Mechanical and Physical Risk Prevention

Studies and Research Projects

REPORT **R-844**

Seat Belt Assemblies for Counterbalanced Lift Trucks

Preliminary Study of Normative and Usability Criteria

Denis Rancourt
Sylvie Beaugrand
Christian Larue
Geneviève Masson

The Institut de recherche Robert-Sauvé en santé et en sécurité du travail (IRSST), established in Québec since 1980, is a scientific research organization well-known for the quality of its work and the expertise of its personnel.

OUR RESEARCH
is *working* for you !

Mission

To contribute, through research, to the prevention of industrial accidents and occupational diseases and to the rehabilitation of affected workers;

To disseminate knowledge and serve as a scientific reference centre and expert;

To provide the laboratory services and expertise required to support the public occupational health and safety network.

Funded by the Commission de la santé et de la sécurité du travail, the IRSST has a board of directors made up of an equal number of employer and worker representatives.

To find out more

Visit our Web site for complete up-to-date information about the IRSST. All our publications can be downloaded at no charge.
www.irsst.qc.ca

To obtain the latest information on the research carried out or funded by the IRSST, subscribe to *Prévention au travail,* the free magazine published jointly by the IRSST and the CSST.
Subscription: *www.csst.qc.ca/AbonnementPAT*

Legal Deposit
Bibliothèque et Archives nationales du Québec
2014
ISBN: 978-2-89631-760-8 (PDF)
ISSN: 0820-8395

IRSST – Communications and Knowledge
Transfer Division
505 De Maisonneuve Blvd. West
Montréal, Québec
H3A 3C2
Phone: 514 288-1551
Fax: 514 288-7636
publications@irsst.qc.ca
www.irsst.qc.ca
© Institut de recherche Robert-Sauvé
en santé et en sécurité du travail,
October 2014

Mechanical and Physical Risk Prevention

Studies and Research Projects

REPORT **R-844**

Seat Belt Assemblies for Counterbalanced Lift Trucks

Preliminary Study of Normative and Usability Criteria

Denis Rancourt[1], Sylvie Beaugrand[2],
Christian Larue[2], Geneviève Masson[1]

[1]Université de Sherbrooke
[2]OHS Problem Prevention and Rehabilitation, IRSST

Disclaimer

The IRSST makes no guarantee as to the accuracy, reliability or completeness of the information in this document. Under no circumstances may the IRSST be held liable for any physical or psychological injury or material damage resulting from the use of this information.

Document content is protected by Canadian intellectual property legislation.

Clic Research
www.irsst.qc.ca

A PDF version of this publication is available on the IRSST Web site.

This study was funded by the IRSST. The conclusions and recommendations are solely those of the authors.
This publication is a translation of the French original; only the original version (R-765) is authoritative.

PEER REVIEW

In compliance with IRSST policy, the research results published in this document have been peer-reviewed.

SUMMARY

Since the coming into force of a new section of Québec's Regulation respecting occupational health and safety (ROHS), counterbalanced, center control, high-lift trucks with a sit-down, nonelevating operator station must be equipped with a restraint device that prevents the operator from being crushed by the FOPS (falling object protection structure) in the event of a tipover. Lap belts are one of the most commonly used means of meeting this requirement. Based on the literature, a brief examination of certain types of seat belts sold on the Québec market, interviews and observations of twelve operators and seven supervisors at seven companies, this exploratory study provides an overview of seat belt use, from two points of view: seat belt performance standards and seat belt usability in the workplace.

In the companies visited, the lift operators had some difficulty accepting the obligation to wear a seat belt. Most of the operators mentioned, however, that over time they had developed the habit of wearing their seat belt. That said, several of them indicated that they found it useless or annoying, mainly because of the truck's limited speed, the restrictions the belt places on their physical mobility when travelling in reverse, and above all, because their tasks required them to get on or off the truck frequently. Our observations of the operators at work revealed in fact that some of them got off their trucks on average every 2.6 minutes. While the average time period needed to actually fasten the seat belt is only five seconds, it can increase significantly when the retractor rewinding system does not work properly. Other factors, such as poorly attached retractors, webbing that is too short, a hip restraint that hinders belt fastening, non-optimal buckle placement or buckle attachment hardware, and interference between the webbing and a tool pouch are factors likely to compromise acceptance of the seat belt, its ease of use, and operator safety.

Based on the analyses performed in this study, it is not currently possible to recommend a retractor that reconciles the factors of safety, comfort, and compatibility with task-related needs and for every situation. In the field, belts with an automatic locking retractor (ALR) are a frequently installed model. These retractors automatically take up the slack in the webbing and prevent it from unwinding at all times. The operators' ability to move on their seat is therefore limited, for instance, when travelling in reverse. When vibrations are present and the operator moves relative to the seat belt anchorage points, the tightening of the webbing can become particularly uncomfortable. Use of an emergency locking retractor (ELR) is an alternative option available on the market. This retractor ensures good operator mobility since, under normal operating conditions, the slack in the webbing is automatically taken up by a slight pull exerted by the retractor, yet without activating the webbing locking mechanism. However, from the point of view of operator safety, while seat belts with ELRs comply with the SAE J386 reference standard applicable to off-road work vehicles, the retractor may not lock in numerous situations involving lift truck tipovers, because the acceleration magnitude of the truck and the operator may be lower than the locking threshold values specified in the standards. Standard SAE J386 is similar in many regards to the standard FMVSS 209 49 CFR, which describes the requirements for seat belts used in automobiles in Canada and the United States. However, the kinematics of lift trucks in terms of speed and acceleration differ from those of cars during rollovers or collisions. Lower values for belt locking thresholds might improve the performance of ELRs, depending on the tipover conditions. To ensure compliance, such criteria would potentially

require the use of new locking mechanisms. A seat belt that differentiates the vehicle-tilt-sensitive locking threshold from the vehicle-acceleration-sensitive locking threshold would do much to improve ERL performance, provided that the tilt threshold value is limited to between 12 and 15 degrees.

Seat belt assemblies with manual retractors, which require the operators to adjust the webbing length themselves, have the advantage of not tightening on the user. Such retractors also appear to offer a good solution in terms of protecting the operator in all situations. However, it is important to ensure that there is relatively little slack in the belt (less than five centimeters), which may, in turn, limit the operator's mobility when seeking rearward visibility. This type of belt also requires each new operator who drives the truck to readjust the webbing.

When choosing equipment, a large number of people responsible for health and safety in companies are interested in devices that facilitate management of seat belt use (e.g. webbing colour, warning signal that sounds when the seat belt is not fastened). However, before purchasing equipment, a needs assessment, taking into account the characteristics of the seat, belt, users, and tasks to be performed, could reduce some of the inconveniences associated with seat belt use. Such an analysis should include operator input. This report provides guidelines intended to fuel this reflection process. In addition, malfunctions could be minimized through proper seat belt maintenance.

ACKNOWLEDGEMENTS

We would like to thank the members of the study follow-up committee and their advisers for supporting this project. Their invaluable assistance enabled us to recruit volunteer businesses to help us produce this first overview of seat belt use by lift truck operators. Thank you to the Association paritaire pour la santé et sécurité du travail du secteur minier (APSM), the Association sectorielle fabrication d'équipements de transport et de machines (ASFETM), the Association paritaire de santé et de sécurité du travail, secteur imprimerie et activités connexes (ASP imprimerie), the Association paritaire pour la santé et la sécurité du travail – Secteur fabrication de produits en métal et produits électriques (ASPME), the Association de la santé et de la sécurité des pâtes et papier et des industries de la forêt du Québec (ASSPPQ), Via Prévention, Liftow and Préventex.

For confidentiality reasons, we cannot name the companies that participated in our study, but we sincerely thank them for their hospitality and availability. Thank you to the managers, employee representatives, health and safety officers and, above all, the lift truck operators and supervisors who agreed to answer our many questions and generously shared their experience with us.

Lastly, thank you to Maud Gonella and Christian Sirard of Institut de recherche Robert-Sauvé en santé et en sécurité du travail (IRSST) for their assistance and enthusiasm in collecting workplace data.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION

Lift trucks are usually driven in controlled conditions that do not appear hazardous for the operators of these solid, sturdy-looking vehicles. Appearances can be deceiving, however, because in some conditions lift truck operators can be seriously or even fatally injured. For instance, it is recognized that lateral tipover can cause death if an operator is crushed by the Falling Object Protective Structure (FOPS). A lift truck can also hit objects along its trajectory or be destabilized by unexpected surface irregularities. Lastly, in frontal impacts, the operator can be thrown against the mast structures. All such incidents can lead to voluntary, involuntary or reflex exiting of the operator from the cab, which can be fatal.

Approximately 30% of fatal accidents involving counterbalanced lift trucks occur in lateral tipover [Male, 2003; Tellier, 1995a]. Of the 22 tipovers reported in Québec from 1974 to 1994 [Tellier, 1995b], 17 were fatal. In 2009 and 2010, Commission de la santé et de la sécurité du travail (CSST) investigators showed, for each of five deaths caused when a counterbalanced lift truck rolled over onto the operator, that either the operator was not wearing a seat belt or the lift truck was not fitted with a seat belt or other restraining device (ref. accident investigation reports, CSST Documentation Centre).

Eliminating the hazards associated with lift truck operation begins with proper workplace organization and adequate operator training. Depending on the working conditions, some risk may remain and, under the occupational health and safety regulations, the employer must take mitigation measures to reduce such risk to an acceptable level.

Among potential employee protection mitigation measures, use of a restraining device is mandatory. Section 256.1of the ROHS (2008) states that:

> *“A counterbalanced high-lift truck with a centre operating system, that cannot be lifted with the operator in a sitting position, referred to in the second paragraph of section 256, must be equipped with a retention device, such as a safety belt, mesh doors, enclosed cabin, bucket seat or winged seat to prevent the operator from being crushed by the structure of the truck in the event the lift truck tips over.*
>
> *The devices must, where applicable, be kept in good order and used.”*

The regulation states that the restraining device must meet three requirements: prevent the operator from being crushed by the structure of the lift truck if the truck tips over, be kept in good order, and be used. A seat belt is one of the means commonly used by companies to comply with this regulation, as lift trucks are usually fitted with seat belts. In fact, although the use of a seat belt is not explicitly required under Québec regulations, it seems implicitly recognized that it should be, because lift truck manufacturers include this requirement in their technical documentation.

A study by Bourret et al. (2008) showed that a seat belt, if used correctly, prevents the operator from being ejected and crushed by the lift truck's protective structure[1]. However, seat belt in good order is not enough to protect a lift truck operator. The operator must willingly choose to wear a seat belt and the organizational context must encourage and enforce seat belt use.

Such goals are not always easy to achieve in an industrial setting. The ergonomic study of Vezeau et al. (2009) "Amélioration des situations de travail impliquant les opérateurs de chariots élévateurs : étude ergonomique et analyse des stratégies de conduite des caristes" [Improving working conditions for lift truck operators: ergonomic study and analysis of operator driving strategies] showed that a lift truck operator's work is varied and involves a whole set of constraints and requirements. For instance, operators perform tasks requiring them to get off the lift truck frequently. The authors noted that the frequency of mounting/dismounting depended on the task at hand, averaging once every 2.4 minutes during order preparation. Belt characteristics that affect ease and speed of fastening (and unfastening) are key considerations in promoting seat belt use.

In addition, the operator must constantly cope with reduced visibility, mainly caused by the lift truck structure (e.g., mast, back guard, FOPS) and the load transported, and must lean out of the cab for visual cues during stacking and unstacking operations. Lateral flexion of the trunk is common, particularly on the left (seat positioned off to the left and shifters to the right). Vezeau et al.'s study (2009) also shows that operators drive the lift truck in reverse from 30% to 48% of the time. To maintain a clear visual field in the direction of movement, operators twist around in their seat, usually to the right (the left hand being kept on the steering wheel).

Other work-related activities are frequently performed inside the cab: using a scanner, radio, notepad and pencil, purchase order, etc. These examples of seeking visibility and reaching for objects show that operators must have good physical mobility to perform their work and protect their own safety and that of people around them. A seat belt should therefore hinder or restrict operator movement as little as possible in all circumstances. Operators who have trouble meeting production targets, are uncomfortable, or feel that their own safety or that of the environment is threatened (e.g., through reduced visibility) may very well decide not to wear a seat belt.

---

[1] Following this project, the video "*Lift trucks:Wearing a safety belt can save your life.* " was produced by the PERSEUS group in the mechanical engineering department at Université de Sherbrooke; http://www.irsst.qc.ca/en/-webtv-Chariot-elevateur-le-port-de-la-ceinture.html

Other factors that may encourage or discourage seat belt use include:

- the type of seat and lift truck with which the seat belt is used;
- the presence of an interlock system preventing the lift truck from being used if the seat belt is not fastened;
- operator anthropometry;
- bulky clothing (winter clothing);
- equipment worn at the waist (e.g. portable radio).

1.1 Study background and objectives

Studies carried out under the IRSST's program (Bourret et al. 2008 ; Vezeau et al. 2009) have provided insight into a lift truck operator's work, the determinants that can lead to lift truck tipovers and the most effective means of restraint. However, these studies have overlooked two major points. First, Bourret et al.'s study (2008) provided no details on the effectiveness of different types of seat belts on the market. Secondly, Vezeau et al.'s study (2009) was completed before the regulations came into force, so the observed operators were not wearing a seat belt. No data have been collected on the potential effects of seat belt use on operator comfort and work efficiency. To our knowledge, there is no status report on the technical performance and usability[2] of seat belts in the context of lift trucks.

More specifically, the coming into force of the new seat belt regulation gives rise to these questions:

- What types of seat belts are available on the market?
- What types of seat belts are fitted on lift trucks?
- Are there standards on seat belt performance in a context of use to ensure that lift trucks are operated safely?
- How does wearing a seat belt affect operator comfort and work performance?
- What are the characteristics to look for or avoid in promoting seat belt use and operator safety?

Based on information from the literature and the Internet, and seat belt data collected in several Québec companies, this exploratory study sets out to answer the above questions. By choice, and within the project's limited scope, the study focus on technical seat belt characteristics and is meant to provide a basis for identifying available technologies on the market and understanding their operating mechanisms, thus highlighting potential safety and usability issues.

---

[2] *ISO 9241-11 defines* ***usability*** *as "the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction, in a specified context of use"* (Wikipedia). This term is generally used in computer interface analysis. In this study, the term is used to describe, in various contexts, the extent to which a type of seat belt is easy to use, allows the operator to perform work, and causes no particular discomfort or dissatisfaction.

The initial study design also proposed to identify available helmets that would most effectively protect the operator's head against impact with the ground or the truck's protective structures during a tipover. After a preliminary analysis, it quickly became evident that because operators are often required to move around in the workplace, they should use helmets certified for industrial/construction use, ideally Type II, designed to sustain lateral impact, as prescribed by ANSI Z89.1-2009 American National Standard for Industrial Head Protection. This requirement significantly narrows down the choice of helmets and, consequently, this issue was not further examined in this study.

1.2 Content of the report

The first component of the project, a literature and Internet review, made it possible to identify and characterize a number of seat belts available on the market, identify Canadian seat belt standards and regulations and discuss the protection offered by these seat belts. This phase also included visits to lift truck equipment distributors. The results of this phase are presented in Section 2 of this report. Concurrently, a second component surveyed the main factors promoting or hindering seat belt use (such as discomfort or performing work). The information was gathered in companies through interviews with lift truck operators and managers, actual work observations and activity simulations. The methodology and results of this in-plant study are presented in Section 3. Guidelines to help companies choose a seat belt are provided in Section 4. Lastly, the study limitations and remaining issues are discussed in Section 5.

2. THE LAP BELT AND SAFETY

This section describes the different types of lap belts available on the market. It introduces the associated standards and discusses factors that can affect protection during accidents. This survey is based on a literature review. OHS and engineering databanks (Canadiana, CSST, Compendex, Ergonomics Abstracts, ERIC, Google Scholar, INRS, NTIS, OSHLINE, OSH Update, Pascal, PsycINFO, PubMed, Social sciences full text) and the Internet were consulted. The search identified only a very small number of studies on seat belts used in off-road vehicles. No studies were found that addressed seat belt use in lift trucks and the relation to work performed.

Studies on construction, forestry, agricultural and road vehicles were also reviewed, although these vehicles are used for different types of work activities and in different operating conditions than lift trucks. The study of Smith et al. (2005) of the U.K. Health and Safety Executive (HSE) on seat belt performance for quarry vehicles is one of the most comprehensive and relevant in the area. Myers (2006), in a study addressing seat belt use in agricultural tractor overturns, states that there are no seat belt performance criteria in the event of overturns; he quotes Rains (2000), who stresses the lack of research on tractor seat belt effectiveness.

Information on seat belt performance and manufacturing standards can be found online, however. For instance, the ISO and SAE standards contain material on acceleration-related locking thresholds, seat belt manufacturing and testing bench design. In addition, an automatic locking retractor (ALR) and two types of emergency locking retractors (ELR) were purchased to explain how these mechanisms work and their potential malfunctions. In this study, these retractors were not subjected to performance tests as described in the standards.

Before analyzing these standards and scientific papers, it is important to understand the types of seat belts that are available and their functions.

2.1 The lap belt and its components

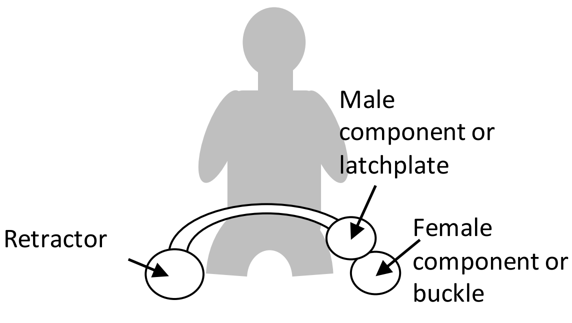


Figure 1. Lap belt

The seat belts sold to companies for installation in lift trucks are “lap belts,” also called “pelvic” or “sub-abdominal” belts (Figure 1). They consist of webbing that extends over the hips, a fastening system and two anchorages on either side of the user, as shown in Figure 1. They usually have a retractor that automatically rewinds the webbing into a housing. The purpose of the seat belt purpose is to contain the operator at all times within what is considered a safe zone, whether during normal operations, accidents or tipovers.

2.1.1 Webbing

The webbing is a flexible component typically made of woven polyester strands. It is designed to contain the body within the vehicle and transmit force to the anchorage points through the buckle. The webbing is usually 5 or 7.6 cm (2 or 3 in.) wide, 110 to 150 cm long and can elongate by up to 20% on application of an 11.1 kN force (cf. standard SAE J386). It comes in a range of colours. Brightly coloured webbing makes it easy to see from a distance whether the seat belt is being worn. There are also extensions typically measuring 20 cm (8 in.) that can be used by solidly built operators.

