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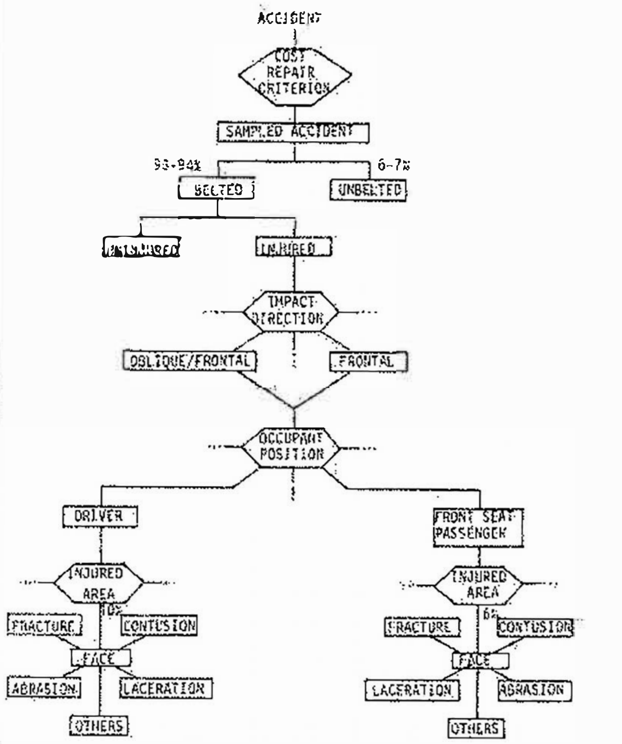
Appendix 1



Flow chart, accident sample

The Child in the Volvo Car

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Abstract

The objective of this report is to describe Volvo's development work in the field of child safety. Experience from car accidents involving children is used to describe different modes of travel for children of different age groups, the effectiveness of different child restraint systems and problems of misuse.

The problems of differences in the requirements of child safety legislation are discussed.

This experience combined with experience gained from laboratory tests constitutes the basis for development work on child safety systems in Volvo cars.

Volvo's new child safety program covers all age groups of children and needs for different ways of travel.

Volvo Safety Design Philosophy

To Volvo, safety has always meant safe transportation in a real traffic environment. Volvo Safety Design Philosophy can be illustrated by a circle as in Figure 1.

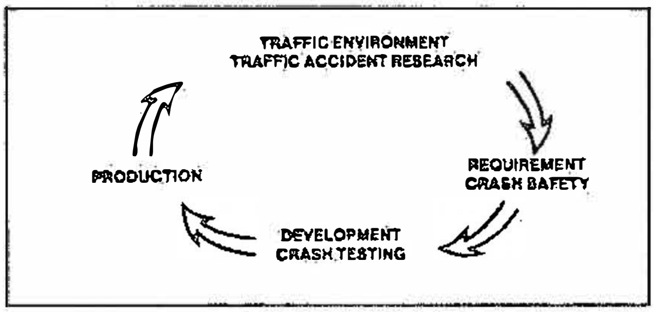


Figure 1. Volvo safety design philosophy

For many years the Volvo Traffic Accident Research Team has been extensively engaged in investigating accidents and increasing its know-how about the crashworthiness properties of complete vehicles and their various design systems, and about the various occupant injury mechanisms. This knowledge is used both for short-term and long-term feedback in the development of future vehicles.

This feedback is one important source of information for establishing the safety property requirements of a car. These requirements then provide the basis for design and development work.

Traffic Accident Experience

Experience gained from the Volvo accident material described below gives us knowledge of the way children travel in cars and injury risks for different modes of travel.

Background Data

Each year, Volvo compiles information on about 2,000 of the most serious road accidents in Sweden involving Volvo cars. The accident material is based on a repair cost criterion where all cars of a repair cost of 15,000 SEK or more are selected. In addition, in-depth studies are made of between 150 and 200 serious road accidents, in which a Volvo car was involved as well as a number of special studies.

The accident study material for the years 1976-1986 covers approx. 1000 serious road accidents in which at least one child was an occupant of the car. The material involves Volvo cars of the 140/160, 240/260, 340/360 and 740/760 models.

Mode of Travel

There were a total of 1601 children involved in the accident material. In the case of 1463 children, it is known whether or not they were travelling restrained. Only these 1463 children are covered in the following analysis.

Figure 2 below shows how children split into different age groups have been travelling during 1976-1986.

Comments. Of the childen in the age group 0-11 months, 6 travelled in an infant seat and 4 in a child seat. All seats facing rearwards.

28 of the children between 0-11 months travelled in a carrycot. The reason for this is that up to 1984 it was recommended in Sweden that infants should travel in a carrycot. In 1984, however, infant seats were introduced in Sweden and today—1987—approx. 90% of the infants travel in infant seats.

Since only rear facing childseats are recommended in Sweden all except two seats in the accident material were facing rearwards.

In figure 3 the percentage of children in different age groups using some type of safety equipment is shown. In this report safety equipment is recognized as infant seats, child seats, booster cushions and seat belts.

As we can see from figure 3, restraint use is highest amongst children from 0-1 years (53%) and for children from 1-3 years (46%).

