provide an objective method of assessing the degree to which a glazing type remains resistant to breaches of security even after being subjected to repeated impacts.

Glazing more resistant to intruders must not be so impenetrable that that the safety risks associated with occupant entrapment are significantly increased. Testing has indicated that externally-damaged laminated glazing produces greater lacerative damage than impacts onto undamaged laminated glazing. However, this is to be expected, and it is clear that an impact sufficient to shatter laminated glass would also shatter toughened glass. The difference in lacerative injury potential between the glazing types would depend greatly on the dynamics of the impact and on the occupant's trajectory relative to the glazing. Furthermore, if laminated glass were used instead of toughened glass, the glazing would be expected, based on experimental results, to be damaged but to stay in situ and this has the potential to result in greater levels of occupant entrapment in a small proportion of cases. However, this may not be the problem that it appears for three main reasons. Firstly, cases where egress is only possible through a window are very rare, accounting for only 85 of 6,823 accidents contained within the CCIS database. Secondly, if the occupant is injured to the extent that they cannot make use of an available door, then it is likely that the glazing type will be irrelevant because the emergency
services will be required to extricate them from the vehicle. Thirdly, the forces required to push out laminated glazing, if damaged in a similar manner as in the pendulum impact test, can be easily achieved by using feet to push the glazing from the frame. If the occupant was capable of this, then egress from the vehicle may be possible by pushing out the laminated glazing in 90.2% of the CCIS cases where the driver's door was jammed shut. In addition, the fitment of laminated glazing to the side and rear windows would result in a significant reduction in partial and total occupant ejections. This is important because studies have shown that ejected occupants have a risk of being severely or fatally injured of up to 40 times that of occupants who are not ejected.

The additional costs associated with the fitting of laminated glazing instead of toughened glazing may be easily balanced by the cost savings due to the reduction of occupant ejections and reduced thefts of and from cars. Approximate figures suggest that the annual cost of fitment of laminated glazing to the entire new car fleet would be approximately £300M or £150 per vehicle. Even if the benefits of laminated glazing saved only 10% of the annual car crime costs in the UK, this would fully compensate for the fitment costs.

In addition to the advantages of improved security and overall safety, laminated glazing has the advantages that it can reduce the levels of external noise by 5-10 dB(A) over a broad frequency range of between 2,000 and 8,000Hz. Furthermore, this glazing is capable of preventing 95% of UVA and UVB rays entering the vehicle, and with Infrared (IR) treatment, can reduce solar energy transmission by up to 45%, therefore improving the efficiency of air-conditioning units. Therefore, these benefits mean that the vehicle interior would be quieter and more comfortable and that the occupants and interior materials would be better protected from solar damage. Overall, it seems likely that the fitment of laminated glazing throughout the new car fleet would improve security, safety, comfort, and also be financially beneficial.
LAMINATED GLAZING: SECURITY AND SAFETY ASPECTS

ABSTRACT

Automobile glazing security has become an increasingly important topic, since the advances in other areas of security, such as door locks, immobilisers and alarms have improved disproportionately compared with glazing. Thus, the traditional toughened glazing fitted to the side and rear windows has become an increasingly obvious target for thieves. Laminated glazing has been shown to increase security and the past disadvantages that precluded its fitment do not currently apply. Therefore, it seems likely that laminated glazing may be fitted as standard equipment to all vehicles in the future.

This report has tested laminated glazing, toughened and plastic film-covered toughened glass against the specification of BS AU 209 Part 4: 1995, the Standard applicable to glazing security. The results of these tests have been examined so as to assess the performance of the glazing types and also the test methods and criteria described by the Standard itself. In addition, the implications for occupant safety have been thoroughly assessed.

1. INTRODUCTION

This work is an updated and revised version of work which was previously reported to the DETR in 1996. The objective of this research programme was to examine the security of various glazing types against the specification of the published British Standard relating to vehicle security, with a specific view to assessing laminated glazing and the applicability of the tests contained within the Standard. In addition, the implications for safety for different types of glazing tested were investigated by examining injury and entrapment data. The research carried out under this programme included work in accordance with the published standard and also other work which was considered in the previous draft standard.

Laminated glazing consists of two layers of heat-strengthened glass with a polyvinyl butyral (Pvb) interlayer. Compared with standard toughened glass, which is manufactured from a single monolithic piece of thermally toughened soda-lime float glass, laminated glass does not disintegrate on impact but is held together by the Pvb interlayer. At present, most vehicles have laminated glazing fitted in the windscreen and toughened glazing in the side and rear windows. However, recent advances in glazing technology have made it feasible for laminated glazing to be fitted in place of toughened glazing in the side and rear windows, since past problems with the overall glass thickness and weight have now been overcome.

The theft of vehicles and the theft from vehicles is an ever increasing problem. For example, in 1995 approximately 1.3 million instances of car crime were reported in the UK with an overall cost of nearly £3,000 million (Cambridge, 1997). Earlier work suggested that approximately 50% of these crimes involved thefts from the interior of the vehicle and in an estimated 80% of these,
the entry point on the vehicle was via the side or rear glazing (Morris et al, 1993). One of the reasons for this is the relative ease of illegal entry possible though the toughened side glazing, since toughened glazing usually shatters completely on impact, enabling easy access to the vehicle interior. Esposito (1998) states that toughened glazing provides about 2 seconds of resistance to attack, compared with 20-30 seconds of resistance for laminated glazing, and even longer for high security glazing which uses advanced materials such as polycarbonate within the laminate layer. At present, however, thieves tend to target side glazing as opposed to rear glazing for the reason that access to the vehicle interior, where valuables may be visible, is easier and there is no de-misting circuitry to complicate entry into the vehicle. Thus, this report concentrates on access via the side glazing, although it should be noted that the general principles apply to toughened glazing in any position on the vehicle.

Methods of improving the resistance of automobile glazing to opportunist thieves are therefore desirable, especially since automobile manufacturers are unwilling to install elaborate and expensive door locks when it is easier to gain unlawful access to the vehicle by breaking the side or rear glazing. Advances in alarm and immobiliser systems have had some effect in reducing the theft of entire vehicles, but the steps necessary to improve the resistance of glazing to illegal entry have not kept pace with these developments. Methods by which the side or rear glazing can be made more secure include using laminated glazing as an alternative to toughened glazing, or by covering the surface of toughened glazing with a plastic film laminate. It has been proposed that using laminated glazing for all vehicle glazing would offer a level of security that might deter the opportunist thief, therefore greatly reducing "smash and grab" thefts (Blizzard and Howitt, 1969).

In order to assess the glazing types and to assess the standard itself, TRL tested these glazing types to the specification of BS AU 209 Part 4 (1995), which is the only standard that relates to the performance requirements for security glazing (shown in Appendix 1). An earlier draft of this Standard, BS AU 209 Part 4 Draft (1987), also included a retention test (shown in Appendix 2) which was subsequently withdrawn from later revisions and from the published standard due to its subjectivity. However, the glazing types tested were also examined using this section of the 1987 revision in order to understand the limitations of the methodology.

In addition, the safety of the individual glazing types was also assessed in order to ensure that any improvements in glazing security would not have a detrimental effect on occupant injury potential. This was achieved by carrying out impact tests to discover the Triplex laceration index for externally-damaged laminated glazing and by analysing injury and entrapment data.

2. SECURITY ASPECTS

A recent study stated that the present requirement for a vehicle to remain resistant to unauthorised entry, using 'everyday objects' that a thief might employ, should be in the range of 2-5 minutes (Cambridge, 1997). Although this requirement may be difficult to achieve with respect to the integrity of the glazing, it is likely that a delay in entry of 10 seconds or more would deter a potential thief (DasGupta, 1996). Therefore, standard glazing should be reasonably resistant to breaches of security and this must be assessed objectively by the relevant standard.
It is, therefore, necessary to:-

1) Design an objective test that is repeatable and with requirements that are practical to achieve.

2) Establish that the energy input to the glazing is realistic of a person wielding a typical attack implement such as hammer.

3) Establish the criteria to apply in order to prevent entry into the vehicle.

The Standard BS AU 209 Part 4: 1995 states the specification for security glazing of passenger cars and car derived vehicles. This test procedure given in BS AU 209 Part 4 (1995) was used to evaluate laminated glazing, toughened glazing and toughened glazing covered with a plastic film.

2.1 DETERMINATION OF IMPACT FORCES

The first part of the test programme was designed to assess how representative the pendulum impact test, as described by BS AU 209 Part 4: 1995, was of a person wielding a typical attack implement. This is important since the test for resistance to illegal entry must be representative of real life situations. This was determined by measuring the force of impact achieved by eight volunteers when striking an instrumented plate (see section 2.1.1). The values obtained from each subject were then compared with the force achieved when using the pendulum test as prescribed by BS AU 209 Part 4 (1995).