2.1.2 Anchorages

The anchorages are attachments to which the seat belt parts attach. They can be located on the floor of the lift truck or, ideally, on the seat structure. They are usually made of steel and can withstand a very strong force.

2.1.3 Belt buckle

The seat belt fastening system has two components: the female component, or buckle, and the male component, or latchplate. This system can withstand heavy loads during an accident yet remains easy to open, even if the belt is or was heavily loaded. Annexe A provides more details on these components.

2.1.4 Webbing adjustment system

The webbing length can be adjusted manually or automatically by means of a retractor, depending on which type of belt is selected. The next section explains how various webbing adjustment mechanisms work.

2.2 Manually adjustable belt

There are several types of manual adjustment. Like airplane passenger seat belts, some belts can be adjusted by taking up the slack in the webbing that passes through the latchplate, ensuring that the webbing locks.

Other belt assemblies have a spool that turns around a central axis and rewinds the webbing (Figure 2). One or two locking gears (flat toothed cog) are attached to the spool. These gears usually form the spool’s side walls, which direct the web rewinding. A locking mechanism stops the spool from unwinding by maintaining a locking plate engaged with one or more teeth of the gear(s). The mechanism can be manually unlocked so that the webbing length can be adjusted as needed. In Figure 2, a red release button actuates the mechanism. A coiled rewind spring system, attached to the spool, automatically respools the webbing if it needs to be shortened, after first releasing the locking mechanism.

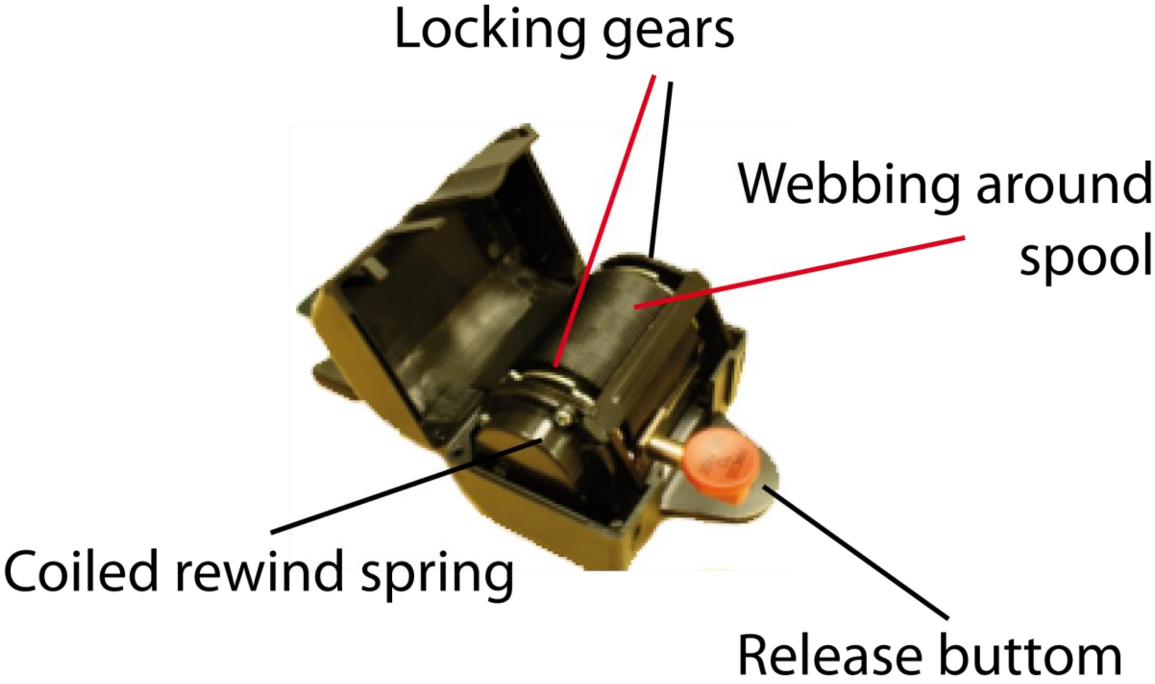


Figure 2. Interior view of a manual retractor.

2.3 Automatically adjustable belt

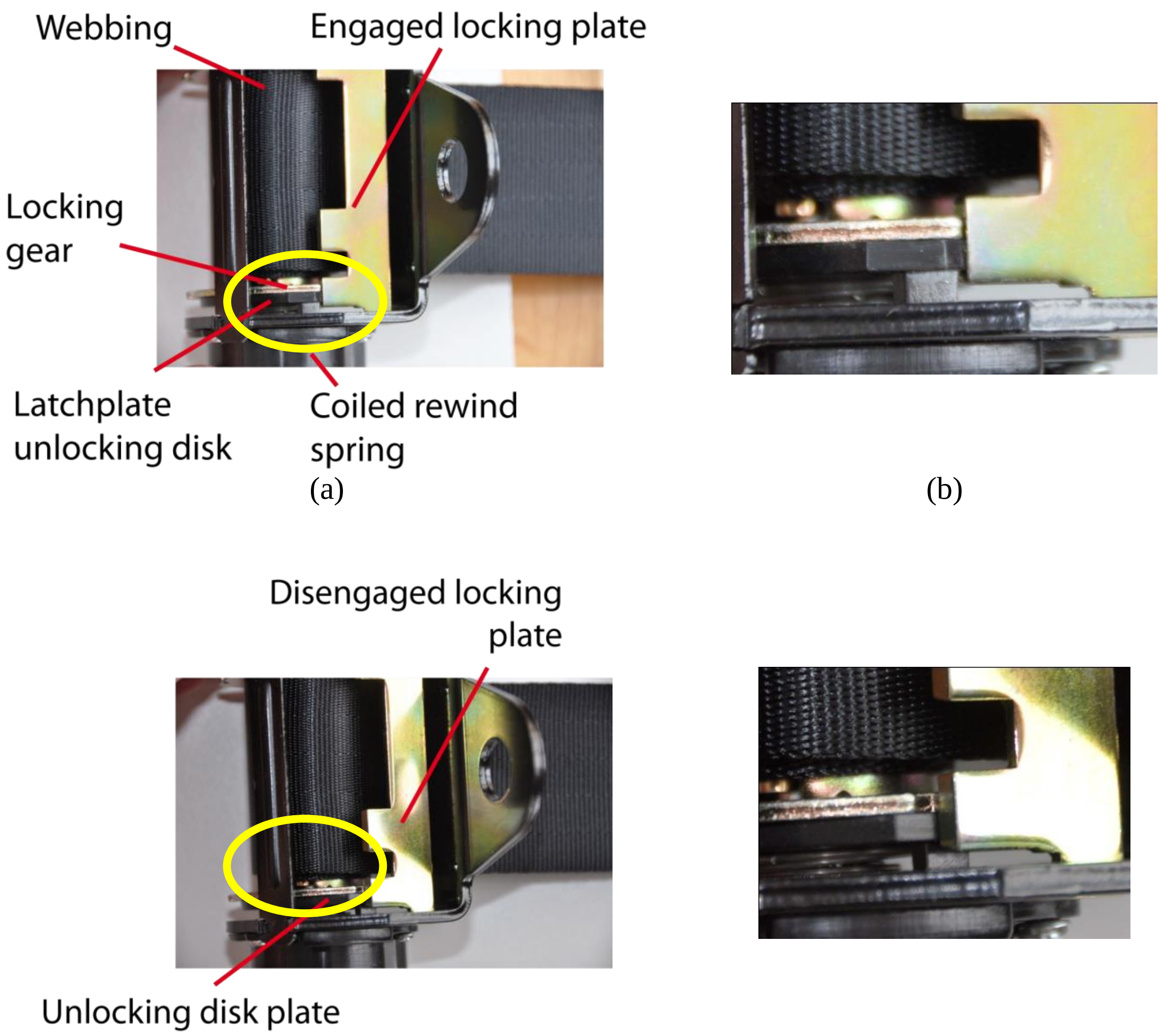
Automatic locking retractors (ALR) or emergency locking retractors (ELR) automatically adjust the webbing length. This section briefly explains how these retractors function.

2.3.1 Automatic locking retractor (ALR)

An automatic locking retractor is designed to rewind any surplus webbing, with no action by the operator, and then at all times prevent the webbing from extracting by means of a gear locking system rigidly connected to the spool. The maximum pre-locking extraction length is partially determined by the number of teeth on the locking gear(s) (Figure 3). This type of retractor has the advantage of effectively restraining the operator, but the disadvantage of constantly tightening on the user as soon as there is enough slack in the belt, due to the coiled rewind spring. This gradual retraction is commonly known as “cinching.”

Cinching may occur, for instance, when the lift truck is moving over a rough surface with a suspension seat and the belt is anchored to the floor or the vehicle structure rather than the seat. The problem is mitigated if the anchorages are mounted on the seat, but this issue can also arise if there is foam on the seat surface and a large number of teeth on the locking gear(s).

To loosen or readjust the belt, the user must unfasten and automatically respool it up to the retractor, through the action of the spiral rewind spring connected to the spool, which can make it tedious to use. Internet research, a visit to a lift truck parts supplier and in-plant observations showed that many lift trucks are currently fitted with ALR seat belts.



(a) (b)

(c) (d)

Figure 3. Interior view of an ALR.

a) Engaged locking plate, b) macro view of engaged locking plate, c) released locking plate and d) macro view of released locking plate.

2.3.2 Emergency locking retractor (ELR)

An ELR will automatically adjust the seat belt to the volume of the operator's body located between the belt and the seat, while keeping minimum tension in the webbing. Rewinding is done through a spiral rewind spring and, in normal operating conditions, unwinding occurs freely in practice under minimum webbing tension. In some operating conditions, however, the webbing may be automatically locked by one or more toothed levers attached to the spool (cf. Figure 4a) or the retractor housing (cf. Figure 4b, 4c). These levers engage with the respective locking gear(s) of the housing, retractor or spool. The retractor locks only if:

1. the lift truck accelerates or decelerates beyond a specific threshold in any direction;
2. the lift truck tilts excessively from the horizontal; and, in some cases,
3. the rate of change in webbing extraction speed (i.e. its acceleration) or the extraction speed itself exceeds a specific threshold (cf. system as discussed by Cannon et al. 2002).

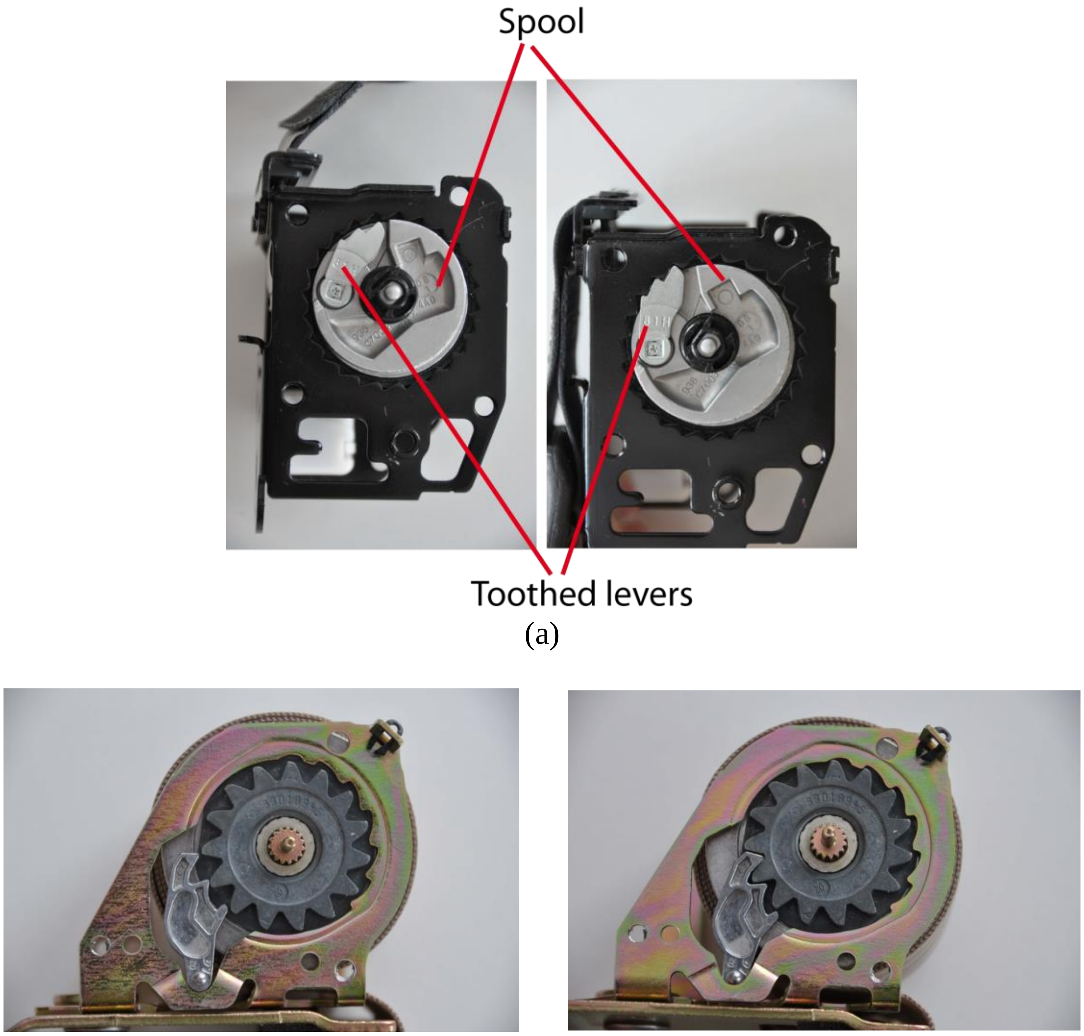
As mentioned, these levers can be actuated by a mechanism sensitive to the spool's angular acceleration or, according to information found in the literature (Cannon et al. 2002), the spool's angular speed. This type of belt is called an "anti-cinch" belt because it does not cinch on the operator when he/she moves relative to the seat, as can happen in the presence of vibrations. This type of retractor has been used for many years in road vehicles.

According to the existing seat belt standards, a retractor must have at least six basic functions (e.g., SAE J386:2006):

1. Locking shall have occurred when the deceleration of the machine reaches 0.7g[3];
2. The retractor shall not lock for values of acceleration of the webbing (rate of change of webbing extraction speed) of less than 1g;
3. The retractor shall not lock when tilted within a 12 degrees range from the reference position. When a retractor is fitted on a lift truck, its tilt must therefore be properly adjusted (*Authors' note: this function is designed to prevent the seat belt from locking if the vehicle is slightly tilted*);
4. Conversely, it must lock when tilted more than 40 degrees from the reference position;
5. Retractors sensitive to webbing acceleration only shall not be used for pelvic restraint;
6. The amount of webbing movement which may occur before the retractor locks shall not exceed 50 mm.

---

[3] Here "g" designates Earth's gravitational acceleration, which is 9.81 m/s^2



(a)

(b) (c)

Figure 4. Interior side view of an ELR.

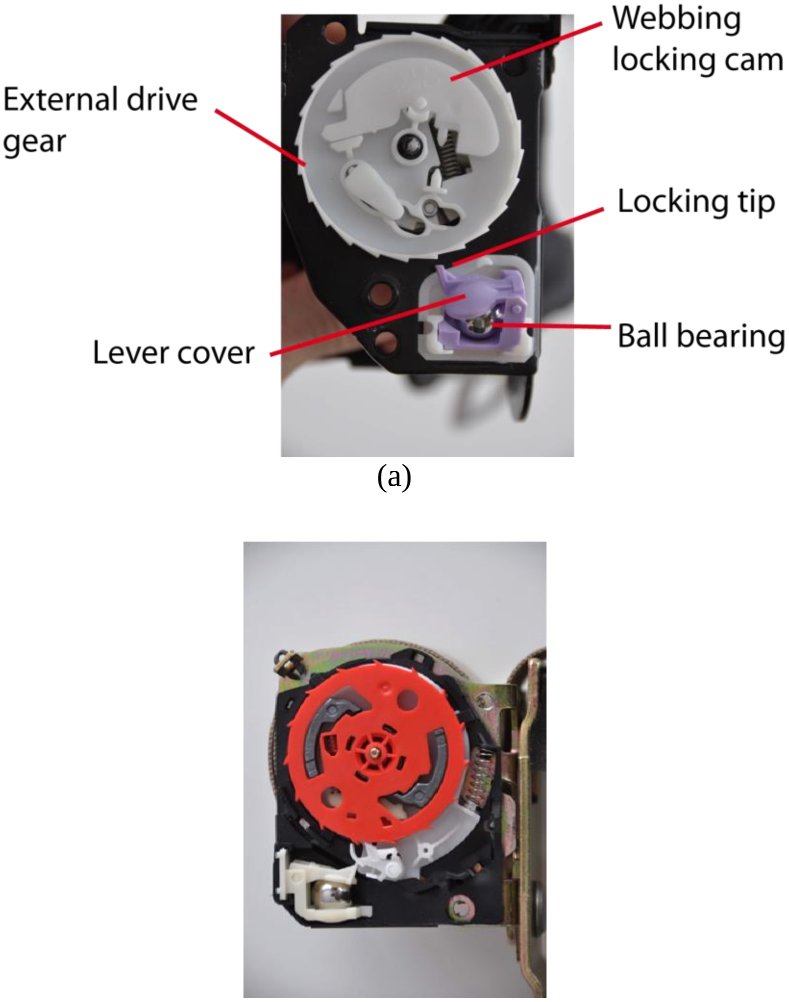
a) Levers attached to the spool, b) levers attached to the housing in released position c) in locked position. The system shown in (b) activates based on the spool's angular acceleration (NOTE: activating system not shown).

Other standards contain similar criteria (e.g., ISO 24135-1, FMVSS 209 or ECE/324 UN regulation 16), but the quantitative values may vary from one standard to another.

An ELR locking system is actuated by different mechanisms based on the functions listed above. In every case, the mechanisms are designed to actuate the metal locking lever(s), as shown in Figure 4. When any of the actuating mechanisms activates, the locking levers pivot radially until they engage with the gear(s) on the spool or housing.

2.3.2.1 Locking mechanism based on retractor acceleration or tilt angle

A well-known locking lever actuation system consists of a ball bearing enclosed in a cavity (Figure 5) by a lever cover, with a locking tip at its extremity, that can engage with the external drive gear (red or white toothed gear shown in Figure 5). Engagement occurs when the ball raises the cover after the retractor accelerates by 0.7g or more according to standard SAE J386, or its angle relative to ground changes by more than 40 degrees according to the same standard. After the locking tip engages with the external drive gear, the drive gear rotates and causes the metal lever to pivot, locking the spool through the locking gear located on the spool or housing. This system is shown in Figure 6.