MODE OF TRAVEL	AGE 0-11 months	1-3 years	4-6 years	7-10 years	11-14 years	TOTAL
RH front seat-belted		2	5	14	15	136
RH front seat-unbelted			1		6	7
Outboard rear seat-belted		7	34	46	69	156
Outboard rear seat-unbelted		41	108	170	213	532
Centre rear seat-belted		4	8	13	5	30
Centre rear seat-unbelted		24	42	56	37	159
Child seat/Infant seat	10	82	5			97
Booster cushion		22	51	36		109
Carrycot	28	6				34
Luggage compartment-unrestrained	2	4	9	8	4	27
Other modes*)-unrestrained	7	64	53	32	20	176
TOTAL	47	256	316	375	469	1463

*) Other modes of travel include lying or standing on the rear seat, sitting on the lap, sitting between occupants

Figure 2. Mode of travel for different age groups during 1976-86. (Volvo accident material)

Children between 4-10 years have the lowest restraint use (31%) while restraint use for the older children is 40%.

However, the restraint use for children in all age groups has increased rapidly from 1981 and onwards, as shown in figure 4.

As we can see from figure 4, the percentage of restrained children increased from 22% in 1976 to 72% in 1986.

The group of children that accounts for the growing restraint use mainly consists of children using booster cushions and seat belts. This primarily means children between 4-10 years, but to some extent also includes children between 1-3 years.

The increased restraint use amongst children from early 1980 can be explained by many factors. During the beginning of 1980s many campaigns were carried out in order to provide knowledge of the importance of using child safety equipment when travelling in cars. Some years later intensive campaigns dealing with the use of seat belt in the rear seat started.

In 1984 some county councils in Sweden started loaner programs of infant seats directed towards people with newborn babies. These loaner programs, which today cover all of Sweden, have meant that approx. 90% of all infants travel in an infant seat today. The infant seats have to a great extent replaced the carrycots as a way of travel for infants. In 1986 a law making rear seat belt use also compulsory came into force in Sweden. Though the law excluded children under the age of 15, it has probably had an effect on increasing public awareness of the need of being restrained when travelling in cars.

Injuries to Children

Injury frequency. In this section the accident material described above is used to analyse the injury risk for restrained and unrestrained children. The injury risks for restrained and unrestrained children are compared. Furthermore, calculations of restraint effectiveness are made.

As mentioned earlier, restrained children are those who use a two/three-point seatbelt, a booster cushion or a rearward facing child seat. Unrestrained children are those who travel in another way, except for children travelling in a carrycot. These children (carrycot) are excluded from the comparisons in this section.

The restraint effectiveness (e) is defined as the injury rate reduction attributable to restraint use, given as a percentage of the injury rate without restraint:

$$e = \frac{\text{injury rate, unrestrained} - \text{injury rate restrained}}{\text{injury rate, unrestrained}} \times 100$$

We will first compare the injury rate for all restrained and all unrestrained children. The injury rates are given for three levels of AIS. Totally there are 528 restrained and 901 unrestrained children between 0 and 14 years of age.

We can see from figure 5 that there is a restraint effectiveness at all AIS-levels. A restraint effectiveness of 50% can be calculated for injuries of a severity level AIS 2-6.

We then divide the restraint group into three subgroups. These subgroups are seat belt, booster cushion and childseat according to the previous definition.

From figure 6 we can see that the injury rate for children using rearward facing child seats is extremely low compared to other modes of travel. For children using child seats and for children using booster cushions there are no injuries more severe than AIS 3.

Injuries more severe than AIS 1 for children using child seat and booster cushions are described in the appendix.

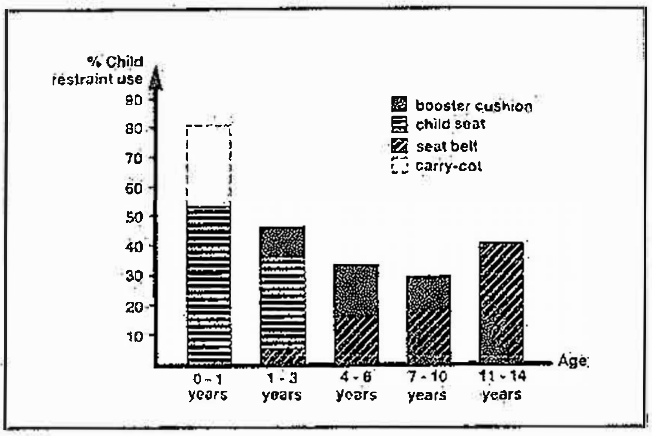


Figure 3. Percentage of children in different age groups using some type of safety equipment 1976-1986 (Volvo accident material)

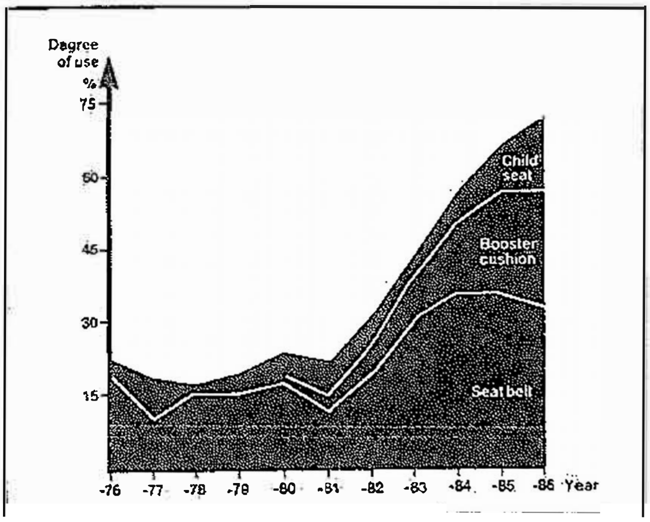


Figure 4. Percentages of children using restraints from 1976 to 1986 (Volvo accident material)

Restraint	Injury rate (%) AIS 1 %	AIS 2-3 %	AIS 4-6 %
Yes	25.9	4.4	0.6
No	30.9	8.3	2.0
Restraint effectiveness	16%	47%	60%

Figure 5. Injury rate and restraint effectiveness at three AIS-levels. Restrained and unrestrained children in the age group 0-14 years

When estimating the effectiveness of the different types of restraints, it is important that each restrained population (e.g. child seat user) does not differ too much from the unrestrained population in variables than can influence the injury rates.

