Proceedings of the Sixth International Conference of the International Association for Accident and Traffic Medicine

Melbourne, Australia. January 31–February 4–1977

Fifteen Years with the Three-Point Safety Belt

A review of the development and experience of car occupant restraint.

By Nils Bohlin.

AB Volvo.

Summary/Abstract

The Volvo three-point safety harness became standard equipment in Volvo cars in 1959, and the retractor belt in 1973.

The usage frequency has increased from about 25% in 1965/1966 to over 90% in 1975.

The effectiveness of three-point safety belts has been continuously studied and evaluated since 1959. The mean effectiveness for front seat belts found to vary from 24% to 68% depending on accident severity and type and injury classification.

The effect of the law of compulsory wearing seat belts in Sweden has been analyzed in the Volvo accident investigation material. The effect of law was found to be very positive and of the same order as of the predicted values.

Little or no difference (not significant) was found in the mean effectiveness figures for retractor and non-retractor belts.

Certain human tolerance data from a joint project, Volvo - Wayne State University, are included.

Injuries related to submarining are also dealt with. Finally, certain questions related to regulations for belt restraints are discussed.

Acknowledgements

I would like to express my sincere thanks to my colleagues Hans Norin and Bengt Kjellberg for their assistance in supplying accident data and results, Harry Nygren for his valuable contribution in commenting on the regulations, and last but not least to Marianne Jacobsson and Karina Friman for their joint achievement in typing my finished manuscript.

Addition: Thanks to John Oussey and Joan Tonge at Volvo Australia Pty. Ltd., for their full time assistance to rewrite the whole thing!

When I - with the object of writing this paper - tried to organize my retrospective thoughts on my experience from various restraint systems, I was suddenly struck by the fact that even in the matter of safety belt the proverb: "There is nothing new under the sun" is true. Already in 1903 a Frenchman, Monsieur Leveau, was granted a patent concerning a restraint harness. And, as you can see, it was quite modern in so far as it comprised both lap and upper torso straps. Maybe M. Leveau, if available, would have been more qualified than I to write a review of restraint with his possible 75 years of experience - I have just 25 years (the first five years in matters related to jet aviation safety and rescue systems).

Development

Fifty years ago (1927) the first Volvo was successfully made. Twenty years ago, 1956-57, Volvo was engaged in the development of an occupant restraint of belt type. In close co-operation with former Swedish Road and Waterways Board our first belt of two-point diagonal type was developed and tested. With trust in a very simple but good restraint we presented the two-point diagonal belt in 1957 as accessory equipment, and as standard equipment for some model cars (anchor points were included in the body). The diagonal belt became soon a popular belt for most makes of cars in Sweden, and later on in many other countries in Europe. It was supposed to be a good belt restraint. In our accident investigations, which we have made systematically since then, it proved to be a rather good belt, but not good enough according to our accident experience. Some shortcomings in the restraint effectiveness appeared soon, especially in accidents involving door openings in association with ejection of belted occupants. Consequently, we made measures for immediate improvements and the Volvo three-point safety belt was born. It became standard equipment in front seats in Sweden and some other markets in 1959, and on the US market in 1963.

The original design aimed basically to accomplish a handy, effective restraint device with special attention to primary medical aspects.

Handy:

Easy fastening - one-hand operation. Easy adjustment, one common adjustment unit for both lap and chest straps.

Effective:

In case of an impact, effective protection of the strapped occupant against being thrown forwards and ejection at door opening or window failure. Upper torso as well as lower body effectively restrained.

Medical aspects:

Lap/pelvic area and chest, the strongest parts of the human body, should be engaged by the belt. Positive restraint of the lap strap to stay over pelvic bone (below iliac crest) and to prevent the strap sliding up into the soft abdominal area.

Solution:

Properly positioned anchor points, and most important the common point for the lap and chest straps on inboard side should be located low (preferably below the hip point) and anchored directly to the structure and being the buckle point. No hardware against the body.

Those features were then unique to Volvo. Today many other car manufacturers, partly due to regulations, have adopted some of them.

Our basic restraint philosophy is embodied in the Volvo three-point belt.

The original simple belt concept from 1959 is still in the Volvos in 1977. Not because of stopping development but because of the positive experience of the effectiveness of the basic configuration. Certainly we have had a continuous development work during the years gone past. It has, however, dealt with certain components and detail figures to steadily improve the comfort and handiness of the belt, important factors for usage and total efficiency. The buckle has been improved step by step as the adjustment device has been.