2.1.1 Hammer impact test

An experiment was conducted in which eight male subjects used both a 1lb copper-headed mallet and a 2lb hammer with which to strike a plate connected to force transducers. This plate was mounted vertically onto a rigid frame and positioned approximately the same height above the floor as the centre of the side glazing contained within a Rover 800 front door. A 20mm thick piece of plywood or a 20mm thick piece of plywood with a 20mm thick piece of expanded foam were fixed onto the plate, in order to represent the non-rigidity of glazing fitted into the weather seal of a typical door. The test conditions were randomised in order to eliminate any learning effects by the subjects. The results of these tests are displayed in Table 1.
Table 1. Maximum Force exerted by each subject for each condition

<table>
<thead>
<tr>
<th>IMPACTOR</th>
<th>MAXIMUM FORCE (kN) (FILTERED TO CFC 1000)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hammer</td>
</tr>
<tr>
<td>IMPACT SURFACE</td>
<td>Wood</td>
</tr>
<tr>
<td>SUBJECT No.</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>48.6</td>
</tr>
<tr>
<td>2</td>
<td>38.9</td>
</tr>
<tr>
<td>3</td>
<td>30.8</td>
</tr>
<tr>
<td>4</td>
<td>25.6</td>
</tr>
<tr>
<td>5</td>
<td>27.5</td>
</tr>
<tr>
<td>6</td>
<td>43.6</td>
</tr>
<tr>
<td>7</td>
<td>21.8</td>
</tr>
<tr>
<td>8</td>
<td>39.8</td>
</tr>
<tr>
<td>Mean</td>
<td>34.6</td>
</tr>
<tr>
<td>Range</td>
<td>26.8</td>
</tr>
<tr>
<td>Coeff of Var (%)</td>
<td>27.5</td>
</tr>
</tbody>
</table>

From Table 1 it can be seen that mean peak forces are similar for both test conditions using the hammer. There are also similar mean peak forces for the two test conditions using the copper-headed mallet. The hammer gave greater mean peak forces than the copper-headed mallet for every condition. The mean peak forces for hammer impacts were greater than the mallet impacts by about 145% and 160% for the wood and the wood with foam surfaces respectively. There was also a large range in peak force and the coefficient of variance is high for any given test condition. This was partly due to the variation in strength or technique between subjects and partly dependent on whether the force measuring plate was impacted with a "clean" blow.

2.1.2 Pendulum impact test

In order to ascertain the forces due to pendulum impact, an impact rig was constructed as described in BS AU 209 Part 4 (1995) - Annex B. The total mass of the pendulum was 9.5±0.2kg with a drop height of 700mm as stated by the Standard. The pendulum was impacted ten times onto both wood and wood with foam surfaces as described above. The means of the peak forces and associated impulses are shown in Table 2.
Table 2  Mean peak forces and impulses for eight subjects and ten pendulum impacts for each condition.

<table>
<thead>
<tr>
<th>IMPACTOR SURFACE</th>
<th>MEAN PEAK FORCE (kN)</th>
<th>MEAN IMPULSE (Ns)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Wood</td>
<td>Wood+Foam</td>
</tr>
<tr>
<td>IMPACTOR</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2lb Hammer (0.91kg)</td>
<td>34.6 32.5</td>
<td>21.0 20.3</td>
</tr>
<tr>
<td>1lb Mallet (0.45kg)</td>
<td>14.1 12.5</td>
<td>11.0 10.0</td>
</tr>
<tr>
<td>Pendulum (9.5kg)</td>
<td>19.2 17.9</td>
<td>37.1 36.6</td>
</tr>
</tbody>
</table>

From Table 2, it can be seen that for either test condition, the mean peak forces for the pendulum impacts were larger than those of a person wielding a copper-headed mallet and smaller than those of a person wielding a hammer. However, the duration over which the pendulum impact took place was longer. A further assessment of any differences between conditions may be made by calculating the impulse of the impacts. It can be seen in Table 2 that the impulses from the pendulum impacts were larger than those for both the copper-headed mallet and hammer conditions. The pendulum impulse was about 77% to 80% larger than the hammer impulse and about 237% to 266% larger than the copper-headed mallet impulse for the wood and the wood with foam conditions respectively.

2.2 GLAZING TEST PROGRAMME

The pendulum impact rig was used to make a comparative study of toughened glazing as presently used, toughened glazing with a plastic film laminated to the inside surface and different types of laminated glazing. The types of laminated glazing tested were;

i) Unframed - 2.1/0.76/2.1mm specification.

ii) Partially framed - as (i) with both verticals framed in a U-shaped channel.

iii) Fully framed - as (i) with both verticals and top horizontal framed in a U-shaped channel.

The glazing was either fitted into a standard Rover 800 LHS door or a door modified such that the glazing would fit into a U-shaped channel within it.

2.2.1 BS AU 209 Part 4 (1995) - Annex B: Impact tests for the retention of security glazing

The impact test within BS AU 209 part 4, requires five impacts with a 9.5±0.2kg pendulum,
consisting of mild steel and having hemispherical ends of 75mm diameter, at a predefined array of points on the section of external glazing. The requirements of this test are that a sphere of 40±2mm diameter should not be able to pass freely through any aperture in the glazing or between the glazing and door body as a result of the impact test.

2.2.1.1 Standard door tests

Toughened Glazing

Although the design requirements for security glazing are such that toughened glazing is very unlikely to satisfy all the requirements, it was useful to test toughened glazing as a comparison to alternative types of glazing.

Three pieces of toughened glazing were tested. Two of these shattered on the first impact, the third failed to break after the five impacts required in the procedure thus passing the test. This toughened glazing was further subjected to another six impacts at the third impact position. The drop height was increased in equal increments from 700mm to 1400mm and the glazing still retained its integrity. Usually, toughened glazing would be expected to shatter on the first impact. However, it was considered that the behaviour of this sample was due to inconsistencies in the manufacturing process, which can produce glazing that exhibits this behaviour.

Laminated Glazing

Five pieces of laminated glazing were tested in a standard Rover 800 door - one unframed and two each of the partial and fully framed samples. The results of the test are shown in Table 3.

All the laminated glazing samples, except one of the partially framed pieces, passed the pendulum test. This is not surprising since the unframed laminated glazing was considered to offer a reasonable amount of security and the test procedure was developed for glazing with this level of performance. However, it was notable that each pair of the partially and fully framed glazing behaved differently. One of each pair resulted in the interlayer being torn and in the case of the test on the partially framed glazing, in which no tear in the interlayer occurred, the glazing distorted so much as to open a 38mm gap between it and the door frame.
Table 3. Condition of laminated glazing after impact test, mounted in the standard Rover 800 door.

<table>
<thead>
<tr>
<th>LAMINATED GLAZING</th>
<th>CONDITION AFTER TEST</th>
<th>Pass/Fail</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Approx. length of tear in interlayer (mm)</td>
<td>Approx. distance glazing pulled away from edge (mm)</td>
</tr>
<tr>
<td>Unframed</td>
<td>Sample 1</td>
<td>10</td>
</tr>
<tr>
<td>Partially Framed 1</td>
<td>Sample 1 Sample 2</td>
<td>20</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>20</td>
</tr>
<tr>
<td>Fully Framed 1</td>
<td>Sample 1 Sample 2</td>
<td>20</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>20</td>
</tr>
</tbody>
</table>

*Failed impact test - a 40±2mm sphere was able to pass freely between glazing and door frame.

Toughened Glazing With Plastic Film Laminate

Two pieces of this type of glazing were tested. The first piece was shattered on the first impact but remained in place. On the second impact, the glazing was detached from the clips fixing it to the window winding mechanism and fell down into the door. It was considered that that this occurred for the reason that there was no weather-seal fitted to the door interior. The weather-seal was deliberately not used in the toughened glazing or laminated glazing tests as originally it was felt that it would make little, if any, difference to the outcome. A second piece of glazing with plastic film was therefore tested in a door with the weather-seal fitted. As a result of the first impact, the glazing was totally shattered with the pendulum tearing through the plastic film laminate, opening a hole wide enough for the 75mm diameter pendulum impactor to pass through. The pendulum was removed from the glazing and the glazing remained in situ. No further impacts were conducted. Although the glazing had remained in place, it had parted from the retaining clips and was removed simply by pulling it from the frame.
2.2.1.2 **Modified door tests**

Impact tests were carried out on both toughened and unframed laminated glazing. A modified door, which included a metal channel for the glazing to be seated into, in place of the usual rubber seal, was used for these tests.

**Toughened Glazing**

The toughened glazing shattered and fell away on the first of the pendulum impact tests, therefore failing the resistance to impact test.

**Unframed Laminated Glazing**

The unframed laminated glazing was subjected to the five impacts at the specified sites. As a result of the test there was a tear in the interlayer measuring about 10mm to 15mm long and a separation of glazing from door body of about 10mm wide. The glazing therefore satisfied the proposed resistance to impact tests.

2.2.2 **Tests as proposed in BS AU 209 Draft Part 4 (1987) - Appendix B: Resistance To Removal**

This section of the standard was proposed in 1987, but was withdrawn from later revisions and from the published standard because of its subjectivity. However, the procedures contained within this proposal were reviewed and tested by TRL for completeness.

The 1987 revision of this part of the standard required the glazing to withstand removal by means of simple tools, within four minutes of attack, without distorting the frame or surrounding bodywork. No mention was made of how much force or effort the attacker was to exert during this process. The simple tools listed were:

i) A pointed metallic implement, such as a spring-loaded centre-punch.

This tool was used on two pieces of toughened glazing and an unframed piece of laminated glazing. The force was applied normal to the surface of the glazing. Both pieces of toughened glazing shattered on the first impact, one of these being the piece of glazing that passed the impact test and further testing. The laminated glazing was damaged by the first impact but took 11 impacts at the same site before penetration through the glazing was achieved. Even then, the hole was limited to the initial hole created by the centre punch, which was about 3mm in diameter.

A tool such as this can usually be adjusted to "trigger" at various applied forces. It would be necessary, therefore, to stipulate a "trigger" force. It would probably be simpler and more repeatable to attach a nipple to the end of the pendulum at the point where it impacts the glazing. A nipple of the appropriate dimensions attached to the pendulum could have an effect similar to that of a centre-punch when the pendulum is swung into contact with the glazing.
ii) A general purpose short-bladed handyman's knife.

In earlier sections, it has been shown that laminated glazing offers a reasonable resistance against attack. A knife can be used in many ways, depending on the strength and skill of the individual. To attack the glazing with such a tool with the purpose of gaining entry to a vehicle is somewhat unlikely. The most likely method of attack would probably be to cut the weather-seal surrounding non-opening glazing to expose the edge of the glazing or bodywork and to remove the glazing completely.