There is a difference in age distribution between the groups of children presented.

To reduce the risk of drawing faulty conclusions we compare the effectiveness for seatbelt and for booster cushion only for children in the ages between 3 and 10 years and the effectiveness of rearward-facing child-seat in the age group 1 to 4 years.

The injury rates for all children (0-14 years)(figure 5) and children in the age group 3 to 10 years (figure 7) do not differ much.

From the figures in table 7 we can calculate the effectiveness in reducing AIS 2-6 injuries for seat belts to 58% and for booster cushion to 63%.

If we compare children in the age group 1 to 4 years depending on whether they have travelled in a child seat or travelled unrestrained we can calculate a very high effectiveness for the child seat in reducing minor as well as severe injuries. The effectiveness in reducing AIS 2-6 injuries is about 90%.

Among the children who used a child seat there is only one injury more severe than minor (see case 1 in appendix).

Types of injury. In figure 9 the numbers of maximum AIS 2-6 injuries for each body region are presented

Mode of travel	Injury rate (%) AIS 1 %	AIS 2-3 %	AIS 4-6 %	Total No.
Seat belt	29.6	5.3	1.2	322
Boosters	29.4	3.7	-	109
Child seat	9.3	1.0	-	97
Unrestrained	30.9	8.3	2.0	901

Figure 6. Injury rate for three types of restraints for children age group 0 to 14 years. Three AIS-levels

Mode of travel	Injury rate (%) AIS 1 %	AIS 2-3 %	AIS 4-6 %	Total No.
Seat belt	31.3	3.5	0.9	115
Boosters	35.1	3.9	-	103
Unrestrained	30.0	8.6	1.9	536

Figure 7. Injury rates for unrestrained children and children using seat belts or booster cushions in the age group 3 to 10 years. Three AIS-levels.

for different types of restrained children and for unrestrained children.

The most common type of injury of this severity (AIS 2-6) for each group is the head injury.

Of the 97 children travelling in a rearward facing child seat, there was only one injury more severe than minor, an AIS 2 injury to the head which is described in the appendix (case 1).

The AIS 2-6 injuries sustained by children using a booster cushion are described in the appendix (cases 2-5).

For children in child seats and children using booster cushions none sustained neck or abdominal injuries of level AIS 2-6. For belted children one neck injury case was reported. This case was a severe sideswipe accident with a heavy truck. The belted driver was killed. The 12-year old belted girl in the right rear seat sustained a compression fracture on one of the cervical vertebraes (AIS 2) and a minor bruise on the abdomen.

From these injury figures we can see that the risk of severe neck and abdominal injuries caused by belt use is very low.

Misuse

Misuse can be defined as partial misuse or gross misuse. Partial misuse means, for example, child not properly restrained, wrong size or age of child, restraint too old. Gross misuse means for example incorrect mounting or no mounting of child restraint.

Some surveys(1)(2) have shown that a great percentage of child safety equipment is being misused. However, the consequences of misuse from the injury point of view are relatively unknown and depend on the type of system being used.

Mode of travel	Injury rate (%) AIS 1 %	AIS 2-3 %	AIS 4-6 %	Total No.
Child seat	7.2	1.0	-	97
Unrestrained	26.[illegible]	10.6	1.5	198

Figure 8. Injury rates for children, 1 to 4 years of age, using a child seat or being restrained. Three AIS-levels

Child seats. According to accident data from the USA, a correctly used safety seat reduces the fatality risk by 71% while a partially misused seat reduces fatality risk by 44%(1).

To obtain information on misuse in the Volvo accident material some questions are put concerning mounting of the seat and restraint of the child.

In short this material shows that most of the child seats were mounted correctly. In none of these cases was it indicated that the seat came loose from its attachments. Only in 2 cases was the child not properly restrained in the seat.

This indicates that the misuse frequency of rearward facing child seats is low. This is also confirmed by the high injury-reducing effectiveness (90% for AIS 2-6 injuries).

Booster cushions. In the 109 cases with booster cushions, 105 children used the booster cushion together with a lap-shoulder belt, 4 children together with a lap belt. In some cases children used a booster cushion without being restrained in a seat belt. These children are considered as unrestrained in this report.

From the accident material it has not been possible to draw any reliable conclusions about the mounting of the booster cushions.

The best method of measuring the misuse of booster cushions is probably to make on-the-road inspections of the mounting of the boosters. Such inspections have been made in Sweden and these indicate that approximately 40% of all booster cushions are misused in some way. This type of misuse is mainly partial misuse, where the safety belt is not properly attached to the seat belt guide on the cushion (2).

Although the partial misuse of booster cushions is relatively high, there is a clear effectiveness (68%) in reducing more severe injuries (AIS 2-6).

However, more information is needed about the extent to which the misuse influences the injury outcome.