The introduction of the emergency locking (inertia) reel in 1969 was the great breakthrough. Thanks to those measures to improve the handiness we were successful in reaching a very good belt use figure, much better than in the average car in Sweden prior to the law of compulsory belt use.

Restraint efficiency

The (total) efficiency of a restraint system is mainly the product of the effects of two decisive factors: usage of the restraint and the injury reducing effect of the restraint, when used. It does not matter how effective a restraint is, if not used. Contradictions in experts opinions and ratings in airbag vs belt discussions are often related to the efficiency figures, particularly the usage factors. The injury reducing effect is normally given as the percental reduction of all injuries with no reference to the degree of seriousness of the injury. For more detailed studies, the effect can be referred to a specific type or severity of injury.

The usage - frequency

The public acceptance of the three-point belt in terms of belt-use frequency was rather low in the beginning. For Volvo cars in Sweden it increased from 1959 to average 25-30% for the front seats in 1965/66. It increased then gradually to an average of about 40% in 1971/72. In 1973/74 when the retractor belt and the belt reminder became more common (standard equipment 1973 in Volvo), the use frequency curve rose steeply. Just prior to the law for compulsory use Jan. 1 1975 we were happy to see that the "voluntary" belt usage in front seats in Volvo model years since 1973 was as high as about 70%. The compulsory use law finally raised the average figure for front seats to about 95% in 1975 according to our accident analysis findings.

The belt usage in rear seats is still however - sorry to say - not at all satisfactory. An analysis from 1975 reveals only about 6% use of rear seat belts in the Volvos. This fact must in a way be considered one of the most pertinent problems related to car restraint today, at any rate in our country. Not primarily because of the safety for the rear seat occupant (he normally has a relatively good outcome even unbelted) but for the safety of the restrained front seat occupant. That problem substantiates the primary rule automatic crash safety: All the occupants, including child rear and heavier luggage, dogs, etc. must be restrained in one way or another prevent injury producing interactions.

Volvo Traffic Accident Research

To gain the important input for product development from the real life test - the accident field - , to check the performance of various safety items and systems of the whole vehicle as well as of the human occupant and his injury tolerance, Volvo has had traffic accident investigations running since 1958.

Volvo Traffic Accident Investigations Program, which concerns both the cars, trucks and buses, involves mainly three activities:

1. Broad data collection for statistical analyses
2. On the spot multidisciplinary investigation
3. Special accident investigation projects.

Whereas the first two are running continuously, the third activity is operating temporarily depending on the specific aim.

I think the relevant accident investigation or follow-up is the only way to get true information and final answers to questions related to the safety performance of a component or system and to human behaviour, etc.

The confidence in the investigation findings is very much depending on the representativity of the background material, the consistency and control of certain important parameters.

I consider our background material being unique in this respect. It may even be superior to the material available for and used by other researchers. This is due to the consistency and the control of the vehicle - and the belt parameters.

From the very beginning we thought that the safety belt should have a high safety potential. Consequently, our accident studies have paid a great deal of attention to safety belt data, year after year, to check if it is true. The usage factor is already dealt with. The injury reducing effectiveness of the Volvo three-point is next.

Three-Point Belt Effectiveness

The first time we reported on three-point safety belt effectiveness was in 1967. From an analysis, covering more than 28,000 accidents, we reported the effectiveness for front seat-belted occupants related to accident speed. The results, cited many times since then, gave an overall positive effect of the belt of higher than 50% at lower speeds and about 50% at higher speeds. A very encouraging result indeed. That report happened to play, as far as I understand - a decisive role in two international important occasions: Firstly, in USA 1967 in the question of the new upper torso restraint FMVSS 208 (Jan. 1968) - Should it stay, or not?

It stayed as all of us know. Secondly, in 1969/70 in Australia in the government decisions on laws of compulsory use of safety belts.

In 1973 in Kyoto we reported the belt effectiveness from about 1510 accidents. The background material used there was different to that of the 1967 report - it was somewhat biased to consider more severe impacts than in the normal Swedish accident population.