Tests were conducted to ascertain the forces required in order to cut through the rubber material holding the glazing in place. Two tests were carried out on glazing held in place by a rubber gasket (quarter-light) and two carried out on glazing held in place by bonding (Tailgate). Two vehicles were used, both of which were Vauxhall Cavaliers. One quarter-light test and one tailgate test were undertaken on each vehicle. For each test, a new blade was used. A standard sized blade which fitted into a handyman's knife was fixed to the end of a torque wrench, from which the force at the blade was calculated.

The typical forces on the blade required to cut through the gasket were about 450N. After this had been achieved, the glazing was simply lifted out. The force on the blade required to cut the bonding material was found to be about 800N. However, the glazing remained held fast due to the blade not being long enough to cut through the entire width of the bonding material. A force of 100N was applied perpendicularly for about 10 seconds to the inside surface of the glazing through a hemispherical probe (40±2mm diameter) placed against the glazing near the edge of the glazing/frame. This diameter of probe was arbitrarily chosen so long as it presented a reasonably "smooth" contact surface with the glazing. There was no visible loosening of the glazing from the bonding material.

If glazing that is bonded in position is considered to give an adequate level of resistance to removal, then a test using a knife blade applied with a force intermediate to that found from the two glazing types would provide a quantitative method of assessing the resistance to removal. An objective and repeatable test specifying the minimum performance requirements of glazing installation, based on these tests is presented in Appendix 3. Such a procedure may be suitable for inclusion into any future revision of the Standard.

iii) A large screwdriver.

It was difficult to define a test method that was both realistic and repeatable for this tool, since it depended on the strength and skill of the individual and also on the application of the tool. It is quite likely that an attacker might first create a hole or gap in the glazing and then use this tool as a lever.

It may be more realistic to consider a test that considers both impact and removal. In the case of a screwdriver, the handle may be used to damage and bow the glazing, and the shaft be used subsequently in order to lever a hole that would allow entry. This situation can be considered in terms of a 'force/lever' test and is addressed in the following section.
2.2.3 Impact and force/lever test

A test was devised to ascertain what force was required to open an aperture of 40mm in either a tear in the interlayer of the glazing or between the glazing and door frame, after it had been impacted at five specified sites. The impact to the glazing was as described in BS AU 209 Part 4 (1995) - Annex B as reported in section 2.2.1.1 and the glazing was fitted into the standard door.

A rigid conical tipped probe, dimensions as shown in the Appendix 4, was pushed through any tear in the interlayer or gap between the glazing and door frame after the impact test. The application of force via a conical probe represents the action of a lever by reproducing the actions of levering open a hole or gap between window or edge and frame but in a repeatable manner. The force required to open an aperture of 40mm diameter was measured on a force gauge, recorded and are shown in Table 4.

The test results shown in Table 4 illustrate that the glazing behaviour, namely the interlayer tearing or not tearing, differed as a result of the impact test and consequently affected the second part of the test - the force/lever test.

Although the unframed laminated glazing did not allow an aperture to be opened through the interlayer with a force of 150N, the glazing was so flaccid after the impact test that this force was enough to open a 40mm gap between the glazing and the weather-seal of the door frame.

Table 4. Approximate force required to open an aperture of 40mm diameter through torn interlayer in glazing (Glass) or between glazing and door body (Edge) after impact test.

<table>
<thead>
<tr>
<th>LAMINATED GLAZING</th>
<th>APPROX FORCE REQUIRED TO OPEN AN APERTURE OF 40mm (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Glass</td>
</tr>
<tr>
<td>Unframed</td>
<td>Sample 1</td>
</tr>
<tr>
<td>Partially Framed</td>
<td>Sample 1</td>
</tr>
<tr>
<td></td>
<td>Sample 2</td>
</tr>
<tr>
<td>Fully Framed</td>
<td>Sample 1</td>
</tr>
<tr>
<td></td>
<td>Sample 2</td>
</tr>
</tbody>
</table>

* With a force of 150N the hole in the glazing increased slightly but the aperture appeared between glazing and the weather-seal as the glazing was pushed in.
** Gap width less than approximately 5mm that was required to insert the tip of a conical probe.
With the partially framed glazing, only one of the two pieces impacted resulted in an interlayer tear. The glazing with a torn interlayer yielded to a force of 100N to open a 40mm diameter aperture. The gap between the glazing and door frame was not sufficient to allow the use of the test at this location. The glazing with no tear in the interlayer resulted in the gap between the glazing and door frame being 38mm - failing the proposed test. As the gap was so large initially, it only required a force of 5N to open the aperture to 40mm.

As with the partially framed glazing, only one of the two pieces of the fully framed glazing impacted resulted in a torn interlayer. It similarly yielded to a 100N force to open an aperture of 40mm. The second piece neither resulted in a torn interlayer nor opening a gap wide enough between the glazing and door frame to carry out the test in this location.

3. SAFETY ASPECTS

It has been shown that laminated glazing presents a greater resistance to being attacked than toughened glazing, since on impact, laminated glazing bows inward and is held in place by the PVB interlayer. As such, laminated glass is suitable for use as security glazing. However, if automobile glazing is made more resistant to intruders, the implications for safety, in terms of how the glazing affects both occupant injuries and the ease of egress from the vehicle in the event of an accident, must be reviewed and the risks quantified. The relevant safety aspects are described and discussed in the following sections.

3.1 INJURY DUE TO LACERATION

The "worst-case" scenario for an occupant being injured by laceration might be if the laminated glazing were initially impacted externally in such a way that the glass shattered and the glazing deformed inwards, towards the occupant. As this was found to be comparable to the type of damage seen after subjecting the glazing to the impact test as described in Section 2.2.1, it was decided that this scenario should be assessed by a laceration test. This test was carried out by impacting the convex surface of the damaged glazing with a headform representative of a human head. The headform comprised of a rigid hemisphere of 152mm diameter. The hemisphere was covered with a silicone skull-cap about 6mm thick to represent facial flesh. Two moist chamois leathers were then placed over the silicone layer to simulate facial skin. The leathers were nominally 1mm in thickness, with the leathers being paired so as to take into account the slight variations in thickness. The thinner of the pair of leathers was used as the outer layer and the headform was impacted into the glazing at a velocity of 24.1km/h.

In order to assess the laceration damage, the Triplex Laceration Index (TLI) was calculated (Pickard et al., 1973) for each impact. This index computes an objective measure of the lacerative damage based on the number, length and depth of cuts on the facial coverings on each layer.
The following equation was used to calculate the severity of the lacerative damage.

\[
\text{TLI} = 2 + \log_{10}(1 + 1.16 \sum_{s=1}^{\max} n_{1s}s^2 + 50.8 \sum_{s=1}^{\max} n_{2s}s^2 + 16500 \sum_{s=1,d'=1}^{\max,\max} n_{3ds}s^2 d^3)
\]

where,  
- \(s\) is the length of cut.  
- \(d\) is the depth of cut into the silicone skull-cap.  
- \(n_{1s}\) is the number of cuts of length \(s\) in the outer leather.  
- \(n_{2s}\) is the number of cuts of length \(s\) in the inner leather.  
- \(n_{3ds}\) is the number of cuts of length \(s\) and depth \(d\) into the silicone skull-cap.  

(All measurements in mm)

The TLI is an objective measure of lacerative damage based on the Corning scale. The Corning scale is an integer scale between zero, minimal damage and 9, very severe damage, with the TLI having a good correlation with this scale over the full range. Unlike the Corning scale, the TLI scale does not involve a high degree of subjectivity in its calculation. The TLI has further advantage over the Corning scale in being continuous and unbounded and is heavily weighted to give higher values for cut lengths in deeper layers (see equation given above). All dimensions were measured to the nearest millimetre. Details of the cuts and the calculated values of TLI for the tests are shown in Table 5.

As the TLI is a logarithmic unit to base 10, a change of one unit corresponds to a ten-fold change in lacerative damage. From Table 5, it can be seen that there were differences in the total length of tears in the simulated skin material. There were numerous cuts in the leathers as a result of the framed glazing tests that were not included in the calculation of the TLI. This was due to the glass not cutting through the 1mm thickness of the material, therefore these cuts were not included in the TLI calculation. The TLI ranged from between 6.24 units and 7.95 units with the highest TLI being measured for the unframed laminated glazing. These values correspond to a 'severe' degree of lacerative damage as defined by the Corning Scale. The difference between the unframed glazing and the partially and fully framed glazing is 0.52 units and 1.71 units respectively. This represents an increase in the total lacerative damage of about between 3.3 to 51.3 times respectively.
### Table 5. Lacerative damage to the leathers and skull-cap using laminated glazing with different types of framing

<table>
<thead>
<tr>
<th>TYPE OF LAMINATED GLAZING</th>
<th>TOTAL LENGTH OF TEARS (mm)</th>
<th>Outer Leather</th>
<th>Inner Leather</th>
<th>Skull-Cap (length / depth)</th>
<th>TLI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unframed</td>
<td></td>
<td>111</td>
<td>50</td>
<td>(1 / 3mm) x2</td>
<td>7.95</td>
</tr>
<tr>
<td>Partially Framed</td>
<td></td>
<td>54</td>
<td>15</td>
<td>1 / 4mm</td>
<td>7.43</td>
</tr>
<tr>
<td>Fully Framed</td>
<td></td>
<td>89</td>
<td>11</td>
<td>1 / 1mm</td>
<td>6.24</td>
</tr>
</tbody>
</table>

In real life accidents, TLI values of this order may produce disfiguring and possibly debilitating injuries. However, it would be unlikely that such an injury would be greater than an Abbreviated Injury Scale (AIS) of 2 and would be unlikely to pose a significant threat to life. However, in the case of lacerative injury, it seems that the AIS scale may underestimate the significance of a facial injury and the costs, both financial and societal. Indeed, the effect on the injured occupant's quality of life of such an injury has the potential to be significant.