Mode of travel Body region	Seatbelt No.	%	Cushion No.	%	Childseat No.	%	Unrestrained No.	%
Head, face	15	4.7	4	3.7	1	1.0	70	7.8
Neck	1	0.9	-		-		4	0.4
Neck frontal	-		-		-		1	0.1
Chest	1	0.3	1	0.9	-		9	1.0
Abdomen	-		-		-		9	1.0
Pelvis	-		-		-		3	0.3
Vertebrae	1	0.3	-		-		1	0.1
Upper extr.	2	0.6	1	0.9	-		20	2.2
Lower extr.	2	0.6	1	0.9	-		17	1.9
N =	322		109		97		901	

Figure 9. Injury rate (AIS 2-6) body region vs type of restraint and unrestrained children 0-14 years of age

Test Experience

Each year, Volvo performs about 1000 tests in the Crash Safety Centre. Out of these tests about 80 are fullscale tests, 400 are crash simulations on a Hyge sled and 500 are component tests. Both frontal, rear end, oblique, offset and lateral collisions are tested and simulated. When the development of a new part or an accessory is discussed, relevant crash tests in different cars are planned. It is mostly a question of crash simulations but as far as possible tests in ordinary fullscale collisions are made. For instance, when the new child safety programme was under development almost 300 tests were carried out in the different Volvo cars to make sure that the child seats would behave in a proper way according to our own requirements.

Test Methods

Almost every country in the world has its own national requirements concerning child safety. This creates problems for car manufacturers and others when developing and/or manufacturing child safety equipment intended for different countries. One example of this is that some countries do not permit the transport of children under a certain age in the front seat, even if they are properly secured in a child seat. This means that it is difficult to manufacture a rearward facing child seat as those seats are normally installed in the front seat, leaning against the dashboard.

In North America another problem arises with the rearward facing seat. When certifying a child seat according to the federal regulations, it is only permitted to use a standard bench and a safety belt. It is currently not permitted to use something to lean a child seat against, for instance a dashboard or a front passenger seat. Therefore it is not possible to get approval for a rearward facing toddler seat.

The Swedish authorities, however, encourage both producers and users of child safety equipment to transport children up to approximately 4 years in rearward facing devices.

A European regulation, ECE 44(4) has been adopted by almost all the countries in Europe. Manufacturers of child restraints may choose whether they want to apply for the ECE 44 approval or the national approval in the relevant countries.

What ECE 44 is to Europe, FMVSS 213(5) is to the USA. An overall comparison between the two requirements is made in figure 10. Some expressions have been used in that comparison which may be described as follows:

Classes

- the integrated class, in which the belts and the seat are completely integrated with the child restraint

- the non-integrated class, in which the adult belt is used to restrain the child

Categories

- the universal category, in which the device is connected to the lower seat belt anchorages
- the semi-universal category, in which an extra anchor-point is used
- the specific vehicle category, in which any type of attachment to the car can be used.

It should be noted that FMVSS 213 requires a set of American p572c dummies, 6 months and 3 years old. The 6 month old dummy is uninstrumented while the 3 year old dummy has accelerometers in the head and in the chest.

ECE 44 requires another set of dummies called the TNO-dummies, 9 months, 3, 6 and 10 years old. They are all instrumented with an accelerometer in the chest.

Our experience is that there is a big difference between the two sets of dummies. The 3 year old TNO dummy is, for instance, more sensitive to submarining than is the 3 year old p572c dummy. The 10 year old TNO dummy moves in an unrealistic way. The chest seems to be very stiff which together with a weak 'lumbar spine' means that the dummy has a tendency to slip out of the shoulder belt very easily, i.e. jackknifing. This problem has also been mentioned in other reports, for instance in (3).

Even though we are convinced that a rearward facing child seat offers a better overall protection than does a forward facing one, we have designed the combined child seat to be used in both ways. The reasons for this are:

- Forward facing child seats are generally used in countries outside Scandinavia. With this seat, we want to give people an opportunity to try the rearward facing seat as it is "included in the price" when they purchase it as a forward facing seat.
- To raise the usage rate of child restraints for this age-group as the child seat is useful from infancy up to approximately 4 years of age.

We made some sled tests in complete car bodies with existing forward facing child seats before we started the development work on our new child safety programme. The seats were all approved according to different regulations, for instance ECE 44, FMVSS 213 and F.

No child seat fulfilled our own requirements as regards effect in the car. For instance, submarining occurred with some European child seats. With some American child seats the dummy displacement was so big that the head of the dummy hit the back of the front seats. The reason why these things happened will be discussed below.

One of the most important parameters in the matter of forward facing child seats is the way the seat is secured to the car. FMVSS/CMVSS 213 requires that the seat is secured to the car with the ordinary seat belts while ECE 44 gives the designers free hands to choose whether they want to use the ordinary seat belts or extra fittings.

It is easier to obtain good crash performance with two extra straps that are bolted at the ordinary lower belt fixation points. This is also the most common solution in Europe. There are two reasons for this:

- The designers can choose the location of the straps on the child seat. This is very important as the angle of the straps decides how swiftly the child seat is restrained during a frontal impact. The more upright the angle, the greater is the rotation of the straps before they start to refrain the child seat. This results in a longer displacement of the child, which means an increasing risk of head contact with the interior, especially in smaller cars.
- All cars are not equipped with safety belts in the rear seat.