If the Volvo accidents in Sweden are referenced to four groupings related to the repair cost (a measurement of impact severity), the bias can be pictured as follows:

The 1973 material analyzed covered in percent of the normal repair cost grouping for Sweden:

Total Repair Cost	% covered by Material Analysis
Less than $US 400	0%
Between $US 400 - 1400	10.7%
Between $US1400 - 1800	11.6%
Over $US1800	20%

A further difference to earlier analysis was that the injury recording there was more rigorous or complete in so far as it noted all injuries - even the slightest strain, bruise or scratch. This might have been neglected quite often by the customer when interviewed about his accirdent in 1967 report. In the 1973 analysis the effect at frontal impacts was related to VDI (Vehicle Information Index), which as you know, like accident speed, is a kind of measurement of impact severity. The mean overall injury reducing effect was reported to 32%, somewhat lower than in the previous study. The explanation is believed to be associated partly with the difference in injury classification mentioned above and partly with the difference in the background material.

In frontal impact accidents the effect for drivers varied from about 50% to 30%, decreasing with increasing VDI.

For most side impact parameters the belt effect was found to be little and not significant.

From our most recent evaluation of the belt effectiveness on background material from 1974-1976, I would like to update our effectiveness data in the following summary:

The 1973 report material was in relation to the 1967 material biased to include a larger portion of severe accidents with Volvo cars in Sweden. The 1974-76 analysis material is still more biased in the same respect.

The 1974/76 material covered in percent of the normal Volvo repair cost groupings in Sweden:

Total Repair Cost	% covered by material analyzed
Less than US$400	0%
Between US$400-800	10%
Over US$800	80%

The analyzed material comprises about 6,000 accident cases involving Volvo 140, 240, 160 and 260 cars.

The overall injury frequency for the belted front seat occupants -

all injuries was 29%, whereas it was about 38%
in the unbelted group

Thus the belt effectiveness (AIS 1-6) = 24%

The AIS 3-6 injury frequency was

belted = 1.5%
unbelted = 3.6%

Thus the belt effectiveness (AIS 3-6) = 68%

Discrepancy in effectiveness findings

The effectiveness of the belt restraint has, of course, been the basic point in ratings of its safety potential, particularly in discussions dealing with safety regulations and legislation on compulsory installation and use of belts. The effectiveness figures above (24% and 68%) can be seen as a good example of the difference in the effectiveness related to injury classification which can appear within the same analysis or might be present in different investigations. Inconsistency in other factors such as quantity and quality of the background material, disagreements in identification and coding of primary data, explain the differences in the results debated. That has been particularly true in the question of belt vs airbag. The debate has concerned the effectiveness of a particular type of belt as well as the comparison of various types of belt.

In total, however, I think it is fair to say that thanks to the steadily gained information from accident analyses in various countries, most researchers nowadays agree that the three-point safety belt has a substantial overall injury reducing effect - when it is used!

In 1976, however, the Dutch Institute for Road Safety Research (SWOV) presented a report "Lap Belts and Threepoint Belts - a comparison of effectiveness" which caused a lot of debate (3). The SWOV report says that "if there are any differences in the effectiveness of lap belts and three-point belts, these are so small that they cannot form a basis for giving preference to one type over the other", and concludes that both types of belt "are highly effective measures for safety in traffic". In interpreting that report it is, however, very important to follow the advice of the authors that it "must be made with care".

It is certainly agreed that in an effectiveness comparison between two restraint systems certain pertinent parameters must be reasonably similar. Such parameters would be: type of impact and accident, severity of impact, type of obstacle hit, size of car etc.

Even if it is true that there is no significant difference with regard to some of those parameters for the whole groups studied, in the mentioned report it is questioned whether it is still true in the very small breakdown groups of injury severity (AIS 3 and higher). This is important because the qualified injury causing accidents will produce a possible difference between two systems, and must therefore be well known.

Further it must be noted - in the SWOV study as in many other studies - that the common mark "three-point belt" could comprise both good three-point belt configurations and poor ones. The only thing common is the criteria of three anchor points, which will not exclude restraints with poor performance. It is my belief that the poorer types of three-point belt were quite frequent in Europe at the time of investigation (1968-70).

The Effect of the Law of Compulsory Use of Safety Belt in Sweden

Since Jan. 1, 1975 we have in Sweden compulsory use of the safety belt in cars in front seats. Main exemptions are children (14-year-old and younger), cab drivers and those having certain medical reasons. Now after two years we are motivated to ask for the effect of that law. So far, however, no comprehensive official report in this regard has been issued.