(a)

(b)

Figure 5. Interior side view of a ball ELR.

White (a) or red (b) external drive gear, depending on the retractor model.
Vehicle-acceleration-sensitive locking mechanism.

Note that the 0.7g acceleration threshold is equal to a static retractor tilt angle of 45^{o}, which makes the static threshold (40^{o}) compatible with the 0.7g dynamic threshold. A static tilt angle of 40^{o} exerts a force equivalent to 0.64g (i.e. $g \cdot \sin(40^{o})$) on the ball bearing. This compatibility is guaranteed as long as the static threshold prevails in the locking mechanism design; otherwise, the static threshold cannot be respected. Clearly, as per the very concept of a ball locking system, the retractor must be installed at just the right orientation relative to ground; otherwise, its functionality may be limited.

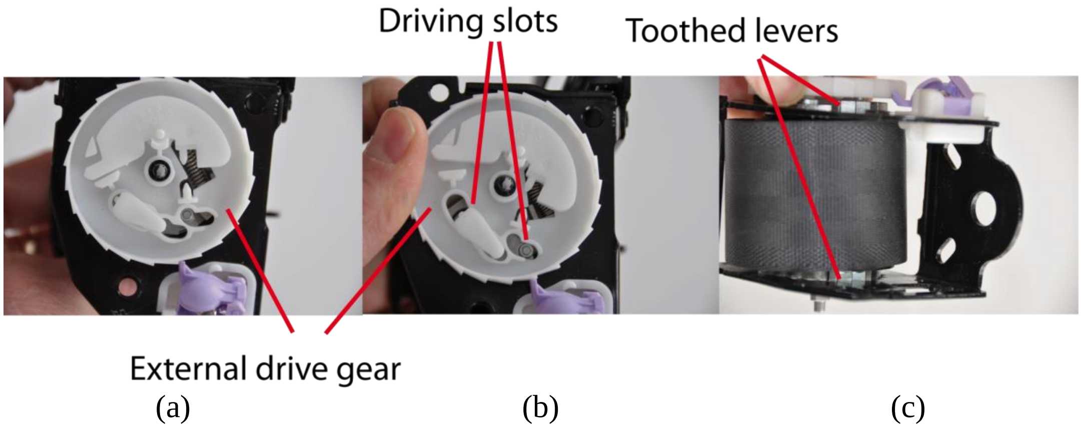


Figure 6. Spool locking mechanism of a vehicle-acceleration-sensitive ball ELR

a) Side view of onset of engagement, b) fully engaged system c) view of engaged toothed levers.

Pendulums that act like the ball system also exist, as shown in Figure 7. A change in retractor tilt angle or acceleration causes the pendulum to rotate relative to its pivot, simultaneously actuating the locking plate that engages with the drive gear. Other actuating mechanisms could be used, but they must satisfy the six functions listed in section 2.3.2.

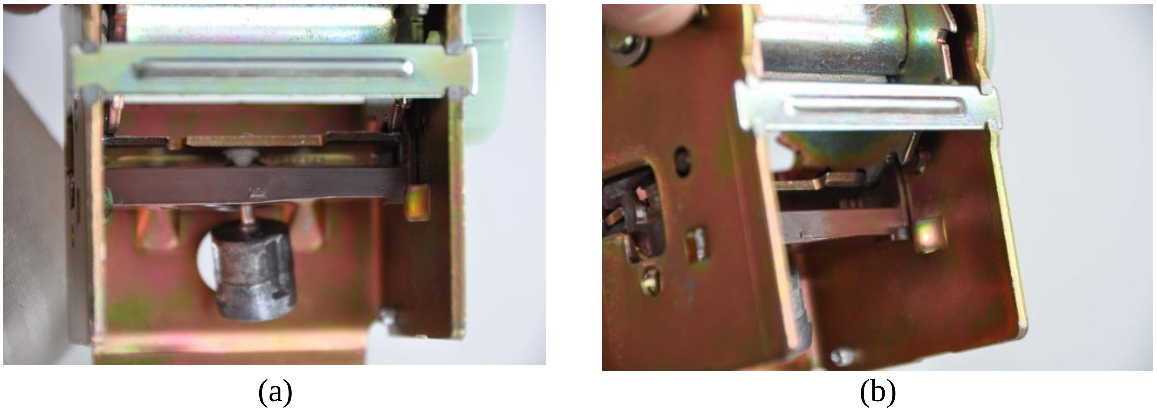


Figure 7. Spool locking mechanism of a pendulum ELR.

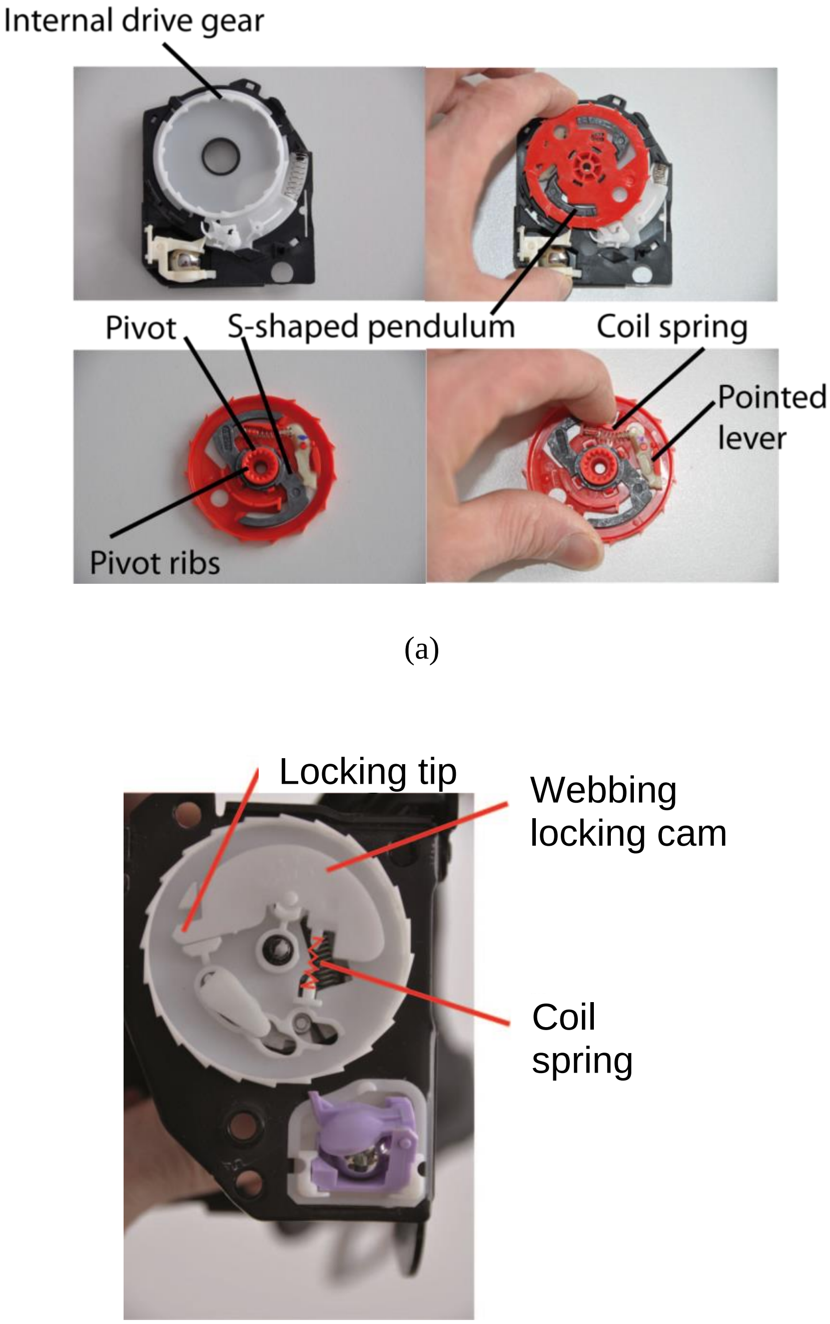
a) Onset of pendulum activation and b) Locking plate engaged in the locking gear.

2.3.2.2 Locking mechanism based on webbing extraction speed or acceleration

There seems to be some confusion about this mechanism in the literature. For example, in Figure 4 of their paper, Cannon et al. (2002) suggest that the mechanism is a function of centrifugal acceleration, which is a function of the spool's angular velocity. The mechanism shown could also be a function of the spool's angular acceleration, as some components are probably not shown. Moreover, because the standards are based on webbing acceleration, and thus angular acceleration of the spool, the system shown by Cannon et al. (2002) very likely reacts to angular acceleration of the spool. Standard ISO 24135-1:2006 (see section 2.6) also suggests that the webbing locking system could be sensitive to extraction speed. Although this function could be relevant for lift truck use, the current U.S. standards contain no related requirements.

Further confusion arises from the locking criterion itself, as expressed in SAE J386, which states that the seat belt must not lock for accelerations of the webbing under 1g, but says nothing about accelerations beyond 1 g. Despite the confusion surrounding the webbing-extraction-sensitive locking criterion, ELR seat belt manufacturers have introduced a mechanism that stops the webbing from unwinding when the spool's angular acceleration is too high. However, the required threshold for this function is not specified in SAE J386; E/ECE/324 sets it at 2g, while Aerospace Standard 8043 sets it at 1.5g (SAE 8043, 2008). For SAE J386, it may be implicitly assumed to be 1g.

A mechanism that complies with the 1g webbing extraction criterion is shown in Figure 8, for two different retractor models. This figure is an interior view of the drive gear shown in Figure 5. The mechanism with a red gear is an S-shaped pendulum (grey in the figure) which is free to rotate (over a span of just a few degrees) around a pivot that is an integral part of the drive gear interior. The interior teeth of the gear engage with the spool. Upon angular acceleration of the spool, the drive gear automatically accelerates as well, but the pendulum is only accelerated by the action of a coil spring. Given the pendulum inertia about the pivot, there must be sufficient angular acceleration of the spool to cause the pendulum to pivot until it causes a pointed lever to pivot radially (in white plastic in the photograph in Figure 8a, lower right). Once the pointed lever has pivoted sufficiently (this is directly related to the amplitude and duration of angular acceleration), it engages with the drive gear's internal teeth, causing it to rotate in turn and finally causing the metal toothed lever to pivot radially and stop the spool from rotating. The coil spring allows the pendulum to swing back and unlock the webbing when its acceleration falls below 1g. A similar pendulum system in the form of a cam is shown in Figure 8b with the white actuating gear mechanism shown in Figure 5.



(a)

(b)

Figure 8. ELR web locking mechanism with drive gear for two different systems.

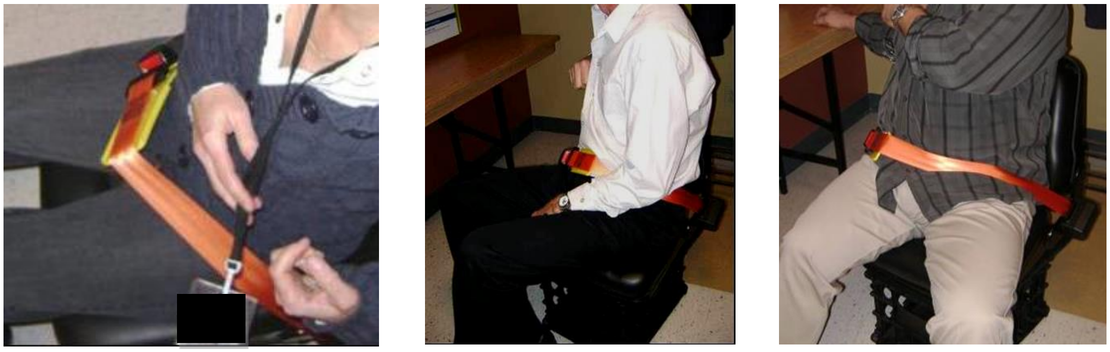
The two locking systems have a ball mechanism but do not have the same web locking system. In the second case (b), the internal drive gear was removed for clear visual access.

2.4 Other devices that can be combined with seat belt assemblies

2.4.1 Leaf spring system

A new type of seat belt assembly for lift trucks has been on the market for some years now. This is a standard lap belt with a plastic-covered metal leaf spring on the buckle side (female part). A plastic plate extends about 18 cm (7 in.) beyond the attachment. This semi-rigid component is meant to prompt operators to fasten their seat belt because it is located in front of the truck controls, hinders operations and prevents the operator from sitting properly unless he or she is wearing the seat belt. This system does not adjust webbing tension, but encourages seat belt use. The belt assembly is fitted with an automatic locking retractor (ALR) that complies with various standards, including SAE J386.

Currently, this type of seat belt is rarely used in lift trucks in Québec and it has not been evaluated in the workplace. A lift truck equipment supplier allowed us to briefly examine this seat belt assembly. The tension created by the metal spring prevents the retractor from fully taking up the slack in the webbing. Three subjects tested the belt, without forcing the retractor to respool the surplus webbing and thereby offset the tension in the spring. There can be considerable slack with a slender person (Figure 9a). For a slender man (Figure 9b), there is approximately 8 cm (3 in.) of slack. There is less slack, although still some, for a person with a bigger waist circumference (Figure 9c). The slack left in this type of belt may allow greater freedom of movement for work purposes (e.g., trunk rotation or lateral flexion), but too much slack could compromise operator safety (section 2.7.3 provides more information on proper seat belt adjustment).


[redacted]

(a) (b) (c)

Figure 9. Leaf spring belt trial by three subjects.

(a) Slender woman (b) slender man (c) overweight man.

2.4.2 Anti-cinching

To improve operator comfort, manufacturers offer an anti-cinching system that can be added to belts with ALR retractors. The system can be installed between the buckle and the anchorage point on the floor or the seat, or integrated with the retractor (cf. Figure 10). It consists of a spring or other device and allows the belt to stretch when operator movement exerts a pressure on the webbing.

(a) (b)

Figure 10. Anti-cinching buckle.

a) At rest and b) in use.

2.4.3 Scraper

There may also be a webbing scraper at the retractor opening to reduce contamination inside the retractor and decrease the risk of it being jammed by twisted webbing.

2.4.4 Ignition interlock and warning signal

An ignition interlock system can be installed to prevent the vehicle from starting unless the seat belt is fastened. It may be combined with a seat occupancy sensor system. Other systems will sound an alarm if the vehicle is started before the seat belt is fastened.

2.4.5 Other devices

Numerous other devices are available but the literature makes no reference to any that can be used in lift trucks. In every case, these devices are fitted on belts with an upper body restraint: comfort adjuster, pretensioner, pre-pretensioner, weblocker, load limiter, digressive load limiter, elastic fibers, belt-integrated airbag. Although currently used in road vehicles, research could be done on some of these devices to evaluate their effectiveness in the case of lift trucks. Annexe B provides more details on these devices.

2.5 Other types of belt assemblies

Other types of belt assemblies include the three-point lap-diagonal belts used in automobiles. Harnesses, which can have three or more anchor points, are also used in some construction vehicles and racing cars. The literature review showed no use of this type of seat belt in lift truck applications. In a study on quarry vehicles, Smith et al. (2005) compared the lap belt, diagonal belt and harness. They concluded that, overall, better torso restraint decreased the risk of contact with cab structures. In a frontal impact, for example, a lap belt does not prevent forward movement of the trunk. As a result, the abdomen could strike the steering wheel and the head could strike the steering wheel or other nearby structures. Furthermore, in static and dynamic lateral tipovers, a lap belt does not prevent the trunk from moving forward or sideways, which may result in head or neck injury. Readers can find a more detailed description of lap-diagonal belts and harnesses in Annexe C.

2.6 Seat belt standards

A number of provincial health and safety organizations in Canada specify that FOPS-equipped mobile vehicles and crane tractors must have safety belts meeting the requirements of "*Society of Automotive Engineers (SAE) Standard J386 Feb 2006, Operator Restraint System for Off-Road Work Machines*." Standard SAE J386 generally provides the specifications and performance tests for belt components such as anchorages, webbing, buckles, etc.

There are a number of seat belt standards applying to either road vehicles or work vehicles. Two standards apply directly to seat belt use in lift trucks: SAE J386 and ISO 24135-1 2006. Standards ECE/324 UN Regulation 16 and FMVSS 209 regulations paraph. 571.209 of the Department of Transportation (USA), which apply to road vehicles, have similar requirements, showing that there is some international consensus on this matter. However, such consensus is not necessarily indicative of sufficient performance based on the kinematic conditions of vehicle tipover. The following sections present the main relevant specifications of these seat belt performance standards. ELR performance thresholds are compiled for each standard in Table 1.

Table 1. Comparison of ELR webbing locking performance thresholds according to different standards*

Webbing locking condition		SAE J386 :2006 Off-road work vehicles	ISO 24135-1 :2006 Industrial lift trucks	FMVSS 209 :2008 Road vehicles	E/ECE/ 324 :2009 Road vehicles and tractors for agriculture and forestry	Aerospace Standard 8043 Aeronautics
Locking	Retractor orientation (relative to its reference installation position)	≥ 40°	≥ 30°	≥ 45°	≥ 27°/45° depending on retractor type	N/A
	Retractor deceleration	> 0.7g	idem à SAE J386 ou E/ECE/324	> 0,7g	> 0,45/0,85g depending on retractor type	> 1g
	Webbing extraction acceleration	Not defined**, - Must not be the only locking criterion	idem to SAE J386 or E/ECE/324	> 0,7g	> 2g	> 1,5g
	Maximum webbing extraction on activation of locking system	50 mm	idem to SAE J386 or E/ECE/324	25/51 mm	30 mm	25,4 mm
Non-locking	Retractor orientation (relative to its reference installation position)	≤ 12°	idem to SAE J386 or E/ECE/324	≤ 15°	≤ 12°	N/A
	Webbing extraction acceleration	< 1g	idem to SAE J386 or E/ECE/324	< 0,3g	< 0,45/0,85g depending on retractor type	< 1,5g

* For simplicity, only tilt angle positive thresholds are indicated. Hence, a threshold of ≥ 40° represents either ≥ +40° or ≤ -40°.

**Manufacturers most likely include a mechanism for locking over 1g.

It should be noted that some Canadian provinces include seat belt standard SAE J286 in their lift truck regulations. For example, Nova Scotia requires a seat belt that meets or exceeds the criteria of SAE J386 (OHSA, 1996). Québec has its own regulations and is not subject to this standard.

On the one hand, the Regulation respecting occupational health and safety (ROHS) states that lift trucks built before August 2, 2001 must conform to standards CSA B335.1-1977 or ANSI B56.1-1975, and to ASME B56.1-1993 if built on or after that date. There is no article in the ASME standard specifying the use of any kind of belt whatsoever, nor any recommendations on choosing a belt or detailed belt performance in terms of restraining the operator in the cab during tipover. On the other hand, section 256.1 of the Québec ROHS does not identify any type of seat belt or standard applicable to lift trucks.