ECE 44	FMVSS 213
Classes	
Integral Non integral	"Integral"
Categories	
Universal Semi-universal Specific vehicle (1)	"Universal"
Age groups	
Group 0 < 10 kg Group 1 9-18 kg Group 2 15-25 kg Group 3 22-36 kg	"Infants, 0-6 months (-7.5 kg)" "Toddlers, 6 months-4 years (7.5 kg - 18 kg)"
Other Items	
Special rig with a simulated dashboard.	Special rig, no dashboard.
30 mph frontal collision 20 mph rear-end collision	30 mph frontal collision
It is possible to use extra fittings, the dashboard etc.	The CRS has to be fitted into the car with a lap belt only. It is possible to use one extra fitting, but it is necessary to meet the regulations without the extra strap. It is not permitted to use the dashboard.
Main requirements	
Chest res. < 55g/3ms Chest vert. < 30g/3ms Head displacement No submarining	HIC <1000 Chest res. < 60g/3ms Head and knee displacement

Figure 10. A comparison between FMVSS 213 and ECE 44. 1) It is possible to make the test either in a fullscale crash test or in a special vehicle body on the test-trolley

Use of the ordinary seat belts, as in all American child seats, creates the problem of the difficulty in tensioning the belt across the child and the child seat itself. This means that it is much harder to devise a good "force taking" angle of the lap belt. As many child seats today are designed in accordance with the federal regulations, another problem arises, i.e. that neither ECE 44 nor FMVSS/CMVSS 213 requires a complete safety belt when the crash test is carried out. These regulations do not require the use of a safety belt with a lock and locking tongue which in turn influence the fitness and the behaviour of the child seat in a proper car. As not all cars are the same, one can find cars with very high locks (1.5-2 dm) as well as cars with very low ones. The high locks may mean that it is very difficult to install the child seat as the lock often is very stiff. During a crash, this may result in bending of the lock which may destroy it. Furthermore, the efficiency of the restraint may be lower since the belt tension is reduced. This may also mean that the child seat becomes unstable during normal driving conditions. The big advantage of securing the child seat with the seat belt is of course that it is easier to use.

As mentioned before, tests of certain European approved forward facing child seats resulted in submarining problems in frontal impacts. This is a problem that does not exist in either rearward facing child seats or in North American forward facing seats. The reason why it does not occur in rearward facing devices is obvious. In North American child seats the reason is to be found in the design of the harness.

The ECE 44 regulation requires that if the child is secured by a 5-point harness, then the crotch strap or any other strap passing between the child's thighs must break or disconnect from its fitting at a static load of not more than 50 N. On the other hand, FMVSS/CMVSS 213 requires that the crotch strap shall be fixed and not give way under any circumstances. The reason why ECE 44 requires a releasable crotch strap is the belief that the crotch strap may result in crotch injuries. Our opinion however is that the fixed crotch strap is much better as it keeps the lap belts low down on the pelvis which means that the hips will not move forward and cause injury in the genital area.

We have mounted a high-speed camera during a couple of tests to see what really happens in that region. No problems occurred as the fixed crotch strap held down the lap belts over the hips. What may happen with the releasable crotch strap is that the shoulder belts will pull the lap belts upwards towards the stomach as the shoulder belts are connected with the lap belts. This means that the risk for abdominal injuries increases as submarining may occur. It is, however, possible to design a forward facing seat the "European way" without the submarining problems, which is what we have done. We believe, however, that the European system is rather sensitive to changes in crash-pulses, stiffness of the seat cushion etc. This means that a "European" forward facing child seat ought to be car-specific or semi-universal rather than for universal use.

This judgement is made with the North American and the British markets in mind as no information on crotch injuries is available from the accident statistics. The British regulation permits the use of the fixed crotch strap.

Conventional Infant Seats

It seems that almost all countries believe in rearward facing systems for infants. The conventional pattern for this system requires only the safety belt, lap belt or lap/shoulder belt to be secured in the car; see Figure 11.

This is of course very convenient when installing the child seat in the car, but the simple installation sometimes creates some disadvantages which cannot be neglected.

- The child seat becomes unstable, which can cause problems.
- If an accident should occur the safety belt will only absorb forces in one direction. This means that the infant seat will be well restrained during the beginning of a frontal impact. However, the safey belt cannot prevent the infant seat from rotating towards the seat back of the front/rear seat during the rebound of a frontal impact or during a rear end collision. This means that the infant's head will contact some part of the seat back. Even if the seat back is mostly made of soft material there is a chance that the

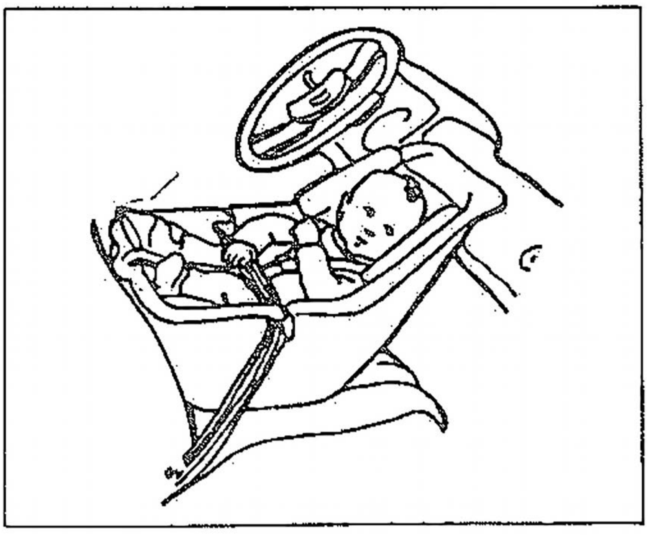


Figure 11. A conventional infant seat.

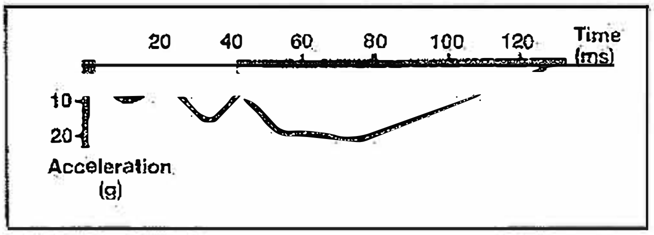


Figure 12. Sled acceleration pulse. Frontal crash simulation.