If we hope to find a simple direct answer in the number of annual car occupant fatalities, we may not at once be too enthusiastic over the result: 564 (670)x killed during 1976, 620 for 1975 against the mean number of 640 the last five years before the law. Some people

x) preliminary figure, (670) = estimated final figure

may say: rather poor results, which contradict those reported from other countries (Australia (5) and France). Has the belt in Swedish cars failed to come up to the predicted positive value? Certainly not. I think that the explanation - when officially analyzed - will be partly related to the fact that the belt-use-law in Sweden had a worse "starting point" compared to most other countries when proving its value, particularly in terms of occupant fatalities.

Prior to the belt-use-law, Sweden had

- a very low car occupant fatality rate
- a high (maybe the highest) voluntary use of belt
- very high percentage three-point belts of good design.

Further carameters, such as number of vehicles, mileage and transportation volume, make their contribution.

The Effect of Belt-Use-Law in Volvo Analyses

To contribute in picturing the belt law effect in Sweden, we have analyzed our recent accident data. It is my opinion that the Volvo accident data in this particular question as well as in many other cases, in evaluating a particular safety component, is very fit for the purpose. The advantage of our material is the consistency of the two very important parameters: the vehicle and the type of belt.

The effect of law, which results in the change of use frequency due to law, is read in terms of change in the injury frequency.

Summary results:

Our background material is derived from accident investigations during 1974, 1975 and partly 1976. The material is mainly grouped: "prior" (to the law) - 2969 cases, and "after" - 2026 cases. The bias (towards more severe accidents) identified above in the "effectiveness" section must again be recognised.

The "prior" group had a mean usage figure of about 50% while the "after" group had as high as more than 90%.

As seen in the table, the result is very positive and very much in the same order as the predicted value.

In summary, the AIS 1-6 frequency for the driver decreased from 33% to 29% and for front seat passenger from 38% to 29%. The AIS 3-6 frequency decreased from 2.34% to 1.29% for drivers.

The law effect for drivers (AIS 3-6) = 45%

For the front seat passenger the AIS 3-6 injuries decreased from 3.28% to 1.1%.

The law effect for front seat passengers (AIS 3-6) = 67%

If the effect is related to body areas, there is a reduction of about 70% of AIS 3-6 head injuries and about 52% reduction of the AIS 3-6 chest injuries. In the chest injury analysis, on the other hand, there was a slight increase (negative effect) for the minor injury group (AIS 1-2). This is, however, in full agreement with the experience reported in 1974, that safety belt use quite often is associated with rib and chest bone fractures in frontal impact accidents (8).

Retractor belt

The retractor three-point belt with the emergency locking reel was introduced to Volvo cars in the late sixties and then limited to some de luxe models. It became standard equipment in Volvo cars in 1973. Ever since the retractor belt came into the business, it has been carefully followed up to see if it would fulfil the expected effect on belt usage, effectiveness and the requirement of reliability. As you know, Sweden has (like Australia) the requirement of dual sensitive locking feature of the retractor.

Retractor Influence on the Belt Usage

The retractor together with the "fasten seat belt" reminder have definite positive effect on the belt usage figure. But surprisingly enough, the usage increase due to the retractor was less than that of the reminder. In our analysis of material in which we could differentiate those belt items, we found a use increase of 25% thanks to the retractor - and as much as 64% for the reminder.

Retractor Influence on the Injury Reduction Effectiveness

Is the retractor belt as good and reliable as the static belt?

That question has been raised many times after its introduction by both laymen and experts.

The first time we formed an answer to the question was in Kyoto ESV Conference in 1973 from a study of about 1500 accidents. We said: "there is no or very little difference (not significant)". Today when we have gained another three years experience of retractor use, we will summarize as follows:

The material analyzed is related to about 6000 accidents with Volvo 140/160, 240/260 cars during 1974, 1975 and partly 1976. Again the bias of the material (towards more sever accidents), which is identified above, must be considered.

Results: (refer to front seat occupants)

Injury frequency:

	AIS 1-6	AIS 3-6
Retractor group	29%	1.2%
Non-retractor group	31%	1.0%

The Effectiveness of retractor/non-retractor belt:

All injuries (AIS 1-6)	Retractor	= 24%
	Non-retractor	= 19%
Injuries (AIS 3-6)	Retractor	= 67%
	Non-retractor	= 73%

Two years ago (1975) the Mackay team in Birmingham, UK, in a report (4) at the 2nd IRCOBI Conference reported critically of the retractor belt regarding both injury reduction and reliability. Our overall experience from accidents involving retractors apparently is contradicting the findings of the Birmingham team. I understand from discussions with Dr. Mackay that a later analysis carried out has clarified that the reported shortcomings of the retractors could mainly be referred to specific designs or makes of the reels involved in the UK material.