2.6.1 SAE J386:2006

According to standard SAE J386 on off-road work vehicles, a company must regularly inspect seat belts and their components and follow manufacturers’ recommendations. Damaged or worn parts, or abraded or torn webbing, must be replaced. The literature also recommends replacing the seat belt assembly after an accident, but none of the material consulted specified the useful life of a seat belt.

SAE J386 defines the minimum design requirements for pelvic restraint systems (belts, anchorages, assembly hardware, etc.) needed to restrain an operator within the vehicle during a collision or tipover. It also provides the performance tests required to certify the restraint system. This standard is similar to the others in terms of seat belt requirements for off-road or even road vehicles. Section 5.4 of SAE J386 is particularly relevant with regard to automatic and emergency locking retractors.

Seven requirements are listed for ELR systems, six of which are described in section 2.3.2 of this report. As explained in section 2.3.2.2, the webbing extraction acceleration criterion is confusing. When selecting a belt, it would be advisable to check that the webbing extraction acceleration criterion also has an upper limit beyond which the webbing will jam, although this is not explicitly required by SAE J386. The performance tests recommended by the standard do not require testing above a 1g threshold, but it may be assumed that the standard contains an implicit locking threshold of 1g or more.

The SAE standard includes an additional requirement if the webbing is locked by an automatic system controlled by an external signal or source. The standard also stipulates that vehicle-tilt-sensitive retractors shall still operate at extreme tilt angles when the vehicle is at idle. However, the term “operate” is not clearly explained.

2.6.2 ISO 24135-1:2006

This standard on industrial lift trucks stipulates that seat belt assembly components must conform to SAE J386 or ECE/324 Regulation 16. This regulation is almost identical to SAE

J386, but includes a few more specific criteria for lift trucks, primarily related to performance and testing.

Like SAE J386, ISO 24135 includes a section on retractors (section 4.4). Unlike the SAE standard, however, the ISO standard states that an ELR’s locking function must not depend solely on webbing extraction speed or acceleration but also on the lift truck’s lateral tilt angle, which must not exceed 30°.

2.6.3 FMVSS 209:2008

This standard, which applies to road vehicles, provides details that allow a better understanding of SAE J386. The requirements are similar to SAE J386, except that for ELRs, the webbing extraction criterion is set at 0.3g instead of 1g. However, the description of the performance criterion for this aspect is identical, so it remains unclear whether locking should occur when acceleration exceeds 0.3g or not. Although not explicit in the list of criteria, careful analysis of the test procedure indicates that the retractor must lock the webbing for **extraction** of 0.7g. Lastly, the standard states that the retractor must lock the webbing for **retractor accelerations** beyond 0.7g.

2.6.4 E/ECE/324:2009 Addendum 15: Regulation 16, Rev. 6

This UN standard, which mainly applies to road vehicles, establishes specifications for restraint systems. It also covers standard forestry and agriculture tractors. The standard contains almost the same provisions as those described above, but provides additional explanations that help clarify the other standards. This standard is more explicit regarding the webbing extraction acceleration criterion for ELRs, stipulating that the retractor must lock when webbing acceleration exceeds 2g.

2.6.5 SAE AS8043

This SAE standard applies to aircraft seat restraint systems. Evidently, tilt is not a performance criterion but aircraft deceleration is, with 1g as the ELR locking threshold. The values provided differ significantly from the other standards and locking must occur when webbing extraction acceleration reaches 1.5g.

2.7 Discussion on lap belt performance

The existing seat belt standards require minimum mechanical resistance for components and functionalities that clearly emerged from long experience with road vehicles. Seat belt performance in one kind of accident, however, is not necessarily the same as in another, particularly in lift truck operation, because the accelerations/decelerations/speeds involved are lower and there is usually no closed cab to contain the operator. A number of issues must thus be addressed with respect to lap belt performance, including:

1. failure modes;
2. compatibility of ELR standards with ELR use in lift trucks;
3. nominal lap belt adjustment;
4. false unlatching;
5. tests reported in the literature.

2.7.1 Preliminary review of lap belt failure modes

Not only can separate seat belt components fail, but seat belts may fail to perform as expected in conditions that are important to determine. The manual seat belt (i.e. no retractor) seems reliable because of the small number of assembly parts involved, but is also the least user-friendly. Seat belts with a manual retractor also seem reliable, but include a manual unlocking system that could be subject to mechanical failure. ALRs and ELRs are more complex, even functionally, so there is more chance of failure.

It is impossible to cover the potential failure modes of all seat belts on the market. However, it is worth analyzing the failure modes of typical ALRs and ELRs available from various suppliers to give an indication of issues that are probably common to many retractor designs. This analysis provides guidelines for any seat belt assembly under consideration.

2.7.1.1 ALR mechanical failures

ALRs have few parts, but some of them are mobile. The retractor analyzed in this study, shown in Figure 3, can apparently fail in at least three ways.

First, the latchplate is a component that swivels by means of rudimentary pivots and responds to a rewind spring, also very simple. If this spring breaks or disengages, the metal levers in the spool gear may fail to lock in a wide range of retractor movement conditions. The spring can also sag over time, in which case it may not pull back the latchplate enough to initiate locking. None of the standards address spring quality other than through general functional tests on the retractor.

Second, dust or grease may interfere with the swinging motion of the latchplate, preventing the retractor from locking when the webbing is subject to a force seeking to initiate unwinding.

Third, the latchplate unlocking disk is known to activate if the webbing is suddenly released, then quickly withdrawn (cf. Figure 3), allowing unwinding if tension is maintained. The latchplate unlocking disk normally stops operating once the webbing unwinds to a length of approximately 10 cm. Because the latchplate unlocking disk is driven by the spool, through friction between two surfaces in direct contact, the presence of dust or grease may facilitate such failure. This third type of failure readily occurs if the webbing is slightly unwound but, fortunately, much less readily if the webbing is unwound to a length corresponding to that used during normal operation. To our knowledge, this type of failure has not been reported in the literature.

In short, it is imperative to maintain ALRs regularly and clean the components as necessary in order to prevent the failure modes described above.

2.7.1.2 ELR mechanical failures

ELRs have many parts, several of which are mobile and made of plastic. One of the retractors analyzed in this study, shown in Figure 4, can fail in three ways.
First, the plastic parts, even if subjected to lower forces, can still age and potentially break. This type of failure has not been described in the literature and none of the standards address the quality of these parts.

Second, the presence of dust or grease can obviously hinder the movement of small sliding or pivoting plastic parts, limiting their functionality and preventing the belt from locking at the thresholds required by the current standards.

Third, although not a failure per se, the locking mechanisms are micromechanical and the tolerances associated with the parts probably play an important role. Tolerances that are too high could cause the retractor locking thresholds to vary. ERLs should be kept in good working condition through regular maintenance.

2.7.2 Compatibility between ELR standards and use in lift trucks

The current seat belt standards are more applicable to automobile driving. Traffic accidents often occur at high speeds and/or with significant deceleration, kinematic conditions quite unlike those observed in lift truck tipovers. There are several types of lift truck tipovers, from simple lateral, frontal or rear tipovers at low speed, to high-speed tipovers on a J-shaped trajectory or frontal or rear impacts. During such tipovers, lift truck and operator speed and acceleration vary widely and, to our knowledge, no study has produced quantitative statistical data on this subject.

The research of Bourret et al. (2008) does however provide information that is useful in estimating these kinematic variables. In a lateral tipover, Table 1 of Bourret et al.’s study (2008) reports tipover times on the order of 1 to 1.5 seconds. Frontal, rear or lateral tipover at low forward speed is of about the same duration. Tipovers in a J-shaped trajectory are a function of travel speed and radius of curvature, as well as lift truck properties. Simulations carried out by Bourret et al. (2008) show that this kind of tipover also lasts on the order of 1 to 1.5 seconds. Lastly, tipover times for frontal and rear impacts are contingent on multiple factors and are much faster, lower by an order of magnitude, unless the lift truck follows a complex, three-dimensional trajectory after impact.

For actual accelerations, retractor acceleration during a lateral tipover is approximately $g \sin\theta$ the same as the ball bearing locking mechanism, as well as the operator who, for all practical purposes, remains seated during a lateral tipover. The same applies to frontal or rear tipovers. For J-shaped tipovers, the studies of Bourret et al. (2008) show that the lift truck is subject to an acceleration with a magnitude that varies based on a number of parameters, including tire properties and lift truck characteristics. For example, the simulations they did with Visual Nastran software show centripetal lift truck accelerations between 0.7g and 2g during J-shaped tipovers. In such conditions, operator acceleration relative to the seat may vary depending on whether the operator manages to stay inside the cab or continues along his original trajectory when the lift truck turns. In the second case, the operator would accelerate by 0.7g to 2g relative to the lift truck at the onset of the tipover. However, because the operator is not entirely free and may, deliberately or by reflex, try to remain inside the cab, the level of acceleration relative to the seat may be below 0.7g, especially if the lift truck follows a complex trajectory during the tipover.

In light of these findings, it is worth determining whether the locking thresholds proposed in the current seat belt standards are compatible with lift truck tipover kinematics in relation to ELRs, given their clear usability advantages.

The kinematics, however, vary by type of tipover. Tipovers can be classified into three types:

1. Frontal, rear or lateral tipovers at low forward or backward speed;
2. Tipovers after the truck follows a J-shaped trajectory on a horizontal or sloped surface;
3. Tipovers following frontal or rear impact, for example, when the lift truck hits a curb with only one of the front wheels. The lift truck may or may not tip over after impact.

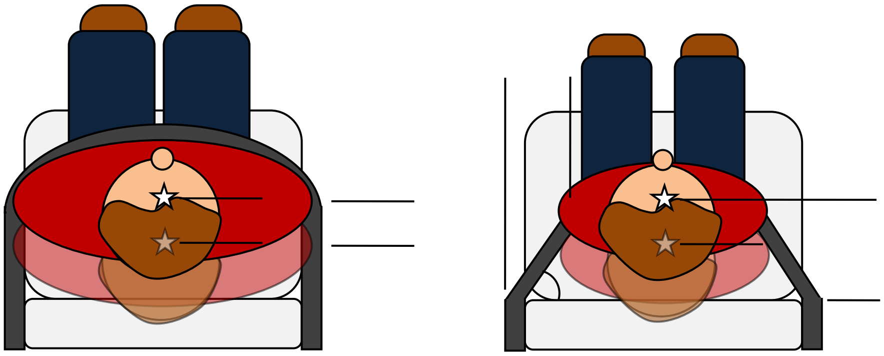
To clarify the compatibility of the locking thresholds in the standards, we will begin by explaining each in detail and analyzing its contribution to operator protection. A summary will then provide a general assessment of the compatibility of all locking thresholds for each type of tipover.

2.7.2.1 Locking thresholds based on webbing extraction acceleration

Standard SAE J386 states that the webbing must not lock if the webbing accelerates by less than 1g, but imposes no locking threshold over 1g. Presumably, manufacturers have implicitly assumed that locking must occur above 1g, because they have added a webbing-extraction-related locking mechanism. Standard E/ECE/324 stipulates a 2g webbing extraction threshold, measured in the direction of webbing extraction, beyond which the seat belt must lock, but provides no guidance for the range between 1g and 2g. SAE AS8043, used in the aerospace industry, provides a single threshold of 1.5g: the webbing must not lock at lower extraction acceleration values, but must lock at higher values. Lastly, FMVSS 209 requires a non-locking threshold of 0.3g and a locking threshold at 0.7g.

These acceleration thresholds correspond in fact to webbing extraction relative to the retractor, not to absolute operator or lift truck acceleration. It is possible to estimate the acceleration levels the operator must reach, relative to the seat, for the webbing to undergo extraction acceleration equal to the extraction locking thresholds stipulated by the standards. It should be noted that if the operator does not move relative to the seat, the webbing-extraction-sensitive locking mechanism will not activate.

For purposes of calculating the relation between operator acceleration relative to the seat and webbing extraction acceleration, a bird's-eye view of an operator is shown in Figure 11. The operator is located at a distance s from the seat as the webbing extends by δL following forward movement δs of the operator. It can be seen that, for a large operator (cf. Figure 11a), the webbing unwinds predominantly in the sagittal plane starting from the anchorages. Consequently, for a webbing extraction acceleration $d^2L/dt^2 = 1g$ (according to SAE J386) (L being the length of the webbing withdrawn from the retractor), a large operator would accelerate by half, i.e. 0.5g, because $\delta s = \delta l = \delta L/2$. In other words, the operator would have to accelerate by 0.5g relative to the seat to activate the webbing extraction locking mechanism, because the standard provides a locking threshold of 1g for this criterion. The situation is similar for a strictly vertical movement, if we disregard the webbing angulation in the sagittal plane which allows the operator to accelerate upwards without significant webbing extraction (see explanations in section 2.7.3).



(a) (b)

Figure 11. Bird's-eye view of operator sitting on a lift truck seat.

Diagram showing operator movement and webbing extraction for a) a stout operator and b) a slender operator.

For a slender operator, the relation is different and more complex. Let's assume that the ends of the webbing form a minimum angle θ of 30 degrees relative to the frontal plane. Webbing acceleration d^2L/dt^2 can then be calculated for forward operator acceleration $a = d^2s/dt^2$. The diagram in Figure 11b shows that:

$$l^2 = u^2 + s^2 \qquad (1)$$

A chain derivative of equation (1) with respect to time yields:

$$2l\dot{l} = 2s\dot{s}$$

$$\Rightarrow \dot{l} = \frac{s}{l}\dot{s} \qquad (2)$$

A second time derivative provides the relation of webbing acceleration for a given operator acceleration:

$$\ddot{L} = 2\ddot{l} = \frac{2}{l}\left[s\ddot{s} + \dot{s}^2\left(1 - \frac{s^2}{l^2}\right)\right] \qquad (3)$$

At the onset of operator acceleration, webbing extraction acceleration will be given by:

$$\Rightarrow \ddot{L} = 2\ddot{l} = 2\frac{s}{l}\ddot{s} = 2\sin\theta\,\ddot{s} \qquad (4)$$

and will increase as the operator picks up speed relative to the seat. For an angle θ of 30 degrees and an initial operator at rest relative to the seat, webbing acceleration is equal to operator acceleration. In other words, for a 1g locking threshold, the operator must accelerate by 1g to activate the webbing locking mechanism. In practice, since the operator's body size is unknown, his acceleration relative to the seat must be considered to range from 0.5 to 1 times the webbing extraction acceleration threshold before the extraction locking mechanism activates, i.e. between 0.5g and 1g according to the threshold provided in SAE J386.

At this level of acceleration, locking that depends solely on webbing extraction would not protect the operator in every type of tipover. During low-speed tipovers, whether frontal, rear or lateral, the operator basically remains at rest relative to the seat and hence, does not accelerate sufficiently relative to the seat to activate webbing-extraction-sensitive locking. This is also true when a lift truck tips over after impact. The operator accelerates significantly relative to the seat on impact, causing the webbing to lock. However, lift truck post-impact kinematics may be complex and the webbing could potentially release. Depending on the level and duration of release, the extraction-based locking mechanism could disengage and then not relock during tipover.

For tipovers following a J-shaped trajectory, operator acceleration relative to the seat ranges from 0.7g to 2g when the lift truck is travelling on a horizontal surface. As the above calculations show, this level of acceleration is sufficient to cause extraction-sensitive locking, unless the operator attempts to remain seated and restricts his movement relative to the seat. If the J-shaped tipover occurs on a slope, the operator acceleration levels will also be lower and thus may fail to initiate webbing-extraction-based locking.

In summary, webbing-extraction-based locking protects the operator in a large proportion of J-shaped tipovers, but is not guaranteed to be compatible with all J-shaped tipovers. In such cases, the webbing could theoretically extract to a length of approximately 50 cm (assuming that the operator accelerates by 0.1g relative to the seat and the tipover lasts 1 second). In other words, the webbing could unwind to its full length and the operator could be crushed by the protective structure after the tipover.

2.7.2.2 Locking thresholds based on ELR acceleration

The standards recommend lift truck acceleration thresholds on the order of 0.7 g, after which the seat belt would lock through a mechanism other than webbing extraction. This threshold is clearly inappropriate for static frontal, lateral and rear tipovers, because the retractor accelerates by less than 0.7g for a good part of the tipover duration.

In principle, a retractor-acceleration-sensitive locking threshold of 0.7g would seem appropriate in many J-shaped tipover conditions. In these cases, centripetal accelerations of roughly 0.7g to 2g are observed (cf. Bourret et al. (2008)). The acceleration levels are lower when a J-shaped tipover occurs on a slope, however, and the locking threshold may cease to be relevant. It should also be remembered that in a J-shaped tipover, the retractor is subject to strong vertical acceleration when the lift truck tilts. This vertical acceleration increases the apparent gravitational acceleration on the ball mechanisms commonly used, such that the retractor acceleration needed to activate the locking mechanism discussed here may be higher than prescribed in the standards. More advanced modelling calculations would be required in order to predict the percentage of J-shaped tipovers that would be compatible with the current ball mechanism.

The 0.7 g lift truck acceleration threshold is nonetheless appropriate for frontal and rear impacts. However, the webbing could unlock if it were to release during the tipover following impact. In brief, it seems that retractor-acceleration-based locking on its own does not protect the operator in many types of tipovers.

2.7.2.3 Locking thresholds based on ELR tilt

As explained above, one problem with the current standards is that the retractor tilt locking threshold is not specifically prescribed between 12 degrees and 30-40 degrees. What threshold would be required for a lift truck? There is no data to suggest a precise value, but a 40 degree tilt locking threshold seems too high. In any tipover, the webbing can unwind to quite a considerable length before the lift truck tilts 40 degrees, depending on the type of tipover.

This deficiency could be mitigated by reducing the tilt threshold but, unfortunately, with the current mechanisms (e.g., ball or pendulum system), the vehicle-acceleration-sensitive locking threshold is intrinsically related to the tilt-sensitive threshold, and one cannot be changed without affecting the other.

2.7.2.4 Summary of ELR locking threshold effectiveness

Based on the comments in the preceding sections, it seems clear that a single locking mechanism cannot effectively protect the operator in every type of tipover. The question is whether the three locking mechanisms combined might effectively protect the operator. Our analysis of the question is summarized in Table 2. We have used the locking thresholds of SAE J386 as a benchmark.