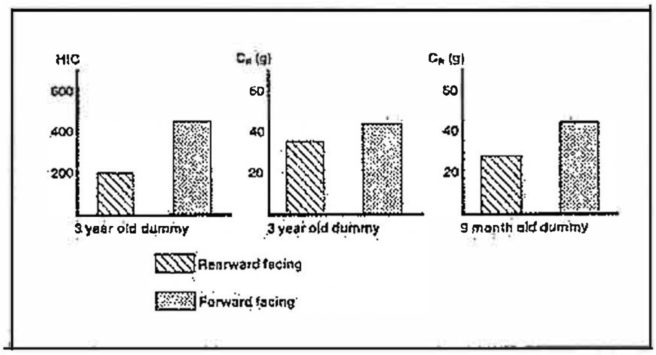


Figure 13. The staple diagrams show the difference in injury criteria between the forward and rearward facing position. A 3 year old American p572c dummy and a 9 month old European dummy were used. The 3 year old dummy shows a 57% lower HIC-value and a 20% lower chest acceleration when sitting facing the rear. The 9 month old dummy shows a 36% lower chest acceleration when sitting facing the rear.

child will hit some structural components in the seat back, the head restraints, or, if it is an angled collision, the B-pillar. Furthermore, in a multiple collision the infant seat can move around in the compartment in an uncontrolled way.

These disadvantages were taken into account in the design of the new combined infant and child seat.

Test Results

A comparison of the injury criteria has been carried out between the rearward and forward facing installation of the combined child seat. The tests were carried out in a Volvo 480 car body on a Hyge sled, with a frontal impact at 30 mph. The crash pulse is shown in Figure 12.

Design Concept

Volvo's Combined Infant and Child Seat

The child seat is intended for children weighing up to 18 kg, i.e. in the age-group from newborns to approx. 4 years old. It is designed to give the child a high crash protection in all kinds of accidents.

The seat is approved according to ECE 44, FMVSS 213 and CMVSS 213. It is possible to place the child seat in the rear seat or in the front seat, facing rearwards and forwards. We believe, however, that all children in this age group, as far as possible, should be transported in rearward facing child seats.

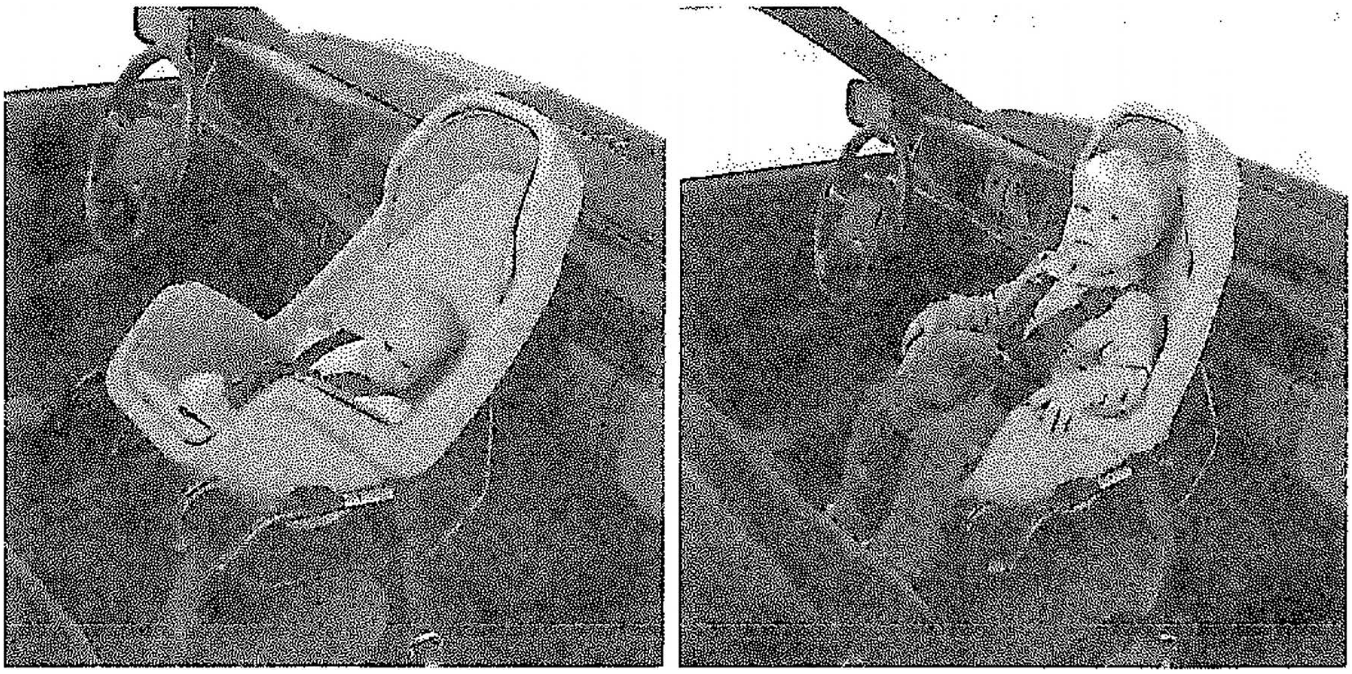


Figure 14. Rearward facing front seat. Infant and toddler position. The child seat is placed on the passenger front seat with its back leaning against the dashboard. It can be adjusted to the desired angle by sliding the front seat forwards or backwards. The child seat is secured by an extra strap together with the passenger safety belt

Figure 15. Rearward facing, rear seat

The child seat is placed on the rear seat with its back leaning against the back of one of the front seats. It can be adjusted to the desired angle by sliding the front seat forwards or backwards. The child seat is secured by an extra strap around the head restraint of the front seat together with the passenger safety belt

The installation of the child seat is very easy in both the rearward and forward facing positions.