Further, it is my belief, that the serious/fatal injuries reported by the UK team to be associated with safety belt use (injuries to head, chest and abdomen) obviously must be referred to the type of three-point belt dominating the UK material; the type of belt where the buckle is attached to a short strap in the middle and located in abdominal area. The belt configuration mentioned is less effective in securing the right position of lap strap, which creates a great risk for belt-produced injuries to abdomen and lower chest.

Thus, the retractor belt in our accident material has proved to behave satisfactorily and to be at least as good as the static belt in general. To make the retractor substantially superior regarding restraint effectiveness to the static belt - which normally is not too well adjusted, it could be advantageous to:

replace the actuation of locking the shoulder strap in emergency locking situations from the retractor unit to the anchor point at door pillar
and/or to bring regulations and testing methods related to retractors closer to reality, as will be discussed later in more detail.

Passive Retraints

A review of restraint development can hardly avoid mentioning passive restraints, the dominating concern of US rule makers and the worry of car manufacturers the last 6-7 years. Of course, Volvo have paid a great deal of attention to the passive restraint matter. Our development program has involved both passive belt concepts and airbag systems. The passive belt because of the simple reason that belt has a documented effectiveness and that we believe in it. The airbag concepts because of the reason that it might prove to be the only concept which in practise can reasonably comply with the interpretation of the "passive" requirement. We tried a number of more or less complicated belt systems but ended up where we started in a fairly simole configuration; an ordinary three-point belt with the outboard anchor points arranged in the door and a retractor at tunnel anchor point (6). It proved to be fully effective and functionally reliable, and it received good acceptance by the public in a panel study (7). Unfortunately NHTSA said: Not passive!

In the airbag concept development also, we went through various systems and ideas. After comprehensive laboratory testing, we decided on an airbag concept developed by Eaton Corporation for field testing.

To gain real life experience on both effectiveness and reliability, and as a contribution to the common information on airbag, we started a field test in co-operation with Allstate Insurance Co in USA two years ago. About 100 cars equipped with airbag, in addition to ordinary safety belt, for the front seats were built. Seventy five of them were placed on the US market, the rest on the home market.

The test is now finished, the results, however, not yet analyzed. In summary, only six of the airbag cars were involved in an accident. All but one of the accidents were of minor severity and below the threshold for triggering the airbag gas generator. Deployment thus happened in one case only. All four occupants sustained AIS 1 injuries at the impact, which resulted in a moderate deformation of the vehicle at the left front corner.

I think that the airbag might have a certain potential for improved restraint efficiency. The airbag might be the only passive restraint practicall. applicable, but we need a lot more knowledge and experience of its overall restraint features before we are ready to decide finally in the question of airbag.

Human Tolerance Related to Safety Belt Performance

The criteria and measurements for restraint performance have been discussed among experts for several years. It is quantitatively

expressed in the US FMVSS 208 in terms of BEV (= Barrier Equivalent Velocity) and Occupant Injury Criteria. To get increased knowledge of human tolerance we made a special study a couple of years ago. In co-operation with Professor L.M. Patrick of Wayne State University, we accomplished a program of in-depth accident investigations of Volvo cars, staged collisions and simulated collisions involving three-point-harness occupants in frontal impacts. The analysis aimed to correlate occupant injury with forces, acceleration or other physical parameters associated with the injuries. Although the study involved as high as 53 mph BEV accidents, it failed to find the ultimate restraint performance of the three-point harness - the "critical" of fatal injury did not show up in the material (8).

The following are some summary conclusions based on the results from this study, which only concerned the Volvo vehicles 140/164 and the Volvo safety belt. Any deviation from the study conditions, such as a different belt system, a different vehicle or a different anthropometric dummy, could mean modifications to the results, depending on how the differences affect the parameters in the studies.