In impacts with toughened glass, the occupant is likely to shatter the window and may pass through the aperture. In cases such as these, there is a potential for lacerative injuries since broken glass tends to remain in place around the perimeter of the glazing after being broken. Glass testing using toughened glass in the early 1970s showed that in a 30km/h frontal impact, an unrestrained dummy sustained lacerative facial damage in the region of 8.0-9.0. In addition, if the glazing is impacted from the exterior and shatters, flying glass particles may cause injury to the occupant.

Consequently, it remains unclear whether the prospects of lacerative injury would be increased or decreased if laminated glazing were widely fitted to new vehicles. Testing has indicated that damaged laminated glazing produces greater lacerative damage than undamaged laminated glazing. However, this is to be expected, and it is clear that an impact sufficient to shatter laminated glass would also shatter toughened glass. The difference in lacerative injury potential between the glazing types would depend greatly on the dynamics of the impact and on the occupant's trajectory relative to the glazing. In the case of laminated glazing, the broken glass would be likely to remain in place, whereas in the case of toughened glass, the glazing would be likely to shatter into glass projectiles. In these cases, the injury risk would depend very much on the position and motion of the occupant during the accident.

### 3.2 Risk Due to Entrapment

Glazing more resistant to intruders must not be so impenetrable that that the safety risks associated with occupant entrapment are significantly increased. In the case of an occupant trying
to exit a car through an undamaged piece of glazing, it is unlikely that there would be a significant difference between toughened or laminated glazing. Both of these types of glazing would offer the same degree of resistance without the use of specific tools. It has been shown that the force of the pendulum impact tests was not always sufficient to break toughened glazing. However, little force is required to break toughened glazing when using a specific glass-shattering tool such as a centre-punch. The question arises how often are these type of tools used. Although this type of tool is readily available in the after-sales market, it is unlikely that many cars are equipped with them for the purpose of use should entrapment arise. For cars fitted with such tools, and in situations where the occupants would be able to use them, laminated glazing would increase the risk of entrapment.

The possibility of entrapment as a result of an accident is a perceived concern to the general public. Glazing which is more resistant to intruders may also increase the time that it would take the emergency services to access an injured occupant. It is clear that the emergency services must have special tools or knowledge that would enable rapid access to the injured occupant in the event of entrapment occurring. Otherwise, entrapment is only likely to be a threat to life if there is a post-crash fire, the vehicle is submerged in water, or if the vehicle is at risk of a further collision. However, these types of scenarios occur in only about 0.1 percent of accidents (Hobbs, 1978).

In order to ascertain the frequency of entrapment, data from phases 1-3 of the Co-operative Crash Injury Study (CCIS) database, were examined. The search was conducted on accidents involving four-door saloons, hatchbacks and estates in all impact cases and considered the situation of the driver. The search highlighted 6,823 cases and these are summarised in Tables 6 and 7. It should be noted that these figures relate to current toughened glazing for side windows and breakage implies a clear escape route, or that the window was easy to remove.

From Table 6 it can be seen that in 6,637 out of 6,823 cases (97.3%) either the door or the side glazing offered an escape route adjacent to the driver. In only 186 out of 6823 cases (2.7%) would the driver be required to find an alternative escape route other than the driver's door or window.

Table 6. Frequency and level of entrapment for the driver

<table>
<thead>
<tr>
<th>DRIVING'S DOOR</th>
<th>DRIVER'S DOOR GLAZING</th>
<th>TOTAL (6,823)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Broken No.</td>
<td>%</td>
</tr>
<tr>
<td>Jammed</td>
<td>1,721</td>
<td>25.2</td>
</tr>
<tr>
<td>Not Jammed</td>
<td>397</td>
<td>5.8</td>
</tr>
</tbody>
</table>

If the driver's door is jammed and the window not broken, the next preferred exit route for the driver would probably be through the front seat passenger's door. Table 7 shows that this was not possible in less than one percent of the accidents analysed. Indeed, in only one case was all the glazing intact and all doors jammed shut. Clearly, entrapment of this type occurs very infrequently.
Table 7. Frequency of cases with door jammed and glazing not broken.

<table>
<thead>
<tr>
<th>DOOR POSITION</th>
<th>ACCIDENT CASES (Total = 6823)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DVR</td>
<td>1862.73</td>
</tr>
<tr>
<td>DVR + FSP</td>
<td>500.73</td>
</tr>
<tr>
<td>DVR + FSP + RSPs</td>
<td>10.01</td>
</tr>
</tbody>
</table>

DVR = Driver, FSP = Front Seat Passenger, RSP = Rear Seat Passenger

However, these figures relate only to toughened glazing and therefore, the scenario where the doors are jammed but all glazing is in place, may occur more frequently in the case of laminated glazing, since very few cars are currently fitted with laminated side windows. At present however, there is no data capable of supplying this information.

If all cars were fitted with laminated glazing and it could not be removed easily from the frame after an accident, then the criteria that might be used to determine entrapment would be if all doors were jammed after the accident. Table 8, below, examines this particular post-accident scenario.

Table 8. Frequency of cases with door jammed

<table>
<thead>
<tr>
<th>DOOR POSITION</th>
<th>ACCIDENT CASES (Total = 6823)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DVR</td>
<td>190727.9</td>
</tr>
<tr>
<td>DVR + FSP</td>
<td>3665.4</td>
</tr>
<tr>
<td>DVR + FSP + RSPs</td>
<td>851.2</td>
</tr>
</tbody>
</table>

DVR = Driver, FSP = Front Seat Passenger, RSP = Rear Seat Passenger

In this case, there are 1,907 out of 6,823 cases (27.9 percent) where the driver would have to find an alternative exit. However, in 1,721 out of these cases (90.2 percent) the glazing was broken and it may have been possible to escape through the window if it were easy to push it out.

Given that entrapment is a perceived concern to the public, and that laminated glazing generally remains in situ when broken, it is necessary to establish what forces are required to push-out damaged glazing. Tests were conducted to establish the difficulty in effecting an escape through laminated glazing that had been first damaged by impact. The laminated glazing was first subjected to the pendulum impact test. After the pendulum impacts at the specified sites, a rigid plate of 200mm diameter was pushed horizontally against the convex surface of the glazing. This was to simulate a person using their feet to push out the glazing. The forces required to push out the laminated glazing after initial damage by the pendulum test are shown in Table 9. The toughened glazing with plastic film laminate is also included for comparative purposes.

In the tests, the greatest push-out force that was required to remove the partially framed glazing.
This force required little effort to achieve. For comparison, the push forces with the feet of a young fit male were found to exceed 550N. In this case, the subject's position was similar to that of being in a car seat and pushing horizontally against the side glazing. This result suggests that, assuming the occupant was not too severely injured, that an exit could be created by pushing out the partially damaged laminated glazing with the feet.

### Table 9. Force required to push out glazing after the pendulum impact test

<table>
<thead>
<tr>
<th>TYPE OF GLAZING</th>
<th>FORCE (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laminated Glazing</td>
<td></td>
</tr>
<tr>
<td>Partially Framed</td>
<td>380</td>
</tr>
<tr>
<td>Fully Framed</td>
<td>260*</td>
</tr>
<tr>
<td>Toughened Glazing With Plastic Film Laminate</td>
<td>215**</td>
</tr>
</tbody>
</table>

*Fully framed glazing did not fit well in weather-seal of door, thus the true forces required may be considerably higher than reported.

**Subjected to only one impact test - pushed from the film laminate side.

Regrettably, due to the small number of samples available, the unframed laminated glazing was not included in the tests. However, unframed laminated glazing was generally distorted more than the other types of laminated glazing after the pendulum impact tests. This would probably mean that no greater force would be required to push out unframed laminated glazing compared with partially and full-framed laminated glazing. Thus, it can be seen that both broken laminated glazing and broken toughened glazing with a plastic film laminate attached could be removed by pushing with the feet, assuming the occupant was capable and aware of this procedure.

### 3.3 RISK DUE TO EJECTION

Approximately 50% of occupant ejection events occur as a result of rollover accidents and about 35% of full ejections and 55% of partial ejections take place through the side glazing (Morris et al 1993). These figures arise from vehicles fitted with toughened glazing and the fitment of laminated glazing would certainly reduce the number of both partial and full ejections. This would be of great benefit to the occupant since Morris et al (1993) quote that the risk of ejectees of severe or fatal injuries is increased between 3 and 40 times compared with if they were retained within the vehicle interior.

As shown in the previous section laminated glazing remains in situ after breaking, unlike toughened glazing, which shatters completely. Although the damaged laminated glazing can be pushed out in the case of the occupant being trapped, it is reasonable to assume that it will also prevent some occupants being ejected. The CCIS database was examined in order to investigate how many occupants in accidents involving four door cars were subjected to either partial or full ejection through the side glazing. The estimated numbers of ejected occupants per year in Great Britain for each injury severity, derived from the CCIS data are shown in Table 10.
Table 10. Estimated number of car occupants ejected through the side glazing per year in GB, by injury level

<table>
<thead>
<tr>
<th>INJURY SEVERITY</th>
<th>Number of Occupants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-Injured</td>
<td>143</td>
</tr>
<tr>
<td>Slight</td>
<td>368</td>
</tr>
<tr>
<td>Serious</td>
<td>238</td>
</tr>
<tr>
<td>Fatal</td>
<td>117</td>
</tr>
<tr>
<td>Total</td>
<td>866</td>
</tr>
</tbody>
</table>

A prospective study is recommended to investigate the reduction in occupant ejections conferred by the fitment of laminated glazing. However, it is certain that laminated glazing would reduce the number of partial and fully ejected occupants.

4. COST BENEFIT ANALYSIS

A brief cost-benefit analysis was conducted in order to compare the use of laminated glazing with toughened glazing in terms of the financial costs.

The potential financial costs associated with using laminated glazing in place of toughened glazing can be summarised as;

i) The additional cost of supplying laminated glazing instead of toughened glazing.
ii) The cost of any increased injuries/deaths as a result of occupant entrapment.