Table 2. Summary of SAEJ386 locking threshold effectiveness (i.e. locking capacity) in different accident scenarios

Locking	Frontal or rear impact (without subsequent tipover)	Frontal or rear impact (with subsequent tipover)	Frontal, rear or lateral tipover at low forward speed	Slow lateral tipover	Dynamic tipover - J-shaped trajectory
Webbing extraction acceleration (1g criterion)	Yes	Yes, but could release during tipover	Unlikely	Unlikely	Likely
Retractor acceleration (0.7 g criterion)	Yes	Yes, but could release during tipover	No	No	Likely
Retractor angle (40 degrees)	N/A	Yes, but may be too late	Yes, but may be too late	Yes, but may be too late	Yes, but may be too late

In frontal or rear impacts without subsequent tipover, webbing-extraction-based locking is as effective as vehicle-acceleration-based locking. Tilt-based locking is not operative in this type of tipover. The lift truck may tip over after impact and, during that time, the locking mechanisms may disengage, leaving the operator unprotected.

In frontal, rear or lateral tipovers at low forward speed, the operator basically follows the seat trajectory and webbing-extraction-based locking becomes ineffective. Lift truck acceleration is also negligible and thus does not protect the operator. Truck-tilt-sensitive locking becomes effective at a given angle, but the operator may deliberately try to jump away from the seat before locking occurs and end up being crushed by the protective structure after tipover.

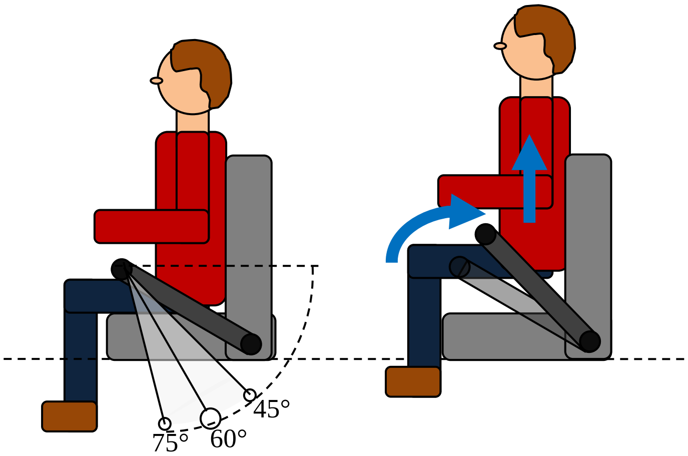
The three locking mechanisms will help protect the operator in J-shaped tipovers, but even combined, they will not protect the operator in all J-shaped tipover conditions, particularly if the tipover occurs on a slope and/or the operator decides to remain more or less partially within the lift truck.

In summary, an ELR that conforms to the current standards is safe in many but not all conditions, because it will not lock the webbing in many foreseeable tipover conditions.

2.7.3 Nominal lap belt adjustment

It is recognized that a number of belt assemblies commonly used in vehicles do not effectively restrain the occupant in the seat structure, allowing the occupant's head and body to move vertically or laterally in quasi-static lateral tipovers (Siegmund et al. 2005; Smith et al. 2005). Such movement can cause different parts of the body to strike the roof and support pillars or even partially throw the occupant's head or body against the vehicle window or door. It has been suggested that this displacement may be due to the anchorage positions or to slack left in the webbing by the user. According to Moffatt et al. (1997, quoted in Smith et al. 2005), the smaller the webbing angle relative to the horizontal, and the longer the webbing (cf. Figure 12), the greater the risk that the user will be displaced towards the top or sides of the vehicle. This is caused by the pivoting motion of the belt, as shown in Figure 12b.

SAE J386 states that the angle of the belt between the anchorage point and the seat index point (SIP) should be 60° ± 15° and the webbing must rest on the pelvic bones. If the anchorages are placed directly on the lift truck structure and operators can move their seat forward or backward relative to this anchorage point, the angle may no longer comply with the standard. In response to this issue, Moffatt et al. (1997) studied the effect of a pretensioner on lap belts and showed that vertical and horizontal displacement of the head can be reduced by 100 mm when the belt is properly adjusted.



(a) (b)

Figure 12. Diagram of vertical occupant movement in a lift truck tipover.

a) Too much slack in belt and insufficient belt angle (<45°) and b) pivoting of the belt and vertical displacement of occupant during tipover.

Likewise, slack in the belt may result in excessive forward displacement of the trunk, which can then hit the interior of the lift truck. In their study on road vehicles, Siegmund et al. (2005) demonstrated that 10 cm of slack (divided equally between the lap and diagonal belts) in a low-speed head-on collision (17.5 km/h) increased horizontal displacement, acceleration and head speed by 31%, compared to a properly adjusted belt.

To our knowledge, there are no acts, regulations or standards explaining the applicable limits for adjusting a seat belt. Relying on the requirements of SAE J386, for example, the tests specify a maximum extraction of 50 mm (2 in.) before locking occurs in the stipulated locking conditions. Hence, inserting a fist between the belt and the body seems to be an appropriate approximate measure for adjusting manually adjustable belts.

2.7.4 False unlatching

The literature (Roberts et al. 2007) reports several cases of false unlatching in road vehicles. The phenomenon can occur in lift trucks as well, because they use the same locking system. False unlatching occurs when the male component (latchplate) feels like it is fully engaged in the female component (buckle), when in fact it is not.

2.7.5 Review of literature on ELR seat belts

Knowing that there are lift truck acceleration ranges in which the seat belt may not lock and actuation of locking mechanisms is a dynamic process that takes a certain amount of time to occur, emergency retractor seat belts may not always be effective. The fact that ELRs may not always lock the webbing on time was also analyzed by Robinson et al. (1996, quoted in Smith et al. 2005) on agricultural vehicles. The same phenomenon was also observed in experimental tests performed by Bourret et al. (2008) at the Institut national de recherche et de sécurité (INRS France) in a study of lateral tipovers without forward speed.

Research on seat belt performance in belt functionality tests remains ambivalent if we compare, for example, those of Toomey et al. 2009; Meyer, 2008; Klima et al. 2005; Thomas, 2002 et Meyer, 2001. The inconsistent findings can be ascribed to the fact that locking is contingent on multiple factors, including:

1. belt maintenance (build-up of dust, grease);
2. specific locking condition thresholds, which can vary widely between belts even though they may comply with one standard or another;
3. presence or absence of webbing-acceleration-related locking;
4. presence or absence of a vehicle-dynamics-related locking mechanism;
5. specific acceleration conditions selected for conducting experiments;
6. the operating speeds, including webbing extraction speed;
7. the forces applied to the webbing during testing;
8. the reliability of specific design parameters of belt assemblies used during the tests, as well as belt orientation, rigidity of springs, component sizes, type of material used, etc. (Cannon et al. 2002);
9. body size of dummies or experimental subjects used in the tests.

Unfortunately, most of this information is not found in the scientific papers that were reviewed, which precludes a valid comparative critique. The work of Smith et al. (2005) provides details on the performance of different restraint systems for earth-moving machinery. Their conclusions indicate that, from the viewpoint of operator safety, seat belts with more than two anchoring points are better for purposes of limiting head and torso movement. However, such belt assembly seems incompatible with the mobility required for a clear all-round view. They also mention that inertial locking mechanisms, like the ones described in this report, will not initiate webbing locking in the kind of low-speed tipovers that can occur in lift truck use.

3. THE LAP BELT AND ITS USE

3.1 Methodology

The purpose of this phase was to determine which seat belts were used in a number of companies and how operators experienced the requirement to wear a seat belt. This is a complement to the preceding technical analysis, which was meant to provide an overview of seat belt options for companies and their potential effects on operator comfort and work performance. The exploratory nature and limited scope of this project excluded larger analyses such as a review of upstream prevention measures, analysis of organizational context and risks, detailed analysis of actual work and the implications of routine seat belt use, and strategies to encourage seat belt use.

For purposes of this survey, one supervisor and one to three operators per company were asked to participate. In most cases, two lift trucks were targeted per company. Depending on availability and patterns of lift truck use, some operators were asked about seat belt use for two different lift trucks. Conversely, some lift trucks were evaluated for more than one operator. This project was approved by Université de Sherbrooke's committee for ethics and research in education and social sciences on August 13, 2009.

The in-plant information gathering was spread over two days. The purpose of the first visit was to:

1. meet with management and employee representatives to review the research objectives and process;
2. personally interview a supervisor familiar with the issue of seat belt use by lift truck operators;
3. tour the premises with this supervisor;
4. take notes on the characteristics of seat belt assemblies and lift trucks in the study sample;
5. briefly meet with the volunteer operators to explain the study and what was expected of them in terms of participation during the second visit.

The purpose of the second visit was to collect information from the operators. As with the supervisor, we met with each operator individually for an interview covering the following aspects:

1. lift truck use (type of lift truck and tasks performed);
2. the transition to mandatory seat belt use; use of a seat belt in daily work; problems with existing seat belts;
3. perceived risk of tipover, falling from loading docks or collision;
4. past accidents.

To document seat belt use, the operators were filmed while mounting/dismounting and fastening/adjusting/unfastening the seat belt 10 times in a parked lift truck. Afterwards, they were questioned about how easy the seat belt was to use. The operators then performed their regular work for 20 to 50 minutes on a lift truck fitted with cameras that recorded images of the operator's body and others showing the connection with the work performed. They were then questioned about whether the seat belt was compatible with their tasks, whether they felt any discomfort, their perception of being protected in case of an accident, desired improvements. The videos were systematically viewed by an ergonomist for purposes of reporting on the seat belt's strengths and weaknesses in conditions of use.

3.2 Participating companies and conditions investigated

The companies were recruited with the help of a lift truck distributor and occupational health and safety sector-based associations sitting on a research follow-up committee. A total of seven companies participated in the study. These companies were generally well organized and proactive in OHS, very likely more so than the average Québec company. Nonetheless, this exploratory study covered a wide range of workplace conditions and the findings and discussions may be applicable to other companies.

In one of the companies visited, information could only be partially collected because of staff unavailability. At the start of the project, a preliminary visit was also made to a lift truck distributor to collect information to supplement the overview. To protect the confidentiality of the findings, given the small number of participating companies and participants, the data were pooled so that the source could not be identified. The participating companies were active in:

- Heavy equipment distribution
- Chemicals distribution
- Manufacturing of mechanical devices
- Paper production
- Printing
- Metal products processing
- Chemicals sorting and transfer

Twelve operators and seven supervisors participated in the study. Certain participant characteristics are described in Annexe D. All the participating supervisors and operators were men. Median seniority in their job was 12 years for the operators and 4 years for the supervisors. The participating supervisors all have at least minimum experience in operating lift trucks. The 12 participating operators covered a wide range of anthropometric features: height from 1.57 to 1.83 m; weight from 68 to 147 kg; body mass index ranging from healthy weight to class 3 obesity. Most operators wore light clothing but some wore a jacket. Since the study was not carried out in winter, one operator was asked to put on a winter coat for a simulation. Some operators wore gloves. Lift truck characteristics, retractor types and seat characteristics included in the field study are described in Annexe D.

In brief, fourteen lift trucks manufactured by four different companies were examined. Lift truck capacity ranged from 1,300 to 7,000 kg. One lift truck was fitted with a manual retractor belt assembly, eleven had an automatic locking retractor (ALR) and two had an emergency locking retractor (ELR). Some seats had armrests or hip restraints and several had suspension.

Lastly, a variety of operator tasks were performed during the filming: production line feeding, stocking of manufactured products, order preparation (compiling the pallets, bringing the products to the dock) and truck loading/unloading.

3.3 Findings on seat belts, users and work

This section summarizes the main findings of the in-plant phase. References to the literature are added when available.

3.3.1 Transition to seat belts, perception of risks and feeling of being protected by the belt

The supervisor interviews revealed that almost all the visited companies had phased in mandatory seat belt use when the regulatory change (ROHS) was announced. They began by informing the operators of the new regulation and making them aware of the need to wear a seat belt. They also granted a transition period during which operators were urged to wear a seat belt, with the supervisor simply reminding them to do so. At the scheduled cut-off date, seat belts had to be worn; otherwise, the operators received a warning that was filed in their record and could result in disciplinary measures. None of the companies said that they had had to take disciplinary measures, although the supervisors reported some operator resistance.

Most of the participating supervisors and operators said that the initial response to seat belt use was negative. But over time, they said, they got into the habit of wearing a seat belt; many compared it what had happened in automobile driving. Although the habit has set in, a third of the operators only wear a seat belt because they have to and find it useless and annoying. The operators explained their reaction by saying that lift trucks travel at low speeds and have closed cabs, the belt restricts their mobility when travelling in reverse and they sometimes have to get on and off the truck frequently.

Two companies allow operators not to wear a seat belt for tasks requiring very frequent mounting/dismounting, in circumstances where the risk of tipover has been evaluated. According to the supervisors, these tasks require travelling over very short distances at low speeds, on level surfaces[4]. One supervisor added that there is a hip restraint on the seat for these tasks.

This study was not meant to be a risk assessment or an audit, but we wanted to have supervisor and operator input on perceived risks in their day-to-day environment. For one thing, more than half of the respondents (supervisors and operators combined) feel that there is little or even no risk of lateral tipover. The most commonly cited reasons were the absence or control of hazardous conditions (low speeds, limited stacking height, flat cement floor), the stability provided by the lift truck wheelbase and weight, and sound work practices (never turn suddenly with a heavy load, drive slowly on slopes). Only one respondent specifically mentioned how unstable a lift truck is when empty. Although sketchy, these results suggest that operators may not always appreciate how laterally unstable an unloaded lift truck can be.

---

[4] These conditions were not analyzed in this study.

In two companies, the interviewees said that they had witnessed a fall from a dock. In one case, the operator got off the lift truck, which continued to move forward. One supervisor who witnessed a fall from a dock, a collision with a column and an object falling one storey, said that the seat belt the operators were wearing when these accidents occurred probably reduced their injuries and even saved a life. Another supervisor reported a collision with a column; the operator, who was wearing his seat belt, was sent to the infirmary but did not have to go to the hospital. One operator said that he had had a real scare when his lift truck almost turned over on its side; his feeling was that although a seat belt will keep an operator in the seat, it does not provide enough protection.

One of the last questions the operators were asked was whether they felt that the seat belt would protect them in an accident. The responses are shared (Table 3). Individuals who had a positive perception of a seat belt’s protection capabilities explained that it restrained them inside the lift truck during an accident or protected their head in a collision. Those who felt that the seat belt did not protect them said that the body is free to move and the seat belt does not protect the head, leaving them exposed to serious injury. Two respondents said that they did not feel that they were in danger because the lift truck moves at low speed. In one company, the operators wondered whether they could be injured by the battery during a tipover. Lastly, although none of the questions addressed this, two operators from the same company thought that a shoulder belt, like the ones used in automobiles, might provide better protection in collisions, while an operator from another company thought that a shoulder belt would interfere with his work.

Table 3. Responses of 12 operators to the question: “I feel that the seat belt would protect me in an accident.”

Totally agree	Mostly agree	No opinion	Mostly disagree	Totally disagree
3	4	0	3	2

3.3.2 Choice of seat belt assemblies and risk control devices for lift trucks

Most companies had selected equipment to manage the safe use of lift trucks. For instance, some had installed systems to limit speed in all circumstances or on curves, impact sensors (G-force), an electronic key system to identify lift truck users, ID key procedures to restrict access to lift trucks, etc. Companies had also selected means for managing seat belt use. For example, two establishments used a system that prevents the lift truck from being used unless the seat belt is fastened. Two others used a warning signal. In one of these companies, however, the supervisor said that this alarm would have little effect on operators who were really opposed to wearing a seat belt, while in the other company, the supervisor thought that the alarm worked well as a reminder, although the beeping stops after a while even if the seat belt is still unfastened. Lastly, many companies used brightly coloured belts (7 out of 14 lift trucks) so that it is easy to see whether the seat belt is being worn. In one company, though, the environmental conditions quickly made the webbing dirty, turning it from fluorescent orange to dark brown (Figure 13).

Figure 13. Orange webbing after exposure to a dirty environment.

The companies less often said that they looked for seat belt characteristics affecting ease of use, such as retractor type, anchorage positions, type of attachment, position relative to the seat suspension. Generally, seat belt requirements are not specifically analyzed; either the existing seat belt is used or the supplier or maintenance staff are simply asked to install a seat belt on the seat.

3.3.3 Fastening/unfastening

This section describes how operators typically fasten and unfasten their seat belt and related problems they may encounter. As a point of reference, analysis of the work videos shows that some operators get on and off the lift truck frequently, at the rate of once every 4.6 minutes, or even every 2.6 minutes for line feeding, packaging and product stocking operations. This frequency is consistent with the findings of Vezeau et al. (2009), i.e. every 2.4 minutes on average for order preparation tasks. Although not all tasks require the operator to get off the lift truck this frequently, there was a perceptible need, in these cases especially, for a user-friendly belt. One company made major product labelling changes (e.g., bar code type) so that operators would not have to get on and off the lift truck as frequently.

3.3.3.1 How do the operators proceed?

Most operators fasten their seat belt with both hands, regardless of the type of retractor used (manual, ALR, ELR). ALR and ELR models are fastened in four steps (Figure 14):

1. pick up the belt on the retractor side;
2. pull out the webbing and transfer the end to the other hand (buckle side);
3. use the hand on the retractor side to maintain some slack and insert the tongue in the buckle with the other hand;
4. position the seat belt on the body (not always done).

(a) (b) (c) (d)

Figure 14. Typical steps in two-handed fastening with ALRs or ELRs.

a) Pick up the webbing, b) pull out the webbing and transfer to other hand, c) keep some slack in the belt and buckle up and d) position the webbing on the body.

There may be some particular habits, such as unreeling the webbing before fastening or positioning the webbing above or below the tool pouch. If the buckle is not rigidly fixed, one hand must hold the buckle, so the other hand must pull the webbing and is not free to maintain slack in the belt (Figure 15).

(a) (b) (c)

Figure 15. Fastening when the buckle is not rigidly fixed (ALR).

a) Hold the buckle in one hand, b) pull the webbing with the other hand and fasten – no slack maintained in the webbing and c) position the webbing on the body.

For seat belts with a manual retractor, there are two possible scenarios: the webbing is not preadjusted to the right length or the webbing has already been properly adjusted. In the first case, the operator picks up the webbing in one hand, then presses the retractor button with the other hand to adjust the length. He inserts the latchplate in the buckle and tightens the webbing to the right length (Figure 16). In the second case, the operator simply has to pick up the webbing and fasten the belt (Figure 17).

(a) (b) (c) (d)

Figure 16. Typical steps in fastening with a manual retractor – with adjustment.

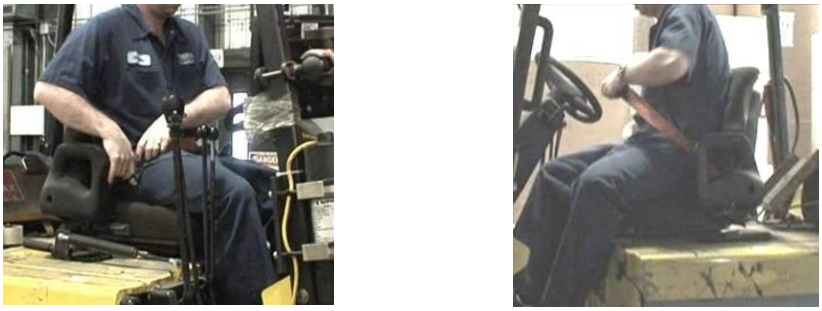
a) Pick up the webbing, b) press the retractor button and pull out the webbing, c) insert the tongue in the buckle and d) use the retractor button to adjust the webbing length.