Conclusions:

1. The three-point harness system is effective in mitigating injury as evidenced by:

   a) no fatalities in the accident sample of 169 occupants at velocities up to 53mph BEV
   b) the maximum injury was single AIS 4 injury
   c) only 16 out of 169 occupants (9.5%) sustained AIS 3 injuries.
   d) the maximum head/brain injury was AIS 2 (two cases)
   e) the maximum neck injury was AIS 3 (two cases)

2. No injuries to abdominal organs except a single case of a ruptured spleen.

3. Rib and sternum fractures without acute respiratory embarrassment were the most common injury, sustained by 8.3% of the total population.

4. Females are injured at lower collision severities than males. The average collision speed for females receiving rib fractures was 20.6 mph BEV while it was as high as 34.6 mph BEV for males.

5. Age is a major factor in the potential for injury in safety belt systems. Only two of the AIS 3 injuries occurred to occupants younger than the average age (= 42.8 years).

6. HIC (Head Injury Criteria) does not seem to be a relevant injury criteria. HIC of 3130, recorded in tests up to 53 mph BEV, corresponded to no head injuries at all in the real accident data.

7. Abdominal and/or torso injuries attributable to submarining are not a major problem.

8. The overall tolerance level of AIS 3 for the three-point safety belt based upon 50% injury rate occurs at 45 mph BEV and results in an upper shoulder strap load of 1930 lbs, chest GSI (Gad Severity Index) of 560 and a peak resultant chest acceleration of 85 g.

Submarining

A good safety belt restraint is designed to apply the load to the human body in those areas which can accept high load without injury. These include the thorax or rib cage, with the force distributed over the thorax, and the pelvic area, which is the strongest part of the human body. The lap belt portion of the seat belt assembly should be worn so the force is applied through or below the anterior spines of the iliac crests. The shape of the pelvic bone normally permits the lap belt to be kept in place if the angle between the lap belt and the horizontal is not too small. The lap belt is thus kept in the angle at the intersection of the thigh and torso.

If the lap belt is improperly worn, or improperly positioned due to the basic configuration, the belt can ride over the iliac crest resulting in the force of the belt being applied to the abdomen rather than to the pelvis. When this occurs, there is danger of injury to the abdominal viscera and the lower spine. Injuries that have been attributed to submarining, in addition to the injury to the abdominal viscera, include vertebral fractures. Some researchers think submarining as being one of the major disadvantages of belt systems. However, it should be noted that investigators who have reported on accidents involving occupants with belt systems, have not found the high incidence of abdominal injury that would be expected from submarining (9-11).

To summarize our gathered experience in this particular respect, I would like to say that submarining sometimes do occur in tests where anthoropometric dummies are used, but that injuries possibly attributable to submarining are rare in our accident investigation files. Only very few possible cases have been observed, all of which were right front passengers, and it is highly questionable whether these were due to submarining since there were no injuries to the abdominal wall. The explanation to the discrepancy between test and reality might be that either submarining does not occur in reality, or, if submarining occurs, that anticipated injuries do not occur.

I think that this very positive Volvo experience is mainly due to the basic belt configuration. Already in the initial design we took great care to set the correct position of the lap strap under loading conditions. We made it by:

locating the intersection between chest - and lap-strap to be as low as possible (lower than hip joint)

anchoring the intersection to the body structure to prevent dislocation of the intersection and the lap strap due to interaction from the chest strap during the loading phase

avoiding buckle - or other hardware being positioned against the occupant body.

Most three-point harnesses on the market during the sixties showed, according to my opinion, unacceptable design shortcomings, which might fully explain the findings of other investigations. Belts having such basic design defects are still frequent on the market even if the defects now are less pronounced.

Children and small occupants in three-point belts

Our recent findings concerning children and small (adult) occupants using the three-point belt will be reported later at this conference in a report by Hans Norin et al (12). For both these occupant categories the results are positive. In view of the number of questions to us (or even complaints) from small car occupants regarding the risk of neck injuries from the shoulder strap passing close to the neck, the result in the Norin report is most important and encouraging. From thousands of accidents we have recorded not a single case with more than AIS 1 neck injury (bruise, abrasions, etc) to the small occupant caused by the strap. The problem of the small occupant is relating to shoulder strap location must therefore be considered rather a matter of comfort than a true safety problem.

Regulations for belt restraints

Probably no other component or system in the car, I think, has attracted such attention by individuals and rulemaking people in terms of various research activities and comprehensive regulations as the simple safety belt. A number of working groups within many organisations (ATAC, SAE, ISO, ECE, CCMC, etc) have been and are active in discussing problems related to belt restraints. I think some of the problems being discussed today are of minor importance. Problems which are not derived from true real accident experience, but possibly from inadequate testing or misinterpreted results. It should be widely recognized that too much attention is paid to minor problems with the risk that the whole is lost for the details. Sure, there was at the beginning of the safety belt sage an indisputable need for research and regulations to exclude basically inadequate belt configurations and those of poor quality.