The potential social cost of any increase in occupant fatalities due to entrapment or the debilitating nature of any lacerative injuries must be considered. However, the effects of lacerative injury have been omitted from this cost benefit analysis because, although it may be conceivable that externally-damaged laminated glass may increase lacerative injury in some cases, it is also possible that lacerative injuries may be reduced because impacted laminated glazing does not produce the hazard of flying glass or exposed glass edges which may injure partially ejected occupants. However, lacerative injuries have the potential to be more severe if the occupant were to strike externally-impacted laminated glass.

Conversely, the potential savings associated with using laminated glazing in place of toughened glazing can be summarised as;

i) The reduction in costs associated with thefts from vehicles.
ii) The reduction in costs associated with injury/fatality costs by preventing partial or full ejection from the vehicle.

In addition to these advantages, modern laminated glazing has the advantages that it can reduce the levels of external noise by 5-10 dB(A) over a broad frequency range of between 2,000 and 8,000Hz. Also, this glazing is capable of preventing 95% of UVA and UVB rays entering the vehicle, and with Infrared (IR) treatment, can reduce solar energy transmission by up to 45%
Therefore, these advantages mean that the interior of the car would be quieter and more comfortable and that occupants and interior materials would be protected from solar damage. Therefore, laminated glazing has the potential to confer a higher level of comfort as well as security. In addition to this, recent advances in glass technology have resulted in the manufacture of laminated glazing which has a lower mass than traditional toughened glazing. Enhanced Protection Glass (EPG) consisting of a 0.76mm layer of Pvb ‘sandwiched’ between two 2.1mm plies of heat-strengthened glass, has a mass of 11.3kg/m, compared with 12.5kg/m for 5mm thick toughened glass (Vehicle Engineering and Design, February 2000 issue). This corresponds to an 11% weight saving over traditional toughened glazing, which may even be increased if the door frame channels are designed with this lighter glazing in mind. Thus, the fitment of EPG would also reduce fuel consumption as well as manufacturing costs, but the extent of this reduction would require further investigation.

The additional cost of fitting laminated glazing instead of toughened glazing is not precisely known. It has been estimated that if laminated glazing is fitted at the vehicle production stage, the extra cost would be between $100 and $200 per vehicle (DasGupta, 1996), which equates to approximately £150 per car. However, this cost would be dependent upon the number of vehicles in the new car fleet which are fitted with this type of glazing, since costs would be increased if only a small proportion of the fleet were fitted.

It has been shown earlier that, in the worst-case scenario of the glazing being damaged such that the glass is pushed into the vehicle towards the occupant, the laceration injuries may be more severe. Although this seems to be a disadvantage of using laminated glazing, the occupant would probably be retained within the vehicle and would not suffer any subsequent injuries that may occur as a result of partial or full ejection. Usually if an occupant is partially or fully ejected then the expected injury level and associated costs are likely to be great. Also, laminated glazing can be designed to minimise the risk of lacerative injury by adding a polycarbonate layer to the interior of the glazing.

There is no calculable cost associated with entrapment as it depends on many factors including whether the occupant is in any risk due to being trapped and whether the occupant can overcome entrapment. Since the risk of entrapment followed by a post-accident fire or being submerged in water is very low, the overall costs associated with this are assumed to be negligible.

In the interests of simplicity, we can assume that the most relevant cost, is the extra fitment cost of laminated glazing. Approximately 2 million cars are sold in Great Britain per year and if all these cars were fitted with laminated glazing, the fitment cost per vehicle is estimated to be in the region of £150. Thus, the total cost might be expected to be approximately £300M per annum.

The major cost savings due to using laminated glazing instead of toughened glazing include:

i) Reduction in injuries due to fewer occupant ejections.

ii) Reduction in theft of and from cars.

The number of occupants subjected to partial or full ejection through the side glazing in accidents involving four door cars was identified from CCIS data. Estimated national annual costs by injury severity of occupants were then obtained from the Road Accidents Great Britain: The Casualty Report (1993) and combined to create Table 11 shown below.
Table 11. Estimated costs associated with occupant ejection per year.

<table>
<thead>
<tr>
<th>Injury Severity</th>
<th>Non-Injured</th>
<th>Slight</th>
<th>Serious</th>
<th>Fatal</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Occupants</td>
<td>143</td>
<td>368</td>
<td>238</td>
<td>117</td>
<td>866</td>
</tr>
<tr>
<td>Cost per Injury Group (£M)</td>
<td>0</td>
<td>2.4</td>
<td>20.1</td>
<td>87.1</td>
<td>109.6</td>
</tr>
</tbody>
</table>

It has been mentioned that it is not possible in the context of this study to quantify the reduction in ejections. However, for the purposes of estimating the possible benefits, if the introduction of laminated glazing resulted in a 50 percent reduction in the numbers injured associated with ejection in each severity category, the total cost saving per year would be about £54.8M.

For simplicity, we might consider that the additional costs of laminated glazing solely due to fitment might be in the region of £300M. The financial benefits conferred by laminated glazing comprise an estimated £54.8M per year as a result of fewer occupant injuries and also the reduced costs as a result in fewer thefts from cars and of the cars themselves. Even if thefts from cars, and the thefts of cars where toughened glazing is the entry point, account for only 10% of the £3,000M estimated by Cambridge (1987) to be the annual cost of UK car crime, this would fully compensate the cost of fitment of laminated glazing to the entire new car fleet. Therefore, it seems likely that the large-scale fitment of laminated glazing to new cars would result in improved safety, security and comfort as well as being financially beneficial.

5. DISCUSSION

5.1 SECURITY

Webb and Laycock (1992) found that reported theft from cars was at a rate of 34 per 1000 cars in England and Wales, accounting for about 61 percent of all car crime. The study also showed that theft from cars is highly under reported and that a common method of gaining access into the vehicle in order to steal from it was by breaking the side glazing. The reason for this is that it is quickest and valuables may be visible within the vehicle interior, therefore prompting opportunist thefts. The in-car audio equipment was the most commonly stolen item, and not only is this often costly to replace, but there are additional costs involved in rectifying the damage caused to gain entry into the vehicle and removing the item free of its fixing. Only 32 percent of these thefts were planned in advance. Although laminated glazing cannot be expected to deter the most determined of thieves, it does offer considerable resistance against the opportunist thief. Laminated glazing, if it were to be introduced on a large scale, may result in deterring all but the most determined thieves and reduce the cost of car thefts accordingly.
5.1.1 Testing using the pendulum impact test, BS AU 209 Part 4: 1995 Annex A

TRL's tests to the above specification clearly showed that laminated glass was superior to toughened glass in terms of its resistance to impact. Indeed, the requirements for security glazing as stated in the Standard are such that toughened glass is unlikely to comply with the pendulum impact test.

The results of the pendulum impact test have shown that the mean peak forces were larger than those of a person wielding a copper-headed mallet but smaller than those of a person wielding a hammer. The mean pendulum impulses were found to be between about 77% to 266% higher than those due to the copper-headed mallet and hammer respectively. If a copper-headed mallet or a hammer are considered to be typical attack implements it might be appropriate to devise an impact test where the peak forces and impulses are more representative of these implements. This could be achieved by using an impactor of a more realistic size, mass and impact velocity.

The framing around the laminated glazing offered greater strength and, after testing, resulted in there being a smaller gap between the glazing and the slot in the weather-seal into which the glazing was originally located. In the case of the fully framed glazing, the fact that there was a gap between the glazing and door frame was probably due to poor fitting of the framework into the weather seal. All but one of the laminated glazing samples passed the proposed pendulum test, in not allowing a sphere of 40±2mm diameter to freely pass through any aperture in the glazing or between the glazing and door frame. However, TRL demonstrated that it would not require a large force to open an aperture to such a size after the pendulum test had been performed and that a thief may try to lever a hole in the glazing after causing impact damage.

The unframed laminated glazing required only a force of about 10N to 20N to open a hole in the glazing large enough to fail the criteria of the pendulum test. The maximum force required to create a 40mm diameter aperture in any of the laminated glazing was 150N. This force can be easily exerted and therefore it would be difficult for such glazing to pass the impact/lever test after the impact test. It may be required, therefore, to reduce the number of impacts so that there is a reasonable certainty that the interlayer is not torn and that the gap between the glazing and the door frame is sufficiently small so as not to allow insertion of the tip of the conical probe.

It was originally envisaged that the combination of the framed door and the framed glazing would be tested. However, the framing supplier was unable to produce glazing framing that would fit into the door framing in the time available for this project. From the results with the individual components of this configuration, this would appear to provide a greater degree of security than those systems tested. However, it is also likely to be the most expensive solution. The modified door with a U-shaped channel fitted with unframed laminated glazing showed similar results in the impact test to that of framed glazing into a standard door. Due to limited samples of glazing, the 'force/lever' tests were not undertaken for this combination.

It has been shown that the method by which glazing in non-opening windows is held in place affects its resistance to removal. It was found that greater force was required to cut through glazing bonding material rather than gasket material. Due to difficulty in inserting a longer blade in the aperture between the glazing and the bodywork and the difficulty in cutting the wide strip of bonding material, it is considered that the use of a handyman's blade is an adequate assessment of the ability to remove the glazing through cutting. On cutting through the gasket material, the
glazing could simply be lifted out. With the bonded glazing, the glass could not be removed after cutting since the blade could not cut right through the entire width of material. In this situation, for this particular combination of standard handyman's blade length and applied force, it is reasonable to assume that a thief would attempt to remove the glazing with force after the cutting has failed. Removal of the glazing would be from outside the vehicle, probably by levering. However, in this test the glazing was pushed from inside so as to perform a test that was simple and repeatable. In the tests conducted for this report, the force was applied near the edge of the glazing to represent the levering of the glazing edge from the surrounding framework. A hemispherical probe was placed against the glazing near the edge of the glazing/frame, after cutting with the blade, and a force of 100N was applied perpendicular to the internal surface of the glazing. The glazing remained in position and showed no signs of being loosened from the surrounding framework while gasketed glazing would have easily been removed with a force of only a few Newtons. A test using a specified knife blade applied with a specified force determined from the test results would provide a more controllable assessment than the original proposal. It must be stressed, however, that bonded and gasketed glazing were investigated on only two examples of a single vehicle model.