(a) (b)

Figure 17. Typical steps in fastening with a manual retractor – without adjustment.

a) Pick up the webbing and b) insert the tongue in the buckle.

ALR and ELR seat belts are unfastened by pressing on the buckle button to release the latchplate (male part of the buckle) and, in most cases, guiding the webbing towards the retractor (Figure 18). For belts with a manual retractor, instead of respooling the webbing, the operator will set it down on a lift truck surface. One participating operator had acquired the habit of draping the webbing over the steering wheel (Figure 19). This would remind him to fasten the seat belt and leave the latchplate in an accessible place.



(a) (b)

Figure 18. Typical steps in unfastening an ALR or ELR seat belt.

a) Press the button to release the latchplate and b) guide the webbing towards the retractor.

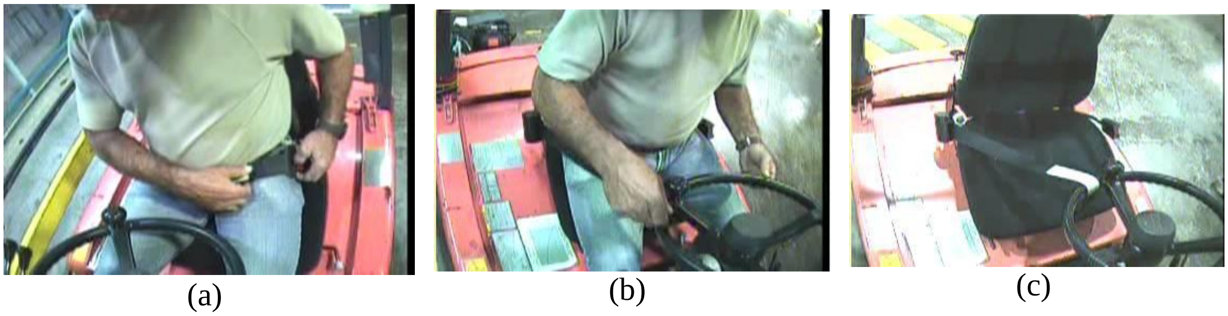

(a) (b) (c)

Figure 19. Unfastening a seat belt with manual retractor.

a) Press the button to release the latchplate, b) and c) set the webbing down, in this case, on the steering wheel.

Based on the ten or so fastening/unfastening cycles each operator was asked to perform, the median seat belt fastening time is five seconds (Table 4). This includes the time it takes to pull the webbing, insert the latchplate in the buckle and adjust the webbing length and/or position. The minimum time needed to fasten a seat belt is two seconds. The maximum, 34 seconds, occurred when there was a problem with the retractor and the belt would not slide in or out.

Table 4. Seat belt fastening/unfastening time, all belt types (n= 145).

	Fastening time (s)	Unfastening time (s)
Average	5.0	2.4
Median	5.0	2.0
Minimum	2.0	1.0
Maximum	34.0	16.0

It takes approximately eight seconds to fasten a manual retractor if the webbing is not pre-set to the right length. However, if the webbing is already set to the right length, it can take as little as two to four seconds, based on observations of actual work. This type of seat belt would therefore be more suitable if a lift truck is used by only one operator (does not have to be adjusted repeatedly).

For all repetitions combined, the median unfastening time is two seconds. This includes pressing the buckle button, guiding the webbing toward the retractor or setting it down (for a manual retractor). The minimum time is one second and the maximum, 16 seconds. Here too, the maximum occurred when the retractor was defective. While performing their regular tasks and during the simulation, the fastening/unfastening method and time were similar, with few exceptions (e.g., webbing not always guided towards the retractor on unfastening).

On the whole, the operators found it quite easy to put on and remove and remove the seat belt. However, some said that there were problems with the buckle or retractor, which was borne out by observation: a retractor that jams or doesn’t fully rewind the webbing on unfastening, webbing that catches on the tool pouch, difficulty reaching both segments of the belt (latchplate and buckle) because of the seat configuration and location of the belt ends. On the basis of one cycle, the most time-consuming problem was the retractor problem, but presumably, over a number of cycles, the accessibility problems may also be irritating.

3.3.3.2 Retractor operation

All the companies said that they had replaced seat belts due to buckle or retractor defects. In the lift truck sample, several ALRs at one company did not work well even though they were quite new and used in a fairly dust-free environment[5]. The webbing sometimes tended to fold back on itself as it entered the retractor. The retractor opening was wide and the retractor mechanism may have been defective as well (Figure 20).

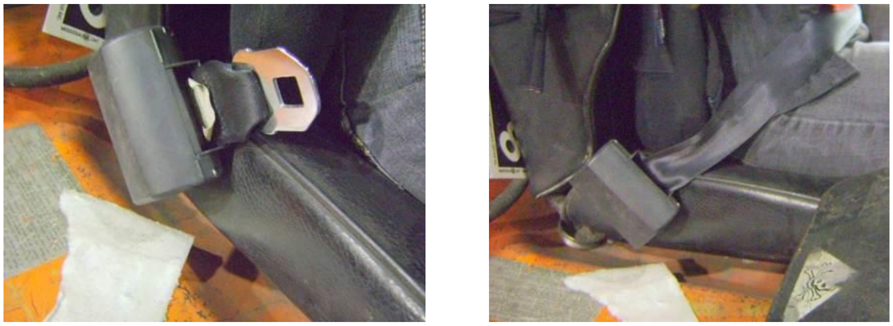
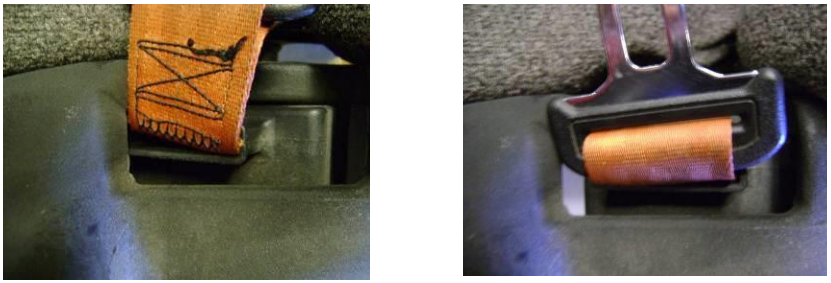


Figure 20. The ALR and webbing frequently jam on this belt.

Poorly attached retractors were also observed in two companies. Figure 21 shows a retractor, mounted in a hip restraint, which is insufficiently screwed in and thus free to move. The position shown in Figure 21 (a) caused the webbing to rub against the edge of the restraint, making it difficult to slide the webbing in and out of the retractor.



(a) (b)

Figure 21. Retractor mounted in hip restraint.

a) Poorly attached retractor causing the webbing to rub against the hip restraint and b) correct retractor position.

---

[5] Smith et al. (2005) state that dusty quarry conditions may cause retractors to malfunction.

Figure 22 shows another case where the retractor is free to pivot, while Figure 23 shows a retractor that is secured to the seat but its position makes it difficult to slide the webbing in and out.

(a) (b)

Figure 22. Retractor poorly attached to the seat and free to pivot.

a) Retractor position when belt is unfastened and b) the retractor follows the webbing's movement when tension is applied.

(a) (b) (c)

Figure 23. Non-optimal retractor orientation for putting on and rewinding webbing.

a) and b) fold in webbing and rubbing and c) guiding the webbing towards the retractor to facilitate rewinding.

3.3.3.3 Webbing length and buckle and retractor position

The webbing lengths observed in the companies are shown in (Table 5). The shortest webbing was 94 cm long and was unsuitable for a large operator. He could buckle the belt but the webbing, stretched to its maximum, was uncomfortable, even though the retractor was an ELR. The other webbings were all at least 110 cm long and suited the operators. In terms of length available for buckling, the buckle stalk can be added to the webbing length (Table 5). The median length available for buckling was 142 cm, but on one seat it was only about 94 cm.

Table 5. Length of webbing and buckle attachments and lateral distance between retractor and buckle.

	Webbing length	Approx. webbing + buckle stalk length	Lateral distance between buckle opening and withdrawal of webbing from retractor
Median	121 cm (47 in.)	142 cm (56 in.)	49 cm (19 in.)
Min.	94 cm (37 in.)	94 cm (37 in.)	38 cm (15 in.)
Max.	152 cm (60 in.)	183 cm (72 in.)	53 cm (21 in.)

Smith et al. (2005) report that it can be difficult to use a seat belt while wearing warm clothing (coat and gloves) and mention that the webbing is not long enough for large operators. These problems, as well as bulky clothing, are frequently reported in the case of road vehicle seat belts (Balci et al. 2001). In a simulation of a fairly stout operator wearing a winter coat, the 118 cm webbing was suitable (total of 140 cm with buckle attachment) (Figure 24a). Some of the six operators who periodically wear a warm, heavy coat said that they:

1. found it harder to reach belt parts that were hidden under the coat;
2. had to pull more webbing out;
3. had to run the webbing under their coat because it was too short;
4. felt uncomfortable (chafing, feeling cramped).

Two operators said that the position of the belt parts is important, especially when a coat is being worn. One would have liked the two belt segments to be a bit further away from the body, the other liked that the buckle was on a long stalk rather than being embedded. Figure 24 (b and c) shows how even less bulky clothing can affect belt use.

(a) (b) (c)

Figure 24. Examples of how the seat belt is worn.

a) Webbing stretched over the winter coat mid-thigh, b) webbing placed under the lower front jacket pocket c) webbing worn under the jacket. The operator pulls back the jacket and fastens the belt.

As mentioned above, the location of the buckle can make fastening easier. In the visited companies, both segments of the seat belt were attached to the seat. Some buckles were mounted on the side of the seat, others were held by rigid stalks of varying length, while yet others were attached in a semi-rigid manner (i.e. do not stay in place) (Figure 25). Some operators said that they like the rigid stalk because they have quick access to the buckle, which is always in the same position.

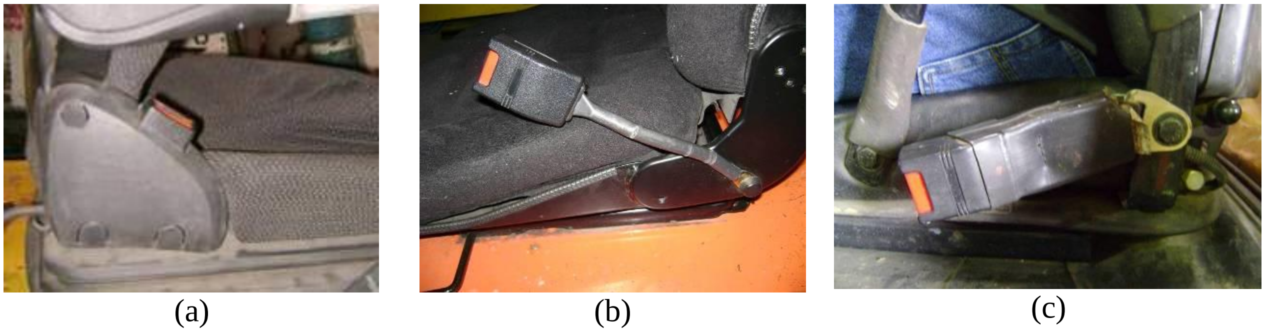

(a) (b) (c)

Figure 25. Buckle attachment types.

a) Embedded, b) rigid stalk and c) semi-rigid sheath.

The lateral spacing between the two belt segments can facilitate fastening/unfastening but also hinder maneuvering of the seat belt. On narrow seats, the belt anchorages are too close to the operator's body. Some operators have to lean over and free up space to reach for the webbing and buckle (Figure 26). In the seat sample, the median lateral distance between the two belt segments is 49 cm, the maximum distance, 53 cm and the minimum distance, 38 cm.

Figure 26. Narrow seat – webbing hard to reach.

3.3.3.4 Armrest and hip restraint

Many lift truck seats are fitted with armrests or hip or chest restraint systems. There were no special comments or observations about chest restraint systems and seat belt use. If there were armrests, the left one was raised in the lift truck sample. The right armrest, which has an extension with finger-activated pick-up equipment controls, was lowered. In this position, the armrest restricts access to the belt buckle (Figure 27). To facilitate fastening, one operator thought that the buckle should be attached to a longer stalk.

Figure 27. Armrest restricting access to fastening/unfastening.

Similarly, hip restraints, which are fixed, run the width of the seat and are in the zone of access to the two belt segments. Figure 28 shows how the restraint can restrict access to the webbing; the operators must lean sideways to free up the webbing zone. Operators who use seats with hip restraints find the webbing a bit harder to reach than colleagues who use seats without hip restraints.

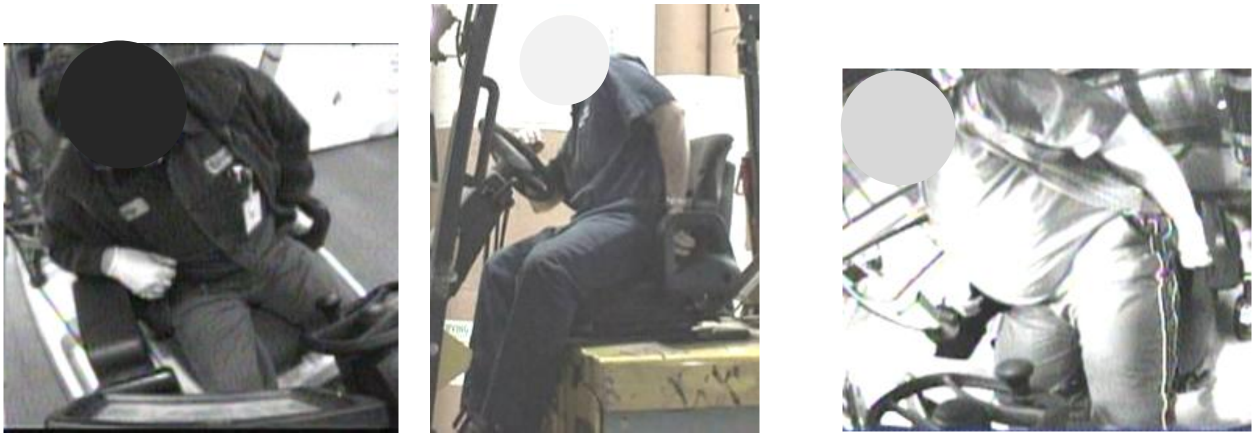
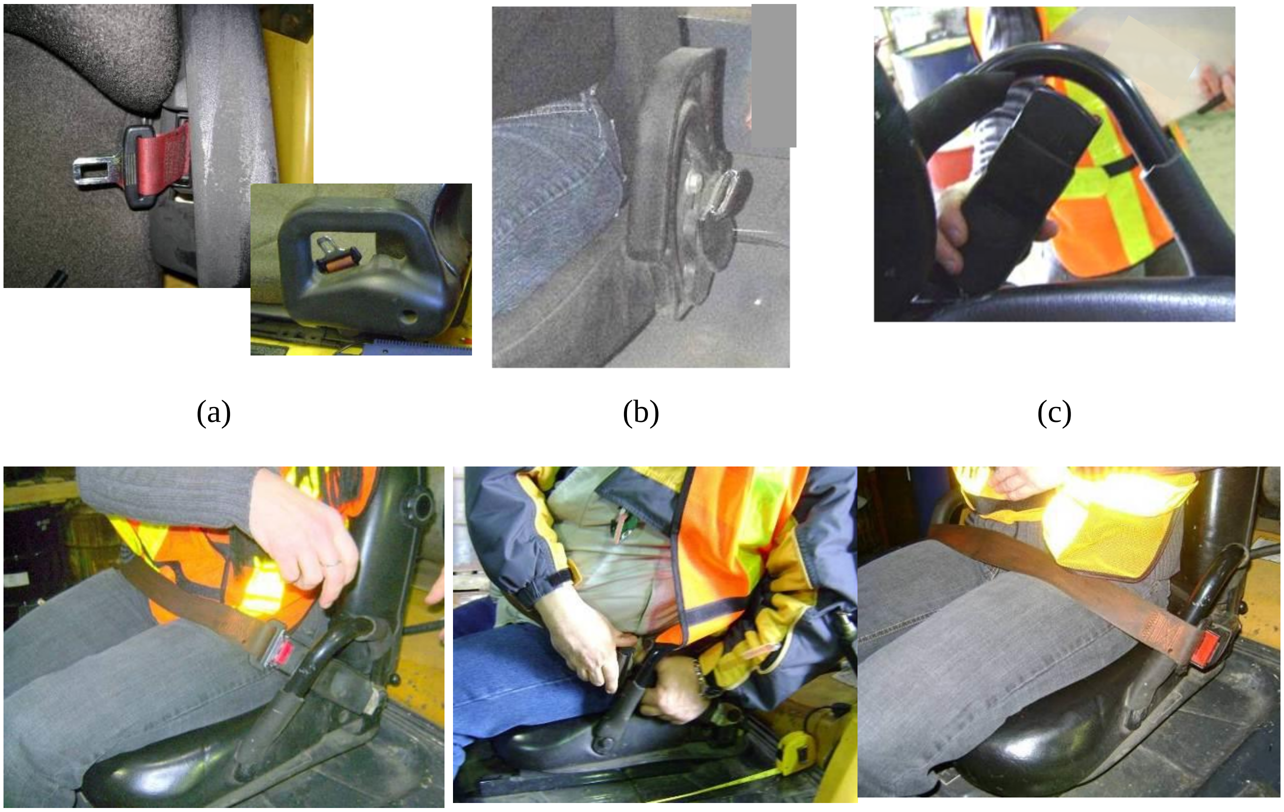


Figure 28. Examples of hip restraint restricting access to webbing.

The retractor may be embedded in the centre of the restraint (Figure 29a). In other cases, the retractor and buckle are attached to the seat on the far side of the restraint (Figure 29, b and c) and the webbing and buckle must go through the restraint opening in order for the belt to be fastened close enough to the body (Figure 29d). Buckling up can be difficult in this case (Figure 29e). Figure 29c shows that removing part of the foam sheath on the restraint makes it easier to reach the buckle attached on the outside. In one company, the belt was fastened over the hip restraint (as in Figure 29f). The operator said that this way he does not feel the belt (ALR), it doesn’t bother him, it’s like it’s not even there. He added that it would probably be different if he had to fasten the belt under the hip restraints. Fastening over the restraints has several advantages: it is easier to buckle up; a portion of the belt does not touch the operator’s body; the webbing tension partially depends on contact with the restraints, which likely reduces automatic tightening of the webbing. However, if small operators fasten the belt over the hip restraints, some slack will probably be left between the webbing and the body (Figure 29f), which raises the question of how much protection the seat belt would provide in an accident.