Let me give a few examples. Some of todays problems are dealing with the webbing requirements. The importance of the webbing elongation characteristics is greatly overrated, I think. In the complex system of interacting components (occupant's body, variations of clothing, seat cushions, webbing, reel and adjustment hardwares and, not to forget, the anchorages in the vehicle itself), which all are more or less yielding, the webbing elongation is not a decisive factor in reality. Beyond the general trend towards low elongation figures, which is principally advantageous, the rather sophisticated regulations nowadays on elongation and hysterisis are not, I think, very important, particularly in addition to inadequate "static" testing.

The Australian ADR 4C rule is very comprehensive and generally well founded. However, I would question the true value of the "static" testing of elongation/hysterisis in a time history of 120-205 seconds instead of the about 100 milliseconds in the real accident loading. According to my experience the elongation of the webbing is very much depending on the time involved.

The ECE draft R88 (coming R16) too is generally well founded after quite a number of experts discussions. However, unfortunately, those experts have found it necessary to carry over, from an earlier issue, the webbing abrasion requirement related to manually adjustable belts.

The sophisticated perfection of that requirement is manifested in:

max adjustment force 50 N
max micro slip 25 mm after 100 cycles, frequency 0.5 Hz, loading 50 N
min 75% remaining break load of the webbing after abrasion in the adjustment device with 5000 cycles, frequency 0.5 Hz and loading 25 N.

It is questioned if any adjustment device can comply with all those requirements. Particularly tough is the abrasion test because of temperature raise up to 50°C in the webbing due to the high cycle frequency. The relevancy is questioned again. What superman (Batman) pulls 3000m loaded webbing up and down through an adjustment mean in 2.7 hours?

Regarding testing of belts in general, the main irrelevancy or shortcoming is the fact that there is a component test instead of a system test. The safety belt is just one part of a restraint system. The other part is the vehicle body, without which the belt cannot be operationally effective. Consequently, the belt ought to be tested and evaluated in combination with the vehicle concerned. Before then no substantial improvement will be gained from the result of regulation discussions and rulemaking.

Today the safety belt must be designed to comply with requirements related to a dynamic testing procedure, which has very little in common with the real impact situation: an irrelevant retardation pulse, a seat impossible for a car, and a very poor substitute for the human being (the test dummy), which does not behave like the human necessarily, therefore gives information which can be misused or misinterpreted.

In discussing the relevancy of regulations and testing procedures, the matter of emergency locking retractors (inertia reel) must be dealt with. Certainly, the retractor of good design has proved to be very good in effectiveness, and very reliable. Information gained from the accident field indicates that some further refinement could make it even better. The present regulations, however, then have to be changed, i.e. the testing again must correspond better to the reality. So far there are no regulations today on the testing of the vehicle sensitive locking function which probably reflects the reality, I think. In most countries a "lock-up" method is used. That means that the retractor unit is accelerated to the requirement level (0.3 g - 0.7 g) with a rate of onset of about 10 g/sec. It is questioned whether the time to reach the set level in the test (40-50 ms) can satisfactorily cover the variations in reality - from the 100-200 milleseconds (ms) appearing in emergency braking to the very few milliseconds in a barrier head-in impact.

The regulation further states that the strap should be kept against moving during the time of acceleration of the unit, i.e. that the strap is given the same acceleration in relation to the retractor as the retractor itself. In reality, we have found from emergency braking experiements, the pull-out acceleration of the strap from the reel is substantially lower than the acceleration of the retractor unit. The testing procedure should take that difference into consideration.

It is therefore proposed that the regulations regarding the emergency locking features of the retractor should be seriously reconsidered. To some extent the specific retractor design might compensate or neutralize the shortcomings of the present regulations. The question of how many retractors have been inappropriately disapproved of by the authorities, is certainly less important than the question how many retractors have been approved on compliance with the specification, although not being fully fit for the demands of the real life accident situation.

Killed in an accident - the belt "failed"!

"How could it happen?, he used his safety belt". "She sustained chest injuries in spite of wearing the belt". Quite often such words with an undertone of surprise, can be heard from people commenting on a traffic accident.