A Half-integrated Child Seat

A new type of child seat which is the first step towards integrated child safety has been developed for children with a weight between 9 and 18 kg, i.e. in the age group of about 9 months to 4 years of age.

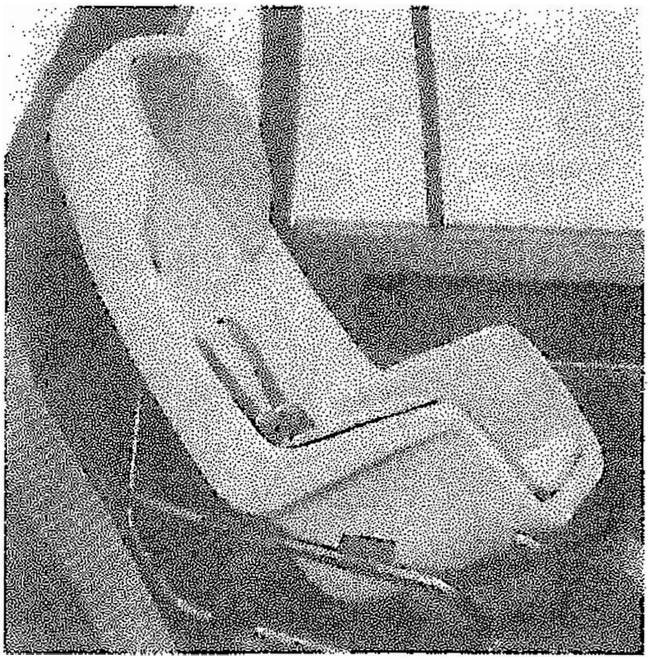
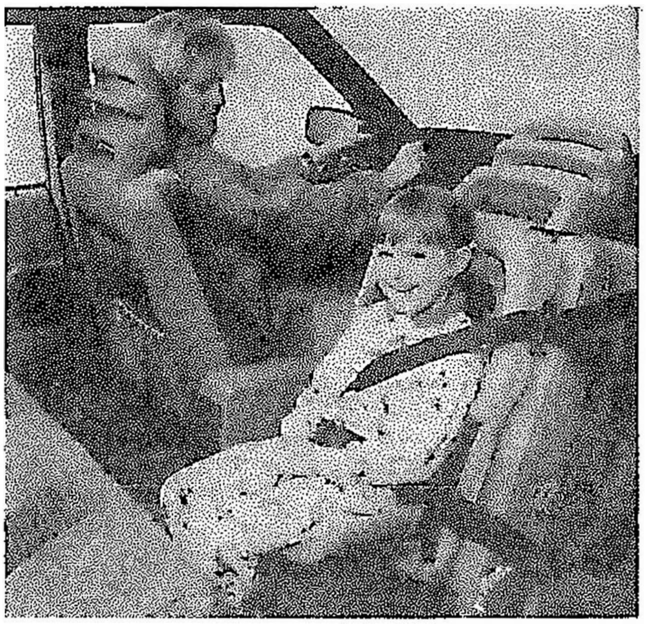


Figure 16. Forward facing

The child seat is secured with the ordinary seat belts of the car, i.e, the lap/shoulder belt or the lap belt

The child seat is installed on the rear of the front passenger seat and is intended for use in the Volvo 740/760 from model year 1985. This means that it is a car-specific child seat which can only be approved according to ECE 44.

The big advantage of the seat is that it can simply be folded out of the way when it is not in use. This



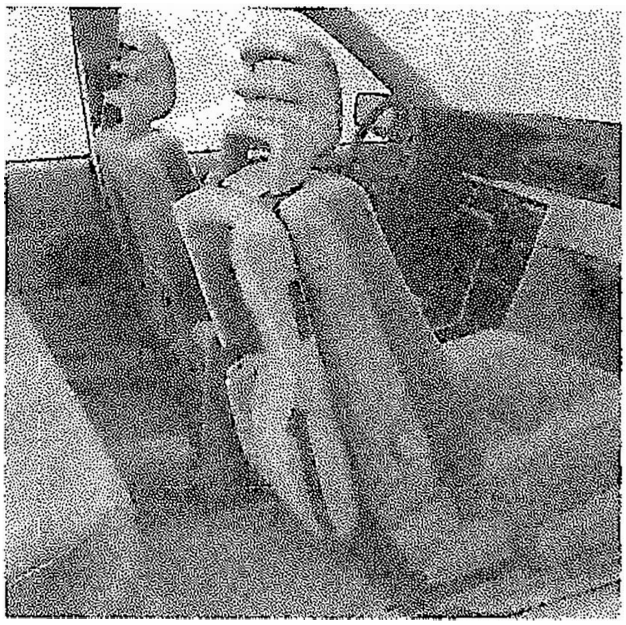


Figure 17. The half-integrated child seat. The child is secured by the front passenger safety belt

Figure 18. The booster cushion can be supported with a backrest. The backrest works as a head restraint when the child's head reaches above the edge of the seat back

means that it is possible to transport 5 adults without having the problem of removing the child seat.