(a) (b) (c)

(d) (e) (f)

Figure 29. Examples of retractor and buckle positioning.

a) Belt buckle embedded in centre of hip restraint b) buckle fixed outside the hip restraint c) foam on hip restraint removed so belt buckle can be slipped through the opening, d) buckle under the hip restraint; small subject (simulation), e) position taken to fasten the belt under the hip restraints (simulation) and f) fastening the belt over the hip restraints; small subject (simulation).

3.3.3.5 Buckle button, gloves

The buckles used in the various lift trucks have a button on the side or the end (Figure 30). One operator greatly preferred end buttons (b), finding them easier and quicker to press. Aside from buckle release problems, no difficulties were reported in unfastening the seat belt, regardless of the type of button.

Because of their handling duties, many operators wear gloves while driving a lift truck, even in summer. Other operators only wear them in winter. No problems were reported in fastening or unfastening the seat belt while wearing gloves.

(a) (b)

Figure 30. Types of buckle buttons.

a) Side button and b) end button.

3.3.3.6 Equipment worn at the waist

In the companies visited, telephones, scanners and other equipment were found inside the lift truck cab. However, four operators wore a tool pouch at their waist; three had put it beside the retractor, and the fourth, beside the buckle. The work observations show that because of the tool pouch, operators must sometimes reposition the webbing when buckling up (Figure 31a) and if the webbing is placed under the tool pouch, it can catch when they unfasten the seat belt (Figure 31b). On several occasions, it was also observed that the ELR would not take up all the slack because the webbing was caught under the tool pouch (Figure 31c). Only one operator reported that the tool pouch caused some discomfort. Two operators wore the seat belt (manual retractor, ALR) over their tool pouches, and one said it was to avoid discomfort.

(a) (b) (c)

Figure 31. Drawbacks of wearing equipment at the waist.

a) Webbing catches in tool pouch on fastening, b) manual retractor: webbing catches under the tool pouch when the operator gets off the lift truck c) ELR: excess webbing, caught under the tool pouch, not retracted when the operator sits down again.

3.3.4 Use of a seat belt while working

Several operators said that it was a nuisance to have to fasten and unfasten the seat belt while working, especially if they have to get on and off the lift truck frequently. Five operators reported discomfort in the lower abdomen under the webbing and one, in the hip, when they get ready to back up.

Vezeau et al. (2009) reported that lift trucks travel in reverse 30% to 48% of the time. An operator may also have to back up over long distances when transporting large loads. For example, one participating operator backed up repeatedly for an average of 31 seconds and two others drove in reverse for 1.5 minutes.

Two operators who had to drive in reverse over long distances reported the added difficulty of turning around while wearing a seat belt. In one case, the seat belt had an ALR (Figure 32, a and b); in the other, the retractor was manual and a swivel seat was added to offset the operator's lack of mobility (Figure 33a). Another operator who used a belt with a manual retractor adjusted the belt length so it wouldn't bother him when he turned around; based on our observations, he kept about 5 cm of slack in the webbing (Figure 33b). One operator who used an ELR belt confided that he had used an ALR but no longer wanted one (Figure 32c). Lastly, one operator reported that he had lost neck mobility over the years and found it increasingly difficult to turn his torso and head rearward; the ALR belt doesn't hinder him but he doesn't turn around completely. Partially shifting the pelvis on the seat will improve rearward vision, so [vision] should not restrict this movement. The observations show that the ELR is the mechanism that provides the best mobility.

(a) (b) (c)

Figure 32. Postures taken to see while reversing.

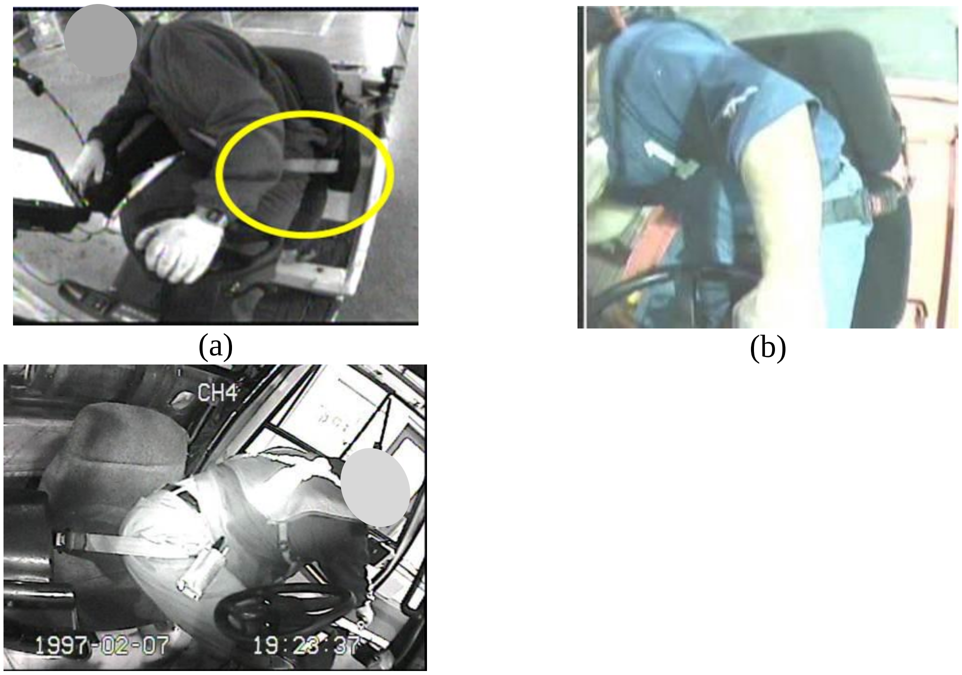
a) and b) ALR and c) ELR.

(a) (b)

Figure 33. Manual retractor – turning around to see while reversing.

a) seat swivelled to right and b) straight seat, belt a bit looser.

In their work, operators must also lean sideways and forward to see, scan, access order lists, etc. It is difficult to assess how much mobility each type of retractor provides, given the wide range of conditions and the small study sample. Slack in the webbing enables larger body movements. For ALR belts, this slack may result from the location of the anchorages, small operator size (Figure 34a) or having the seat belt fastened over the hip restraints. In addition, with a manual retractor, slack can be left in the webbing at the operator's discretion (Figure 34b). Lastly, with ELRs, unless the webbing is too short, the webbing length will conveniently adjust to the operator's movements (Figure 34c).



(a) (b)

(c)

Figure 34. Bending over to see or scan.

a) ALR, small operator, b) manual retractor with slight slack in the webbing c) ELR.

The system shown in Figure 35 was installed in a lift truck fitted with an ALR seat belt; it has an expandable section between the anchorage and the belt buckle. If this mechanism is installed on the right, as in the visited company and in the pre-field work, and the operator turns to the right to see rearward, the left hip pulls on the belt and the mechanism has no effect. If the operator turns to the left, his right hip will pull on the mechanism and activate it. However, given the spring's resistance, the gain seems insignificant. The operator who worked with this kind of belt assumed that there was some advantage but could not confirm whether the mechanism ever activated. The work videos suggested that the mechanism expanded when the operator leaned forward from the opposite side (Figure 35c). In these circumstances, the body weight also pulls on the mechanism, and on an appropriate axis. It could not be ascertained whether the mechanism expanded in the presence of vertical jolts. On the belt assembly observed onsite, this spring allowed the belt to expand by a bit less than 5 cm. Overall, keeping in mind the limited number of observations, this system increased mobility and comfort in only a few special cases.

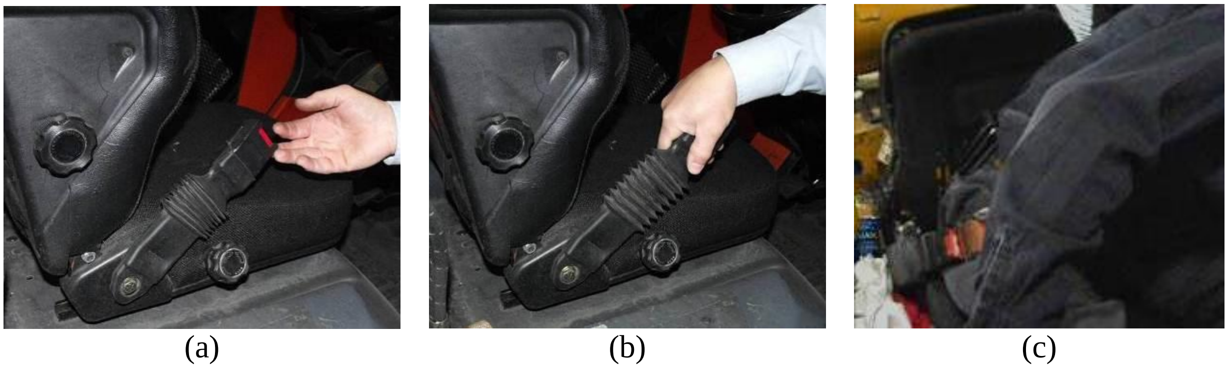

(a) (b) (c)

Figure 35. “Non-locking” system.

a) Unextended, b) extended to the maximum and c) working conditions in which it activated.

One of the companies’ concerns was to dampen jolts and vibrations. Some carefully maintain driving surfaces in order to reduce shocks and vibrations. Only three of the fourteen seats in our sample did not have suspension. One was pneumatic; the others were mechanical. Four suspensions were on the backrest and the others were under the seat.

Wilcoxon (1998) states that static belts (no retractor) and ALR belts are most frequently used in off-road vehicles and that users reported discomfort from tension applied by the belt. When the anchorages are installed on the lower, fixed part of the seat, and the backrest and seat surface move with the suspension, an ALR can indeed tighten the webbing. Tightening can also occur if the operator shifts on his seat. In one company, operators driving on level ground said that small jolts of the lift truck were enough to make the ALR tighten at times, which causes discomfort. ALR seat belts must be completely respooled before the webbing can be adjusted. One supervisor said that some operators, uncomfortable with ALR seat belts, used a safety pin to stop the webbing from retracting. However, this was neither done during our observation nor reported by any of the participating operators.

In the companies visited, some operators added a cushion to their backrest (Figure 36). One of them explained that it gave him more back support and, more importantly, moved him closer to the steering wheel so that he was more comfortable. This operator said that compression of the cushion probably caused the ALR belt assembly to tighten at times.

Figure 36. Cushion on backrest.

Smith et al. (2005) and Sullman (1998), in studies on construction vehicles, note that even ELRs can lock in the presence of jolting or slopes. This did not happen in the company that used ELR seat belts because the driving surfaces were quite smooth and level.

4. GUIDELINES FOR CHOOSING A LAP BELT

In light of the information contained in this study, a number of guidelines should be considered when choosing a lap belt for use in a lift truck. Operators should have a say in this process in order to promote the installation of user-friendly options suited to the working conditions.

4.1 Compliance with standards

There are several standards on seat belt design and manufacture, which provide specific criteria on aspects such as resistance to micro-organisms, mechanical strength, resistance to cycling, temperature, stiffness, etc. The SAE J386 standard, which applies to off-road work vehicles, is quite detailed and addresses many practical aspects of seat belt use. Other standards have similar requirements on these aspects. The standards also provide locking thresholds for different types of automatic retractors, such as ALRs and ELRs, but do not specify which type of retractor to use for a particular application. Because seat belts were probably designed to meet the needs of the automobile industry and not for more specialized applications like lift trucks, the thresholds provided in the standards are not necessarily compatible with all lift truck operating conditions in the field. This was demonstrated in section 2.

4.2 Seat belt length

The useful length of a seat belt is calculated by adding the webbing length to the buckle attachment length. It is important to take into account variations in operator body size, as well as winter clothing and tool pouches. According to our field study, 140 cm was a suitable length, while 94 cm was too short.

4.3 Anchorage positioning and seat characteristics

It is far better for the seat belt anchorages to be located above the seat suspension, so that the seat surface and anchorages move as one when the suspension is operating. The dimensions of the seat must be such that operators can easily reach both belt buckle sections. It is particularly important that these sections do not end up behind the operator, which can happen if the seat is very narrow. For example, at the companies visited, a lateral distance of 50 cm between the anchorages was better than a distance of only 38 cm, measured on one seat. Companies using seats with hip restraints should consider options that minimize fastening/unfastening hindrances. If the belt is attached outside the restraints, it can be awkward to pass the belt segments through the restraints. Fastening the seat belt over the restraint may seem like a good solution, but this leaves some slack between the user and the belt so slender users may have less protection. Flip-up armrests should be used to facilitate access to both parts of the belt. Lastly, for ease of fastening, a rigid and fairly long buckle attachment (e.g., stalk) is better than a flexible attachment.

4.4 Seat belt installation, maintenance and use

When selecting a seat belt, it is also important to consider installation, maintenance and use aspects, including:

1. **Retractor installation**
    - Ensure that the retractor is fixed as per manufacturer instructions and the standards.
    - The belt should be tilted 60°±15° to reduce vertical movement of the occupant (see SAE J386).

2. **Seat belt maintenance**
    - Periodically check that seat belts are in working order (retractor, buckle, webbing).
    - Clean the mechanisms (e.g., check that the ELR ball can move easily and other mobile parts are free to move).
    - Make sure that both belt segments are securely fixed (i.e. the retractor doesn't move).
    - Check that the retractor has any parts (e.g., sheath) needed to facilitate webbing retraction and reduce dust contamination.

3. **Waist equipment**
    - Examine and test different types of tool pouches on the market; some may be more compatible with seat belts. This study did not explore the available options.

4. **Buckling up**
    - When buckling up, make sure that the latchplate is securely fastened in the buckle.
    - Do not leave too much slack in the webbing and make sure the belt lies across the pelvic bones. The SAE standard allows a maximum of 50 mm of slack before locking.

4.5 Retractor type

The retractor is by far the most important consideration because it will affect operator safety, comfort and vision as well as the safety of the environment in which the lift truck operates. Based on the information contained in this report, there are a number of considerations in selecting the most appropriate retractor:

1. Frequent change of operator

In some companies, different operators may use the same lift truck during a shift. In these circumstances, if there are frequent changes of operators, manual retractors are less suitable because each new operator must readjust the webbing length. ALRs and ELRs, which automatically take up any slack on fastening, provide the flexibility needed in these conditions.

2. Mobility, freedom of movement

Whether an operator is free to move while wearing a seat belt depends on a range of factors (anchorage position, hip restraint characteristics, swivel seat, etc.) including the retractor type, which plays a key role. If there is insufficient slack in the webbing, the operator will not be able raise his hip or shift his pelvis on the seat to see rearward when backing up. The most restrictive belts remain locked at all times, with the webbing very close to the body (slack of 4 cm or less). Conversely, ELRs that allow the webbing to unwind in normal conditions (i.e. no significant acceleration or steep inclines) are much more suitable if operators need good mobility to reach for equipment or twist around in their seats to drive in reverse over long distances. This is an important safety consideration for pedestrians or structures in the lift truck environment.

3. Vibrations, suspension, seat cushion compression, added backrest

ALRs have the most drawbacks. This type of belt assembly takes up slack created in the webbing when a cushion compresses, the operator shifts or the seat moves down relative to the anchorages. The webbing tightens on the operator, who must unlatch the seat belt, spool it back into the retractor, readjust and refasten it. On a suspension seat, the belt anchorages should be attached to the seat to minimize cinching.

4. Comfort

An analysis of mechanical characteristics and operator perceptions suggests that seat belts with ALRs are less comfortable. This point is related to the two preceding points; more specifically, limited scope for moving around on the seat and tightening and automatic locking of the webbing by the retractor. However, given the limited number of work observations and participant perceptions of manual retractors and ELRs, it cannot be concluded that one retractor is more comfortable than the others in various working conditions.

5. Ease of maintenance

Manual retractors require less inspection and maintenance because they have far fewer parts. The ALR comes next in terms of complexity and, as discussed, it is more likely to malfunction. Moreover, an ALR can be complicated to maintain in case of contamination, so follow-up is required to keep it in good working condition at all times. The ELR is the most complex retractor. It has the most parts, which means that there are more ways in which it can malfunction, based on the type of contamination. ELRs are certainly not easy to maintain and must be monitored carefully and regularly.

6. Retractor’s ability to restrain the operator in tipovers

A manual retractor with little slack in the webbing, i.e. < 5 cm (2 in.) offers superior restraint capabilities for the operator in any tipover conditions. Properly adjusted webbing effectively restrains the operator within the FOPS. However, if there is more than 5 cm (2 in.) of slack in the webbing, the operator restraint capabilities of the belt may be compromised. Although a seat belt with a manual retractor used with slack in the webbing may prevent an operator from jumping, it may not contain the operator entirely within the cab during tipovers, in which case, this system will not prevent the operator from being crushed between the ground and the FOPS.

ALR restraint capabilities are equal to a manual retractor. Moreover, unlike with a manual retractor, slack cannot be left in the webbing (unless the operator uses a bypass). Slack is determined by the number of teeth in the spool locking gear and it is standardized at 50 mm maximum (cf. SAE J386).

ELRs lock at different lift truck acceleration or tilt thresholds and, in some cases, webbing extraction thresholds. Section 2 provided detailed explanations showing that an ELR can be effective in many lift truck tipover conditions, but ineffective in others. Because tipover conditions vary, an ELR is not a universal operator safety solution.

7. Compliance with standards

As discussed earlier, there are a number of standards that define seat belt design requirements, particularly for retractors. We saw that although the standards contain similar criteria, they have different thresholds. For lift truck use, FMVSS 209 seems relevant in terms of locking thresholds, but the tilt threshold is not conservative enough to ensure operator safety. SAE J386 is better in this respect, but less conservative or even ambiguous in terms of webbing-extraction-acceleration locking thresholds. Nonetheless, this is the standard used for lift truck seat belts in many Canadian provinces.

5. DISCUSSION

In Québec, a seat belt is one of the proposed restraint devices for preventing an operator from being crushed by a lift truck's protective structure during a tipover. However, the regulations, manufacturers and scientific literature do not provide guidance on the most appropriate type of seat belt for counter-balanced lift truck use. The purpose of this study was to collect technical information on seat belt assemblies and their usability to provide an overview of their use in counter-balanced lift truck applications.

The guidelines of lift truck manufacturers stipulate that a seat belt should be used. Although the Québec Regulation respecting occupational health and safety does not explicitly require the use of a seat belt, it is commonly accepted that this is the minimum requirement.