5.1.2 Assessment and potential improvements to the pendulum impact test

The pendulum impact test, as described in BS AU 209 Part 4 (1995) - Annex A, has been found to be a simple test which is scientifically repeatable. Therefore, it is a good method whereby different types of glazing may be compared against the requirements of a specific test method. However, the test requires refinement so that the impact test is more realistic of a typical break in. The first step to improving the Standard is to research the common tools employed by thieves to commit car crime. Once this has been established and an appropriate attack object identified, an improved test can be designed. It may be that several different impactors representing different attack objects may be necessary, since the speed, mass and geometry of the impactor used has a great effect on the damage inflicted to the glazing being tested. For example, Offermann et al (1998) showed that the failure of the glazing was highly dependent on not only the glass and interlayer structure and the strength of the glass at its juncture with the door frame, but also on the impact conditions and the impactor. They found that the manner in which the glazing fails, whether by penetration through the glass and interlayer, or by the glazing being pushed in because of failure between the glass and frame, is highly dependent on the mass and geometry of the impactor. For instance a heavy, blunt impactor is likely to cause 'push-in' failure, which may be unaffected by changes in the glass and interlayer structure and thickness. However, a pointed impactor causes localised damage and is likely to cause penetration failure and the thickness of the glass, and especially the interlayer, are very important factors in this case, whereas the door frame may be relatively unimportant.

In TRL's tests, one sample of toughened glass passed the requirements of the pendulum tests and even failed to shatter when higher than prescribed drop heights were used. This hints at a general drawback of the test, since although providing a good methodology to compare samples, the test itself is not representative of real life since Offermann et al (1998) state that toughened glass can be shattered with a very low energy, as low as 1J, impact if a pointed tool such as a centre-punch or chisel is used. Although it is impossible to take account of all the objects a thief may use in order to gain entry to a vehicle, the Standard should aim to test at, or near to, the worst case
As a simple improvement to the resistance to impact test, fitting a small rounded spike to the centre of the impactor, or using a centre-punch in each of the impact locations prior to the pendulum impact, would provide a more realistic test of the glazing surface. It is thought that this may then be more representative of the type of implement that a thief may employ in order to break into the vehicle. In this case, it is thought very likely that all toughened glass specimens would comprehensively fail the test and the higher level of security conferred by laminated glazing would be better emphasised. Furthermore, this method would allow further advancements in materials used in the laminate layer to be assessed. However, care must be taken to ensure that the safety implications of high impact resistance glass are fully addressed.

5.2 SAFETY

5.2.1 Facial laceration

As a result of the tests performed, the TLI values for the laminated glazing were found to be between 6.24 units and 7.95 units. Since the TLI index and the Corning scale measure lacerative damage, it cannot be directly compared with the Abbreviated Injury Scale (AIS) per se, although such lacerative injuries would not be more severe than AIS 2. The TLI values were found, however, to be higher than the TLI of 6 units obtained by impacting an undamaged laminated windscreen (Kay et al., 1973). This difference between the level of damage to the windscreen and side glazing before head impact is relevant. In frontal impacts, it is extremely rare for the windscreen to be impacted by an external object prior to contact with the head, except in the case of severe under-run. The side windows, however, are almost in the same vertical plane as the other bodywork of the car side. In side impacts, the intruding side usually injures the occupant, rather than the occupant striking an undeformed structure. Thus, the concern regarding laceration from side windows would relate to the head or face striking a window already broken from the outside and deformed inwards toward the occupant.

The tests showed that the level of framing of the laminated glazing was inversely proportional to the total lacerative damage. This difference may be attributed to the way in which the glazing was damaged due to the pendulum impacts. In the case of the unframed glazing, the glazing was pushed in about 150mm after only four impacts - the last impact was not undertaken as excessive damage may have been caused to the pendulum arm by the door frame. After the pendulum impacts this glazing was more bowed than either of the other types of glazing. As a result, there were longer shards of glass that were separated from the interlayer into which the headform was impacted. The effect of framing caused a lesser degree of bowing after the pendulum impacts with fewer long shards of glass being separated from the interlayer. The greatest lacerative damage occurred when the frame of the glazing was such that the glass was deformed inward to the extent that the inner layer of glass exposed sharp edges of broken glass to the headform. If partial or full occupant ejection occurs, the lacerative potential may be greater for toughened glazing since broken glass often remains in place around the perimeter the window frame. If laminated glazing were used, this would reduce the risk of the ejection event occurring. However, testing indicates that externally-damaged laminated glazing that has deformed inward towards the occupant poses a high risk of lacerative damage. Future research should attempt to
reduce the lacerative potential by adapting the design of the glazing to make the inner face of the glass less susceptible to shattering. Ways in which this could be achieved include the use of a plastic or polycarbonate layer on the inside of the inner ply of the laminated glazing. One of the major challenges in the design of future laminated glazing is how to ensure that the glazing provides not only increased security, but also reduces the risk of occupant laceration. This is important because lacerative injuries, although not often life-threatening, are often disfiguring and public concern over this type of injury must be addressed.

5.2.2 Entrapment and ejection

Any glazing type that improves security by being more resistant to impact must not do so at the expense of safety. Occupant ejection and entrapment are the two crucial aspects of safety that must be assessed. Entrapment is a post-accident condition where the occupant is trapped within the vehicle because the doors are deformed to the extent that they will not open. Cases where all doors are jammed and all the side glazing remains unbroken is very rare and occurred only once in 6,823 accidents present in the CCIS database. Data from this source revealed that the driver's door was jammed in 27.9% of accidents, with the driver's window also shattered in 90.2% of these accidents. In only 1.2% of accidents were all the doors jammed, making egress through the windows necessary. If laminated glass were used instead of toughened glass, the glazing would be expected, based on experimental results, to be damaged but to stay in situ and this has the potential to result in greater levels of occupant entrapment in this small proportion of cases.

However, this may not be the problem that it appears for three main reasons. Firstly, cases where egress is only possible through a window are very rare, accounting for only 85 of 6,823 accidents contained within the CCIS database. Secondly, if the occupant is injured to the extent that they cannot make use of an available door, then it is likely that the glazing type will be irrelevant because the emergency services will be required to extricate them from the vehicle. Thirdly, the forces required to push out laminated glazing, if damaged in a similar manner as in the pendulum impact test, can be achieved by using feet to push the glazing from the frame. If the occupant was capable of this, then egress from the vehicle may be possible by pushing out the laminated glazing in 90.2% of the CCIS cases where the driver's door was jammed shut. The glazing type may be a greater issue in side impacts, since in frontal impacts, even toughened glazing often remains intact within the driver's window.

Laminated glazing would offer the most resistance to being pushed out after being damaged as a result of a light impact. In such a case, it would be more likely that the occupant would sustain lesser injuries and would be contained within the vehicle. Entrapment is only a true concern if as result of an accident there is an additional threat to life by being trapped in the vehicle. These situations include the vehicle being submerged in water, the risk of fire, the occupant requiring immediate medical attention or if the vehicle has come to rest in a position likely to cause a further accident. For post-accident situations, where the occupant and vehicle are in no further danger, then entrapment should be of little, if any, concern.

It is reasonable to assume that, with all cars fitted with laminated glazing, there will be a reduction in occupant ejection through the side glazing due to the glazing remaining in situ after impact. At present, there are an estimated 866 occupant ejections per year, including 177
fatalities. If the fitment of laminated glazing reduced the occupant ejections by a conservative 50 percent while retaining the same injury severity distribution, annual savings of about £54.8M might be possible. This savings figure would be increased to an estimated £82.2M if the fitment of laminated glazing prevented 75% of all ejection-related injuries.

6. CONCLUSIONS

1. The pendulum impact test prescribed by BS AU 209 Part 4: 1995 is simple to undertake and provides a repeatable method of comparing the integrity of different types of glazing. However, the geometry and characteristics of the impactor may be improved to make the impact test more realistic of a break-in, since the current test does not always adequately distinguish between the resistance to breakage of toughened and laminated glazing. Fixing a small point to the end of the pendulum is suggested as a simple method in which to improve the realism of the test. However further investigation into the exact dimensions of this addition and also into the types of tool commonly used to gain illegal access to vehicles is required.

2. The way in which the glazing fails is highly dependent on the type of tool used to gain entry into the vehicle. Heavy, blunt impactors are more likely to deform but not tear the interlayer and cause failure of the glazing fails at its juncture with the frame. Conversely, pointed impactors are likely to cause localised damage to the interlayer and cause glazing failure by penetration. Ultimately, it may be necessary to prescribe two or more impact tests, each using an impactor with different characteristics depending on the attack situation being simulated.

3. The force of the pendulum impact was found to be higher than that of a person wielding a 1lb copper-headed mallet, but lower than that of a person wielding a 2lb hammer. The impulse of the pendulum impact was found to be about 237% to 266% higher than that due to a person wielding the mallet and about 77% to 80% higher than that due to a person wielding the hammer. As such, the impactor currently specified by BS AU 209 Part 4: 1995 is suitable to simulate entry into a vehicle using a typical hand-held hammer.

4. All but one of the laminated glazing tested passed the resistance to impact test criteria. Toughened glazing with a plastic security film laminate failed to pass the criteria of the impact test. An aperture of 75mm diameter was opened in the film laminate glazing with as few as two of the required five impacts at the specified sites. This type of glazing, however, does offer a higher level of protection against entry than toughened glazing, of which only one sample satisfied the resistance to impact test.