Booster Cushion

When the child has grown out of the child seat, a booster cushion together with a lap/shoulder belt can be used. The booster cushion affords greater comfort for younger children when the seat belt is used and it eliminates the risk of submarining.

Conclusions

- Restraint use amongst children travelling in Volvo cars in Sweden has increased from 22% in 1976 to 72% in 1986. This is probably a result of intensive campaigns, the infant seat loan programme for newborn babies, the seat belt law for adults, increased public safety awareness.
- The effectiveness of all kinds of restraints for children (child seat, booster cushion, seat belt) is 16% for AIS 1 injuries, 47% for AIS 2-3 injuries and 60% for AIS 4-6 injuries.
- The effectiveness in reducing AIS 2-6 injuries to children in the age group 3-10 years is 58% for seat belts and 63% for booster cushions.
- The most common type of injury for both restrained and unrestrained children is the head injury.
- Severe neck and abdominal injuries caused by booster cushion use or seat belt use are almost non-existent among children in Volvo's accident material.
- Misuse frequency of rearward facing child seats is low.
- Although misuse of booster cushions is relatively high (approx. 40%), there is a clear effectiveness in reducing more severe injuries.
- We find from accident studies that frontal collisions are the more frequent types of collisions and are usually more severe than rear end impacts.

This means that a rearward facing child seat offers better protection to the child, since the crash forces are spread over the back, neck and head of the child. A further advantage with the rearward facing seat is that the risk of submarining is almost negligible.

Volvo's accident research shows that the rearward facing child seat has a very high injury-reducing effectiveness—90% for AIS 2-6 injuries.

Volvo's laboratory crash tests also show that although results and behaviour are good with the new forward facing seat, they are even further improved with the rearward facing one.

- It exists many different regulations on child safety. A harmonisation of the requirements is necessary to encourage car manufacturers and others to increase the development of "international" child safety.
- If a crotch strap is used it shall be fixed (the North American way) and not released at a certain force (the European way). No crotch injuries has been found either in North America or in England.

References

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2. Nygren A. Tingvall C, Turvell T. "Misuse of child restraint in cars and potential hazards". Unpublished.
3. Volvo/TNO Workshop on Child Safety in Passenger Cars.
4. ECE Regulation 44.
5. FMVSS 213, Federal register and NHTSA FMVSS Docket; NHTSA, Washington, D.C.

Appendix

Case 1 (child seat)

The car was hit obliquely from behind by a truck. There was extensive deformation of the right rear end of the car. The belted female driver (injured AIS 1) and two occupants were travelling in the car. One of them was a 7 year old boy (injured AIS 2) who travelled unbelted in the left rear seat and the other was a 2 year old girl who travelled in a rearward facing child seat located in the right front seat. The girl in the child seat was unproperly restrained and was thrown backwards in the car. She sustained a facial laceration (AIS 1) and concussion (AIS 2).

Case 2 (cushion)

The car was hit in the right side by another car. The deformation was 2 according to the VDI-scale. A belted female driver was travelling in the old car (not injured) together with a 31 year old male (injured AIS 2) in the left rear seat with a 2 year old girl on his lap (injured AIS 1) and a 5 year old girl in the rear right seat using a booster cushion. She sustained an abrasion on the left eyebrow and on the chin (AIS 1) and concussion (AIS 2), probably caused by interaction with the adult rear occupant.

Case 3 (cushion)

The car skidded on a snowy road with the left side first into a big tree. The deformation was concentrated to the left side behind the B-pillar (VDI 3). A belted male driver was travelling in the car (uninjured), together with a 35 year old belted female right front seat passenger (uninjured), a 8 year old girl in the right rear seat using a booster cushion (injured AIS 1) and a 5 year old girl in the left rear seat also using a booster cushion. This girl sustained minor lacerations on the upper and lower extremities and a more severe concussion (AIS 3), probably caused by direct head impact to the tree.

Case 4 (cushion)

Another car was overtaking a lorry and caused a severe front end offset impact to the case vehicle. The deformation to the Volvo car was extensive and concentrated to the left side of the front (VDI 6). The occupants of the car were a belted 27 year old female who was killed, a belted 38 year old male in the right front seat (injured AIS 3), an unbelted 32 year old female in the right rear seat (injured AIS 4) and a 6 year old boy using a booster cushion in the left rear seat. The boy sustained a fractured right forearm (AIS 2) and a fractured right lower leg (AIS 2).

Case 5 (cushion)

The car skidded sideways and was hit in the right side by another car. The deformation was concentrated to the area of the right rear seat passenger (VDI 2). The occupants of the car were a belted 50 year old female driver (injured AIS 1), a belted 17 year old male front seat passenger (injured AIS 2) and a 6 year old girl using a booster cushion in the right rear seat. The girl's injuries were facial lacerations (AIS 1), a severe concussion (AIS 4) and right side rib fractures including lung contusion (AIS 3). The injuries were probably due to head impact with the right rear window frame and chest impact with the car side interior.

Modern Testing Techniques in Motor Vehicle Safety Research With Regard to Rear End Crash Properties

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Summary

Modern, lightweight three-door vehicle concepts, like the new Volvo 480, demand a special approach in the development of their rear end crash properties. With this type of car designers encounter special issues, mainly caused by the limited permissible deformation area in respect of the interior compartment, the fuel tank position, the spare wheel and other components.

In order to develop the Volvo 480 efficiently from the viewpoint of its rear end crash behaviour, different techniques were used. Some of these techniques are common practice in the automotive industry, others are less usual. The latter techniques are the subject of this paper.

Introduction

When addressing issues of design in the development phase of a new car, the design engineer will