For some reason, some people expect the safety belt - particularly the three-point belt - to save life always and to reduce all injuries in all accidents. I think it is important to clarify such a misunderstanding. The simple safety device, which the safety belt really is, has never meant to be 100% protective in all the complicated situations the accident might include. The "goal" of the safety belt was, when it came more than 15 years ago - and still is, to offer the strapped occupant a fair good chance to sustain less injuries under certain conditions. "Less injuries" could mean the question of Life or Death. Fatal or critical injuries should be reduced to moderate or minor injuries. Moderate injuries transformed to minor or no injuries. "Certain conditions", which most accidents comply with, means mainly that the passenger compartment should stay substantially intact and should not be too much deformed or penetrated by the impacting obstacle. Further, which is implicit in the basic philosophy to protect by restraining, it means that the strapped occupant should not be subjected to excessive loading from unrestrained luggage or other occupants, e.g. rear seat passengers.

But when those "certain conditions" are present in the accident - and they normally are as said before, the three-point safety belt of relevant design has proved to fulfil the goal said, almost without any exemption. That is my very summarized experience from more than 15 years accident investigations.

On the other hand, it means that in those accidents in which the car and the passenger compartment, due to extreme violence of the impact, is completely compressed or torn into pieces, in these cases no restraint system could be expected to save the occupant. That might be the case when the car is hit by a train or a heavy truck. Or when the accident impact speed is very high. To overcome such limitations of the today automotive safety with adequate and reasonable measures, is positively not a question of occupant restraint design or even car design, but a review of the whole traffic system.

Future attention

To sum up my experience from more than 15 years with the three-point safety belt into some brief suggestions for future attention, it would be as follows:-

General:	Number one problem is the unbelted rear seat occupants and potential missiles within the passenger compartment or cargo area.
Belt system development:	Handling and comfort Retractor emergency locking refinement Increased side impact restraint performance in association with body - seat design.
Research:	Human tolerance data related to belt restraint conditions.
Rules and Regulations:	Injury criteria (HIC and SI) in performance standards. Reconsideration of relevancy and adaption.

Locking criteria for retractors and related test methods. Reconsideration of the relevancy.

Adequate research and justification before mandatory "improvements" are legislated. A world wide effort to produce a "system requirement" rather than a conglomeration of rules all directly related to occupant protection.

References:

1. Nils Bohlin: "A Statistical Analysis of 28,000 Accident Cases with Emphasis on Occupant Restraint Value". Eleventh Stapp Car Crash Conference, P.20. New York: Society of Automotive Engineers, Inc, 1967.

2. N. Hohlin, H. Norin and A. Andersson: "A Statistical Traffic Accident Analysis". AB Volvo, Car Division. Presented at Fourth International Experimental Safety Vehicle Conference, Kyoto, March 1973.

3. Edelman, van Kampen: "Lap-belts and Three-points Belts" - a comparison of effectiveness. SWOV, 1976.

4. G.M. Mackay et al: "Serious Trauma to Car Occupants Wearing Seat Belts". 2nd IRCOBI Conference, Birmingham, UK, 1975.

5. D.C. Andreassend: "The Effects of Compulsory Seat Belt Wearing Legislation in Victoria". National Road Safety Symposium, 1972, Canberra.

6. S. Pilhall, N. Bohlin: "A Passive Safety Belt System". 2nd International Conference on Passive Restraints. Detroit 1972.

7. N. Bohlin, S. Pilhall: "Consumer Acceptance of Volvo Passive Belt System". 2nd International Conference on Passive Restraints. Detroit 1972.

8. L.M. Patrick, N. Bohlin, A. Andersson: "Three-point Harness Accident and Laboratory Data Comparison. Strapp Car Crash Conference, 1974.

9. W.D. Nelson: "Lap-Shoulder Restraint Effectiveness in the United States". Paper 710077 presented at SAE Automotive Engineering Congress, Detroit, January 1971.

W.D. Nelson: "Restraint System Effectiveness". Presented at Fifteenth Annual Conference, American Association of Automotive Medicine, October 1971.

11. G. Grime: "Accidents and Injuries to Car Occupants Wearing Safety Belts". Automobile Engineer, July 1968.

12. H. Norin, Britta Andersson: "The Adult Belt - A Hazard to the Child?" 6th IAATM International Conference, Melbourne 1977.