5. The resistance to removal test as proposed in BS AU 209 Draft Part 4 (1987) - Appendix B was excluded from the published revision of the standard because of its subjectivity. It was not easy to determine how the proposed "simple tools" would be used to gain entry and the test specification was not scientifically repeatable and could not form part of an objective performance standard. Any future test method to assess resistance to removal must be both realistic and repeatable so that the results may be scientifically compared.
6. It is important that any Standard test is repeatable and that the results from different glazing types can be scientifically compared. One of the criticisms that could be aimed at the resistance to impact test contained within BS AU 209 Part 4: 1995 is that it only has a pass/fail requirement and that relative differences between glazing types cannot be quantified. However, TRL devised a force/lever test subsequent to the impact test which could be adapted to ascertain what force was required to open an aperture of 40mm in either a tear in the interlayer or between the glazing and the door frame. This procedure is described in more detail in section 2.2.3. However, the success of the force/lever test was variable because of the extent of the damage produced by the impact test.

7. Due to the small number of samples of glazing available further work would be required to establish the number of impacts to the glazing, the geometry of the impactor and the peak and rate of applied force to be used in the impact/force test.

8. Any glazing type that improves security by being more resistant to impact must not do so at the expense of safety. Occupant ejection, entrapment and lacerative injury potential are the crucial aspects of safety that must be assessed.

9. TRL's tests have shown that externally damaged laminated glazing impacted at 24.1km/h may produce Triplex Laceration Index (TLI) scores of between 6.24 and 7.95, compared with a TLI of 6 for undamaged laminated glass. However, toughened glass may produce severe lacerations and previous impact tests at 30km/h have resulted in TLI values between 8.0 and 9.0. Consideration could be given to types of laminated glazing designed to minimise the risk of laceration, since there are concerns over the way that externally-damaged laminated glazing is held in situ and the broken sharp edges of the glazing are pushed inwards towards the occupant. A polycarbonate layer on the inner face of the glass would protect the occupant from facial laceration by preventing the sharp edges being exposed to the occupant. It is recommended that such a step be strongly considered in order to alleviate public concern over potentially disfiguring facial injuries.

10. Laminated glazing is more resistant to impact than toughened glass and therefore has the potential to increase the risk of occupant entrapment in the post-accident situation. However, this may not be the problem that it appears for three main reasons. Firstly, cases where egress is only possible through a window are very rare, accounting for only 85 of 6,823 accidents contained within the CCIS database. Secondly, if the occupant is injured to the extent that they cannot make use of an available door, then it is likely that the glazing type will be irrelevant because the emergency services will be required to extricate them from the vehicle. Thirdly, the forces required to push out damaged laminated glazing can be easily achieved by using feet to push the glazing from the frame.

11. Since laminated glazing is designed to remain in situ after impact, the incidence of partial and total occupant ejection may be significantly reduced. This is important because studies have shown that ejected occupants have a risk of being severely or fatally injured of up to 40 times that of occupants who are not ejected.

12. Only about a third of thefts from cars are planned in advance by the thief. The increased impact resistance of laminated glass over toughened glass in side windows would increase the entry time from 2 seconds to 20-30 seconds and is likely to deter the vast majority of
opportunist thieves. Future advances in the interlayer material used in laminated glass have the potential to increase this entry time to several minutes. However, laminated glazing with this performance is still in development and is likely to be considerably more expensive than existing laminated glazing.

13. The additional costs associated with the fitting of laminated glazing instead of toughened glazing may be easily balanced by the cost savings due to the reduction of occupant ejections and reduced thefts of and from cars. Approximate figures suggest that the cost of fitment of laminated glazing would be about £300M or £150 per vehicle. Even if the benefits of laminated glazing saved only 10% of the annual car crime costs in the UK, this would fully compensate for the fitment costs.

14. Laminated glazing also has the advantages that it can reduce the levels of external noise by 5-10 dB(A) over a broad frequency range of between 2,000 and 8,000Hz. Furthermore, this glazing is capable of preventing 95% of UVA and UVB rays entering the vehicle, and with Infrared (IR) treatment, can reduce solar energy transmission by up to 45%, therefore improving the efficiency of air-conditioning units. Therefore, these benefits mean that the vehicle interior would be quieter and more comfortable and that the occupants and interior materials would be better protected from solar damage. Overall, it seems likely that the fitment of laminated glazing throughout the new car fleet would improve security, safety, comfort, and also be financially beneficial.
7. RECOMMENDATIONS FOR THE SECURITY AND SAFETY ASPECTS OF SIDE GLAZING

7.1 RECOMMENDATIONS FOR SECURITY

There are many tools and methods that a potential thief may use in order to gain illegal access to a vehicle. Currently, the quickest and most often used method, is by smashing the toughened side glazing. More effective locks and alarms are of little practical use if the integrity of automobile glazing is not improved. Fitting laminated glazing instead of toughened glazing increases the entry time to a vehicle because the interlayer holds the glass in place, preventing the window from shattering. This report has tested different glazing types and has assessed the Standard for security glazing. This has led to the development of the following recommendations for improving automobile glazing security.

7.1.1 Impact test

Laminated glazing of 2.1/0.76/2.1mm specification was first developed some years ago. This type of glazing is generally accepted to provide an adequate level of security against forced entry through breakage and is greatly superior to traditional toughened glazing. This has been confirmed by the tests carried out as prescribed by Annex B of BS AU 209 Part 4 (1995).

Although all but one laminated glass sample passed the impact test, in many cases the glazing was severely damaged and in most cases had a torn interlayer. It may be realistic to assume that a thief that has persisted this far would force an entry through the weakened glazing.

It is recommended that the impact test should be performance based, simple to undertake, and be as realistic as possible of the methods of breaking in through glazing. Such a test is outlined below, although further work would be needed to determine severity of the impact.

i) The apparatus used in the impact test should be as prescribed in BS AU 209 Part 4 (1995), although it is suggested that a small nipple may be fixed to the end of the impactor to create a glass impact more representative of a more pointed implement. If this step is undertaken, the impact conditions may require alteration due to the increased severity of the impact with the glazing surface.

ii) Provided that the glazing has not failed the impact test, it should then be subjected to a force/lever test. In this test, a conical probe shall be used against the glass and/or between the glazing and weather-seal. The probe will be sited at a point where there is the largest tear in the interlayer (where no tear exists the probe will be placed at the point where least glass remains attached to the interlayer). A force of [100±10]N shall then be applied for [10±1]sec. If this force creates opens a hole of 40±2mm diameter, then the sample fails the test criteria.
iii) If any piece of glazing fails to comply with i) and ii), two further separate but identical pieces shall be tested and both shall comply with i) and ii).

7.1.2 Resistance to removal

Tests have been conducted using the range of tools described in the 1987 draft of the Standard. However, because the conditions of the test are not specified, the results are highly subjective. For this reason, this section of the Standard was removed from the later published version.

The tools stated in the draft Standard, such as a centre punch, can be used in many different ways and it is important that the test is repeatable. It would probably be simpler and more repeatable to use the apparatus as proposed in BS AU 209 Part 4 (1995), except that a nipple is to be attached to the end of the pendulum at the point where it impacts the glazing. A nipple of the appropriate dimensions attached to the pendulum could have an effect similar to that of a centre-punch when the pendulum is swung into the glazing. Further work would be necessary to determine appropriate dimensions for this addition.

Resistance to removal using a large screwdriver has been considered in (ii) above (see 7.1).

In the case of a short-bladed handyman's knife the most likely method of attack would be to attempt to cut through the gasket or rubber bonding material holding the glazing in place. A proposed test is shown in Appendix 3. The values given, however, have been established after only a limited number of tests using a simple tool.

Tests were conducted on only a limited number of pieces of glazing for both the impact and resistance to removal tests. It will be necessary to conduct further tests, particularly on other types of vehicle regarding the resistance to removal of glazing, in order to gain confidence in these findings. To obtain accurate values of the force required to cut through weather-seal material it would probably be necessary to construct a special tool.

7.2 RECOMMENDATIONS FOR SAFETY

Overall, the safety benefits of laminated glazing outweigh any safety concerns over entrapment and lacerative injury potential. However, it is important that these issues are addressed and investigated in order to maximise the overall safety of future glazing.

7.2.1 Emergency services access

The glazing must be clearly labelled so that the emergency services can quickly ascertain the type of glazing in the vehicle. Furthermore, the glazing must be easily removable by the emergency services so that the access time to reach an injured or trapped occupant is not greater than that of conventional toughened glazing. This is a major challenge since glazing more resistant to intruder attack may also pose an obstacle to the emergency services. However, in many cases, this may not be issue since the emergency services may cut the vehicle frame in
order to gain access to the occupant. In those cases that remain, it is important that the emergency services have the necessary knowledge and tools to remove the glazing quickly. TRL research has shown that damaged laminated glazing may be relatively easy to remove from the frame, especially if the interlayer is already punctured, provided an appropriate 'lever tool' is used.

7.2.2 Facial laceration

Although the lacerative potential of laminated glazing may not be significantly greater than that of toughened glazing, it is important to take steps to reduce the lacerative injury potential, especially as facial lacerations is a topic likely to create public concern. It is recommended that some precautionary measure is taken to reduce the likelihood of jagged edges of glass being presented towards the occupant in the event of the glazing being externally damaged. This may be achieved by means of a protective film applied to the inner layer of the glazing. However, further research into the practicality of such a step is required.

7.3 RECOMMENDATIONS FOR FURTHER RESEARCH

Further research is necessary in order to ensure the security and safety of laminated glazing and advanced laminated glazing. An ongoing study assessing and monitoring the performance of laminated glazing compared with traditional glazing is desirable and would provide reliable evidence as to the effect on both safety and security of the widespread introduction of laminated glazing into the new car fleet.

In terms of the specific topics of security and safety, the following areas of further research have been identified.

7.3.1 Security

The tools and methods used by thieves, especially the opportunists, require investigation such that a 'worst case' tool may be confidently identified. A reassessment of the resistance to impact test in BS AU 209 is required to ensure that the test is representative of a real life attack on the glazing.

7.3.2 Safety

As detailed in section 7.2, entrapment and facial laceration are the major safety issues that must be addressed. Testing should confirm that emergency access by the removal of the laminated glazing is possible using specialized tools within an acceptable time limit which is not significantly different from that likely with traditional glazing. Additionally, laceration tests comparing the lacerative potential of externally-damaged laminated glazing with impacted toughened glazing should be considered together with methods in which the lacerative injuries
may be prevented by reducing the lacerative potential of the damaged inner face of the glazing.

8. DEFINITION OF TERMS

AIS = Abbreviated Injury Scale. This is a consensus-derived, anatomically based system that classifies the severity of individual injuries by body region on a six-point scale ranging from 1 (minor) to 6 (currently un treatable).

CCIS = Co-operative Crash Injury Study. A UK study which collects detailed accident and injury data from accidents with the following criteria:

The vehicle involved was a car, or a car derivative.

- The vehicle was less than 7 years old on the day of the accident.
- The vehicle was sufficiently damaged for it to have been removed (“towed away”) from the accident scene by a recovery agent.
- The vehicle contained at least one injured occupant, according to the police record.

All such accidents with a fatally or seriously injured occupant in a vehicle which meets the criteria are studied. A random sample of accidents with slightly injured occupants make up the rest of the sample.
9. REFERENCES


Hobbs, C.A. The effectiveness of seat belts in reducing injuries to car occupants. *TRRL Laboratory Report 811.* Crowthorne: Transport and Road Research Laboratory.


APPENDIX 1: BS AU 209 VEHICLE SECURITY PART 4 (1995) - SPECIFICATION FOR SECURITY GLAZING OF PASSENGER CARS AND CAR DERIVED VEHICLES
1. **SCOPE**

This Part of BS AU 209 specifies minimum requirements for the performance of security glazing and its installation in order to prevent or deter unauthorised entry into or use of passenger cars and car derived vehicles.

[This part of BS AU 209 does not apply to windows fitted in soft top convertible vehicles.]

Note: The titles of the publications referred to in this part are listed on the inside of the back cover.

2. **DEFINITIONS**

2.1 "Security Glazing" means approved safety glazing material or glass-plastic glazing material installed in a vehicle in such a manner as to prevent or deter unauthorised entry into that vehicle.

2.2 "Safety Glazing Material" means a product consisting of organic and/or inorganic materials so constructed or treated to reduce in comparison with annealed sheet, plate or float glass, the likelihood of injury to persons as a result of contact with these safety glazing materials when used in a vehicle, whether they be broken or unbroken and for which special requirement regarding visibility, strength and abrasion resistance are laid down.

2.3 "Glass-Plastics Glazing Material" means a product consisting of any glazing material which may comprise one or more layers of glass and one or more layers of plastics in which a plastics surface of the product faces inwards towards the passenger compartment when installed in the vehicle.

3. **REQUIREMENTS FOR SECURITY GLAZING**

3.1 General.

Security glazing shall comply with the requirements of 3.2, 3.3 and 3.4, as applicable, to ensure:

(a) Compliance with established safety requirements for vehicle glazing.

(b) Enhanced resistance to penetration when subject to attack from outside the vehicle.

3.2 For use as a front windscreen.

The glazing shall comply with one of the following annexes to ECE Regulation 43:

Annex 6 - Ordinary laminated glass windscreens

Annex 8 - Treated laminated glass windscreens
Annex 9 - Plastic-coated laminated glass windscreens

Annex 10 - Glass-plastic windscreens

3.3 For use in locations other than in a front windscreen where driving visibility is required. The glazing shall either:

(a) comply with 3.2 except that the provisions of ECE Regulation 43 annex 3, paragraph 9.2 and 9.3 shall not apply, or

(b) comply with category A of BS AU 182 provided the glazing is not used wholly or partly on either side of the driver's seat.

3.4 For use in locations where driving visibility is not required. The glazing shall either:

(a) comply with 3.2 except that the provisions of ECE Regulation 43 annex 3 paragraph 9.1, 9.2 and 9.3 shall not apply, or

(b) comply with the performance requirements of category D of BS AU 182.

4. INSTALLATION REQUIREMENTS

4.1 Resistance to impact.

4.1.1 Security glazing giving access to the passenger compartment shall be installed in such a way that it complies with either 4.1.2 or 4.1.3.

4.1.2 After testing in accordance with Appendix A:

(a) There shall be no separation between the glazing and the body aperture large enough to permit the free passage of a sphere 40 ± 2 mm in diameter.

(b) It shall not be possible to pass a sphere 40 ± 2 mm in diameter freely through any tear or split which develops within the glazing material.

4.1.3 If any piece of glazing fails to comply with 4.1.2, two further separate but identical pieces shall be tested in accordance with Appendix A and both shall comply with 4.1.2.

4.2 Resistance to removal

Security glazing shall be installed in such a way that when tested in accordance with Appendix B it shall not be possible to remove any glazing panel giving access to the passenger compartment within four minutes without distorting the frame or surrounding bodywork.
APPENDIX A: TESTS FOR RETENTION OF SECURITY GLAZING - IMPACT TEST

A.1 Apparatus

The apparatus shall be as shown in figure 1 and shall consist of the following:

(a) A pendulum consisting of a mild steel 75 mm diameter cylindrical head with hemispherical ends of 75 mm diameter steel rod. The total mass of the pendulum shall be 9.5 ± 0.2 kg.

(b) A means of adjusting the apparatus to permit the testing of a range of doors/vehicles.

(c) 1. Glazed doors and other closures

Some form of adjustable rigid support to permit testing of a range of detached vehicle doors and other closures. Provisions shall be made to interpose a rubber strip of thickness 25 mm and 50 IRD between the door/closure and the support during testing to represent the door/closure seal, adjacent to the glazed area (see figure 1).

2. Other glazing

An adjustable rigid fixture to enable the glazing to be mounted either by its in-vehicle rubber seal or by a strip to simulate such a seal.

Note As an alternative to 1 and 2 above, the testing may be conducted on a whole vehicle.

A.2 Test conditions

Tests shall be carried out in the following conditions:

Temperature : 20 ± 5°C

Pressure : 960 ± 100 mbar

Relative humidity : 60 ± 20%

A.3 Procedure

A.3.1 Carry out the test on each piece of suitably sized external glazing in the vehicle (see A.3.3), except that where the left hand side and the right hand side of the vehicle are symmetrically glazed it is only necessary to test one side.

A.3.2 Position the pendulum in such a way that at the point of impact the hammer head is normal to the surface of the glazing.

Subject each piece of glazing to five impacts from a vertical drop height of 700 mm ± 10 mm at each point of a "domino 5" array the outer points of which form a square of side 71 mm ± 5 mm.
and which has one diagonal in the horizontal plane. Use the sequence and pattern shown in figure 2(c).

Position the centre of the array as follows:

(a) for symmetrical glazing, 150 ± 10 mm from the top of the daylight opening on the vertical plane of symmetry, as shown in figure 2(a);

(b) for asymmetrical glazing, within 10 mm of the mid-point of the minimum radius of curvature of a line drawn 150 mm from and parallel to the top and sloping edges of the daylight opening, as shown in figure 2(b).

A.3.3 For small glazed areas, such as sixth lights where the dimensions are too small to accommodate the "domino 5" impact pattern a single impact shall be used at any point which is further that 100 mm from the daylight opening.

If the glazing area is so small that no such point exists, the requirements of 4.1 shall not apply.

TESTS FOR RETENTION OF SECURITY GLAZING
(subsequently removed from published 1995 version of Standard)
APPENDIX B: TESTS FOR RETENTION OF SECURITY GLAZING

Resistance to removal using simple tools.

Attempt to remove the glazing from its aperture using any of the following tools:

(a) A pointed metallic implement, such as a spring loaded centre punch.
(b) A general purpose short bladed handyman's knife.
(c) A large screwdriver.

Publications referred to

ECE Regulation 43, at the original (00) level but as amended by supplements 1 to 3 (Uniform provisions concerning the approval of safety glazing and glazing materials).

4 INSTALLATION REQUIREMENTS

4.2 Resistance to removal

4.2.1 Security glazing giving access to the passenger compartment shall be installed in such a way that it complies with either 4.2.2 or 4.2.3.

4.2.2 After testing in accordance with Appendix B:

(a) There shall be no separation between glazing and the body aperture large enough to permit the free passage of a sphere [40±2]mm in diameter.

4.2.3 If any piece of glazing fails to comply with 4.2.2, [two] further separate, but identical, pieces of glazing shall be tested in accordance with Appendix B and both shall comply with 4.2.2.

APPENDIX B: TESTS FOR RETENTION OF SECURITY GLAZING

Resistance to removal using a general purpose short bladed handyman's knife.

B.1 Procedure

B.1.1 Any trim fitted on or into the weather-seal which is not part of the glazing installation shall be removed prior to testing.

B.1.2 On separate pieces of installed glazing the knife is to be applied to the weather-seal in such a manner as to expose the;

i) Edge of the glazing.
ii) Vehicle bodywork.

B.1.3 The knife is to be applied once only to the weather-seal and drawn along the edge of either the glazing or vehicle bodywork with a force of [700±10]N.

B.1.4 A rigid probe with hemispherical contact surface of [40±2]mm diameter shall be applied normally to the inner surface of the glazing, at a point [25±2]mm from the glazing/weather-seal interface, and with a force of [100±10]N. The force shall be applied for [10±1]sec.

B.1.5 If the glazing satisfies the installation requirements as described in Section 4.2.2 the glazing shall be subjected to a maximum of [two] further tests.
APPENDIX 4: DIMENSIONS OF THE CONICAL PROBE USED IN THE FORCE/LEVER TEST

Radius = 5mm

Dimensions of the conical probe used in force/lever tests