The field component of our study identified a number of factors to consider in evaluating seat belt performance. These factors were identified in a variety of use conditions likely to be observed in other companies in Québec. However, our study's conclusions are limited by the very small sample of companies and lift trucks, particularly those fitted with ELR and manual retractors, and the number of operator interviews. Certain conditions were not investigated, including lift truck operation in outdoor yards or on uneven ground. Moreover, there were no female operators in the sample. Would they have had different comments and needs than their male colleagues?

The field study focused on the use of lap belts, as currently installed in lift trucks. Although the operators say that they are now used to buckling up and that it takes just a few seconds to fasten/unfasten the seat belt, some seem to find the seat belt irritating, especially if they have to get off the truck frequently. These findings corroborate those of Smith et al.'s (2005) study on three types of seat belts used in quarry vehicles (lap belt, lap-diagonal belt, harness). That study shows that acceptance of restraint systems depends on the tasks to be performed. Frequent mounting/dismounting or mobility in order to see are somewhat incompatible with restraint systems, particularly harnesses or shoulder belts.

To promote seat belt use, Sullman (1998) recommends facilitating access to both belt sections and adding a retractor so that the belt can be used with one hand. This exploratory study shows that most operators use both hands to fasten and unfasten the seat belt, regardless of retractor type, even if the anchorages are located on the seat near the operator. Very narrow seats, hip restraints, types of buckles and retractor attachments, inadequate retractor maintenance, bulky clothing or tool pouches can all interfere with seat belt use. In addition, some lift trucks had poorly attached or malfunctioning retractors. When selecting equipment, many companies express interest in devices that facilitate seat belt management (webbing colour, warning signal or interlock if the seat belt is not fastened). Before purchasing equipment, a needs analysis that takes into account the characteristics of the seat, belt, users and tasks to be performed could reduce some of the inconveniences associated with seat belt use. Such an analysis should include operator input so that the best decision can be made. Subsequently, seat belts may have to be inspected and maintained in order to minimize malfunctions.

Overall, our study indicates that each type of retractor has pros and cons, depending on the context of lift truck use. Seat belts with a manual retractor restrain the operator within the FOPS in any type of tipover, but may restrict operator mobility and must be readjusted by each new user. To improve mobility, users could leave some slack in the webbing, but too much slack could compromise their safety in an accident. An ALR does not allow the operator to leave too much slack in the webbing and automatically adjusts to each new operator's hips, but it restricts mobility. This type of retractor can decrease operator comfort, especially on rough terrain when any slack is taken up and the belt tightens on the operator. This phenomenon is partially related to seat suspension and seat cushion flexibility, as well as the number of teeth in the webbing spool locking gears.

In response to the above problems, the ELR may be an option to consider. An ELR offers good operator mobility and automatically respools slack without locking. Although this type of retractor is used in road vehicles, the analysis done in this study shows that the locking mechanisms may fail to actuate in certain kinds of lift truck tipovers or impacts. SAE J386 contains locking/unlocking thresholds that are not fully compatible with lift truck use.

Given the varying locking threshold recommendations and flexible locking/unlocking criteria in most seat belt standards, it is difficult to compare the literature findings to determine which ELR is most appropriate for lift trucks: the scientific papers rarely describe the locking/unlocking thresholds of the retractors used for their analyses. For example, locking is required at webbing extraction accelerations of 0.7, 1.5 or 2g, depending on the standard. Standard SAE J386 proposed for lift trucks contains no explicit locking threshold for webbing extraction acceleration, although it may be implicitly assumed that the level is 1g. Because the standard provides no official threshold, if it is interpreted literally, a seat belt that complies with SAE J386 could have a highly variable webbing acceleration locking threshold, ranging as far as non-existent at one end. With this in mind, when a seat belt assembly is purchased, the manufacturer should provide actual, comprehensive technical specifications on retractor locking/unlocking thresholds. Even with such data in hand, however, it can be difficult to ascertain how much protection the retractor offers, as experimental data on retractor effectiveness in lift truck accident scenarios are currently unavailable.

ELR retractors would benefit from having lower locking thresholds, such as those recommended by automobile standard Federal Motor Vehicle Standard (FMVSS) 209 . This standard seems to have the most conservative acceleration thresholds: it recommends a non-locking threshold of 0.3g for webbing extraction acceleration, compared to 1g for SAE J386, and a retractor acceleration locking threshold of 0.7g versus 1g for SAE J386. However, the tilt criterion is less conservative in FMVSS 209. If FMVSS 209 is used as a benchmark, it should be demonstrated that a 0.3g webbing extraction non-locking threshold will cause no discomfort if the operator shifts on his seat or moves over rough or sloped terrain.

We have not done a comprehensive review of seat belt assemblies on the market. Further studies would be required to determine the specific conditions in which ELR seat belts would be a practicable solution, because they have clear usability advantages. To determine whether ELRs are suitable for use in lift trucks, the following steps should be considered:

- Obtain accurate manufacturers’ specifications for available retractors (locking/non-locking thresholds), beyond test data required by the current standards;
- Specify the working conditions in which these retractors are satisfactory or unsatisfactory in terms of safety and comfort (through simulations, bench testing for safety issues and field studies for ergonomics aspects, for example); it might be useful to demonstrate whether the 0.3g/0.7g threshold of FMVSS 209 meets comfort requirements, knowing that it may be superior to SAE J386 in terms of safety;
- Develop and validate other emergency webbing locking mechanisms that separate the tilt and acceleration thresholds. For example, use accelerometers and a gyroscope (i.e. IMUs or “Inertial Measurement Units”) to detect lift truck orientation and dynamic parameters and activate webbing locking in tipover-, collision- or fall-conducive conditions.
- Identify a seat belt assembly with a tilt locking threshold of 12 to 15 degrees. This characteristic would help offset the shortcomings of ELRs in many tipover conditions. It should be kept in mind, however, that the tilt threshold conflicts with the vehicle acceleration threshold, which is why the standards do not impose a 12 to 15 degree locking threshold. Separating the tilt- and acceleration-sensitive locking mechanisms would yield a more appropriate tilt threshold for lift trucks.

6. CONCLUSION

This exploratory study has profiled the main types of seat belts for lift truck use sold in Québec. An analysis of physical seat belt characteristics and data collection in seven Québec companies in different industries identified the pros and cons of manual retractors, ALRs and ELRs in terms of operator work efficiency, comfort and safety. Aside from the retractor, the study shows that seat belt installation and seat characteristics are instrumental in facilitating seat belt use. Most operators said that they were now accustomed to buckling up, but several found this obligation useless or annoying, particularly if they had to get on and off the lift truck frequently. Before purchasing a seat belt assembly and seat, a thorough analysis of workplace use conditions may help determine requirements compatible with those conditions for purposes of reducing certain stressors. This analysis should include operator input. Although not addressed in our study, organizational factors should be kept in mind in order to reduce work constraints associated with seat belt use (e.g., a better labelling system to reduce the need to get on or off the truck).

Among seat belt components, the type of retractor is key to aligning a seat belt with its context of use. This study reviewed three types of webbing retractors commonly available on the market: ELR, ALR and manual retractor. Our study, based on a literature review and a brief dynamic analysis of webbing function, did not identify a type that satisfied all the reported constraints.

An ELR has numerous advantages in terms of user comfort and working mobility. However, on the strength of the analyses carried out in this exploratory study, this type of retractor cannot be considered a universal operator protection solution. ELRs have three important functional characteristics in terms of safety performance: the webbing-extraction-acceleration level, the lift truck acceleration threshold at which the webbing locks and the retractor angle at which it locks. The reviewed standards on ELR seat belts provide locking thresholds which seem incompatible with the kinematics of many types of lift truck tipovers, kinematics which differ greatly from those observed in automobile accidents. Furthermore, the kinematic trajectories in lift truck tipovers are not clearly understood and, in any case, are quite variable.

A review of ELR-related standards shows that, except for the retractor-tilt-sensitive locking criterion, standard FMVSS 209 on seat belts seems to be the most conservative in terms of operator safety. However, as the acceleration levels required to activate retractor locking are lower than in SAE J386, it should be verified that these thresholds do not cause the belt to lock continually when the lift truck moves over rugged terrain. Moreover, these thresholds must not significantly reduce the operator’s field of vision when he/she turns around. A retractor that separates the vehicle-tilt and vehicle-acceleration thresholds would be ideal, coupled with a tilt-sensitive locking threshold of 12 to 15 degrees. Testing may be needed to quantify the characteristics of commercially available ELRs if they are not included in documentation available to the public. Given the large number of components involved, combined with the varying material tolerances, rigidity and size of these components, performance should be expected to vary from one retractor to another.

A seat belt with an automatic locking retractor (ALR) has drawbacks in terms of comfort and mobility in performing work, but a well-maintained ALR protects an operator by preventing him from being ejected during a tipover. A seat belt with a manual retractor effectively protects the operator, but must be adjusted to minimize slack in the webbing. This requirement makes it seem less suitable if several operators use the same lift truck during a work shift.

7. BIBILIOGRAPHY

7.1 Scientific publications

Balci, R., Vertz, A. and Shen, W. (2001), *Comfort and Usability of the Seat Belts*, SEA 2001 World Congress, Detroit, Michigan, March 5-8 2001, SAE Technical Paper Series, 2001-01-0051

Bourret, P.-É., Martel, S., Koutchouk, M., Roux, M.-A., Gou, M., Aubin, C.-É. and Rancourt, D. (2008), *Sécurité des chariots élévateurs : Étude de l'efficacité de la ceinture de sécurité*, Études et recherches/Rapport R-541, Montréal, IRSST, 139 pp.

Cannon, M.R., Eisentraut, D.K. and Sanahan, D. F. (2002), *Assessment of timely lockup of web-sensing restraint retractors*, SAE International, F565, 2002-01-1548.

Klima, M.E., Toomey, D.E. and Weber, M.J. (2005) *Seat belt retractor performance evaluation in rollover crashes*, SAE International, F569, pp. 2-9.

Male, G.E. (2003) *Safety of Industrial Lift Trucks – a Survey of Investigated Accidents and Incidents (April 1997 to March 2001)*, Specialist Inspector Reports no. 60, HSE, 46 p.

Meyer, S.E. Hock, D., Herbst, B. and Forrest, S. (2001). *Dynamic analysis of ELR retractor spoolout*, SAE International and Messe, Dusseldorf , F566, pp.2-7.

Meyer, S.E., Oliver, A. A., Hock, D. A., Hayden, J. D., Forrest, S. M., Herbst, B. R. and Clarke, C.C. (2008). *The effect of vertical and multiplanar accelerations on differing production seat belt sensor designs*, Proceedings of IMECE2008, 2008 ASME International Mechanical Engineering Congress and Exposition, October 31-November 6, Boston, Massachusetts, IMECE2008-68931, pp. 71-81.

Moffatt, E.A., Cooper, E.R., Croteau, J.J., Parenteau, C. and Toglia, A. (1997). *Head excursion of seatbelted cadaver, volunteers and Hybrid III ATD in a dynamic/static rollover fixture.* Proceedings of the 41st Stapp Car Crash Conference, 13-14 November 1997, Orlando, Florida, USA (SAE technical paper 973347): Society of Automotive Engineers. pp. 509-525.

Myers, M.L., Cole, H.P., Westneat, S.C. (2006), *Seatbelt Use During Tractor Overturn*, Journal of Agricultural Safety and Health, 12(1), pp. 43-49.

Rains, G.C. (2000) Effectiveness of roll-over protective structures in reducing ram tractor fatalities, Journal of Agricultural Safety and Health, 6(1), pp. 13-27.

Roberts, H. A., Partain, M., Batzer, S.A. and Renfroe, D. A. (2007), *Failure analysis of seat belt buckle inertial release*, Engineering Failure Analysis, 14, pp. 1135-1143

Robinson, B.J. Knight I.M., and O'Neill, D. (1996) Agricultural vehicle seatbelts – ergonomics of current designs (final report) TRL Unpublished project report, PR/SE/219/96.

Siegmund G.P., Chimich, D.D., Heinrichs, B.E., DeMarco, A.L. and Brault, J.R. (2005), *Variations in occupant response with seat belt slack and anchor location during moderate frontal impacts*, Traffic Injury Prevention, 6(1), pp. 38-43.

Smith, T., Couper, G., Donaldson, W., Neale, M. and Carroll, J. (2005), *Seatbelt performance in quarry vehicule incidents – Final report*, TRL Limited for the Health and safety executive, Berkshire (UK), 141 p.

Sullman, M.J.M., (1998), *Increasing seat belt usage in logging machinery*, short communication, International Journal of Industrial Ergonomics, 21 (1998), pp. 397-405.

Tellier, C. (1995a) *Sommaire des accidents de chariots élévateurs répertoriés par la CSST de 1991 à 1994*. IRSST, unpublished working document.

Tellier, C. (1995b) *Analyse sommaire des accidents graves et mortels provenant de la banque VREN de la CSST de 1974 à 1994*. IRSST. Unpublished internal document.

Thomas, T.M., Marine, M.C. et Wirth, J. L.(2002) *Emergency-locking retractor performance in rollover accidents*, Proceedings of IMECE 2002, no 39101, pp. 2-26

Toomey, D.E. et Klima, M.E. (2009). *Evaluation of seat belt assembly: physical evidence in properly functioning and intentionally disabled retractor demonstrations*, SAE International, F568, pp. 2-12.

Vezeau, S., Hastey, P., Giguère, D., Gagné, N., Larue, C., Richard, J.-G., Denis, D. (2009), *Amélioration des situations de travail impliquant les opérateurs de chariots élévateurs : étude ergonomique et analyse des stratégies de conduite des caristes*, Études et recherches/Rapport R-601, Montréal, IRSST, 133 p.

Wilcoxon, K.T. (1998) *Improving Seat Belt Comfort on Off-highway Vehicles*, International Off-Highway and Powerplan Congress and Exposition, Milwaukee, Wisconsin, September 14-16 1998, SAE Technical Paper Series, 982058.

7.2 Standards and regulations

ANSI B56.1-1975. *Safety Standard for Low Lift and High Lift Trucks*.

ANSI Z89.1-2009 *American National Standard for Industrial Head Protection*.

ASME B56.1 1993. *Safety Standard for High Lift and Low Lift Trucks*.

CSA B335.1 1997. *Low Lift and High Lift Trucks*.

E/ECE/324 Addendum 15: Regulation 16, rev. 6, May 19, 2009. *Agreement concerning the Adoption of Uniform Technical Prescriptions for Wheeled Vehicles, Equipment and Parts which can be fitted and/or be used on Wheeled Vehicles and the Conditions for Reciprocal Recognition of Approvals Granted on the Basis of these Prescriptions*, online: www.unece.org/trans/main/wp29/wp29regs/r016r6f.pdf, March 1, 2011.

FMVSS 209 49 CFR ch. V:2008 (paragraph 571.209). pp. 831-849. *Seat Belt Assemblies*. Federal Motor Vehicule Standards, Department of Transportation, March 1, 2011, www.crash-network.com/Regulations/FMVSS/fmvss.html.

ISO 9241-11:1998. *Ergonomic requirements for office work with visual terminal (VDTs) – Part 11: Guidance on usability*.

ISO 24135-1:2006. *Industrial trucks - Specifications and test methods for operator restraint systems - Part 1: Lap-type seat belts*.

SAE International J386, *Operator Restraint System for Off-Road Work Machine., February 2006 version.*

SAE, Aerospace standard 8043, *Restraint systems for civil aircraft*, Revision B, 2008.

OSHA, 1996. Nova Scotia, Occupational Health and Safety Act S.N.S. c.7, Part 7 Hoists and Mobile Equipment, section 65(1)(a)(i).

Regulation respecting occupational health and safety, Act respecting occupational health and safety, *Division XXIII, Handling and transporting material, §2 Hoisting devices, 256. Lift truck, 256.1. Lift truck operator retention device,* online: www2.publicationsduquebec.gouv.qc.ca/, 2008.

Annexe A. Buckle and latchplate

The seat belt fastening system consists of a female part, or buckle, and a male part, or latchplate. The latchplate has a tongue that slides into the buckle and, at the other end, an attachment plate attached to the webbing. The buckle is attached to the body of the vehicle or the seat by a cable, strap, metal lath or strap, or enclosed in a housing.

The buckle can have one or more release buttons on the outside surface, front or side, or a combination of these solutions. Harnesses may also have round belt buckles to which several webbings can connect. The tongues are released by turning a lever on the outside. Lastly, “airplane seat” buckles, as the name suggests, are used mainly in passenger aircraft but are occasionally installed in work vehicles. These buckles are said to be designed for a dusty, hostile environment requiring sturdiness and durability.

Like the buckle, the latchplate must be able to withstand the very great loads indicated in the seat belt standards. There are several kinds of attachment plates. The locking attachment plate is a metal bar that keeps the webbing at the length determined by the user. It is found on retractorless lap belts. The free attachment plate, which has no locking system and can slide along the webbing, is fitted on seat belts with a three-point retractor. Lastly, the sewn attachment plate attaches the lap belt and/or diagonal belt directly to the plate. This type of plate is used with seat belts with retractors.

Annexe B. Other emergency devices

The devices described in this appendix are supplied by seat belt manufacturers but are primarily designed for road vehicles with an upper body restraint system. The manufacturers must be asked whether they are appropriate for use in lift trucks.

Pretensioners

In an accident, the pretensioner almost instantaneously tightens the belt on the occupant. On retractorless seat belts (static belts), the pretensioner is positioned between the anchorage and the belt buckle. On impact, the pretensioner pulls down the cable attached to the buckle, removing any slack between the webbing and the occupant. It works the same way on seat belts with retractors (dynamic belts), except that the webbing is rewound by respooling the retractor instead of a cable being pulled. In both cases, the pretensioner's movement is designed to put more pressure on the occupant and restrict his movement.

Load limiter

Load limiters are indicated for use with an upper body restraint. The pelvic bones are strong and can withstand considerable force without fracturing. The rib cage is flexible but, under sufficient force, the ribs can break on impact. A load limiter limits the pressure transmitted to the rib cage. There are three main types of load limiters: simple limiter, mechanical limiter and torsion limiter.

Simple limiter

The simplest limiter is a fold sewn into the seat belt webbing. The stitching is designed to pull apart when a certain amount of force is applied to the belt. Upon loading, the webbing unfolds and reduce transmission of the load from belt to occupant.

Mechanical limiter

A mechanical limiter is a ladder with a set of metal teeth that is attached to the retractor on one side and the vehicle body, through the anchorage, on the other. In normal seat belt use, the metal teeth hold the retractor in place. When increased force is applied to the teeth, they begin to deform and the retractor moves upwards. This releases the webbing and reduces transmission of the load to the occupant.

Torsion limiter

Another type of load limiter, which uses a torsion bar, is found in more advanced seat belt assemblies. The bar is connected to the retractor spool on one side and attached to the vehicle structure on the other. The torsion bar is a metal rod that twists and deforms when sufficient force is applied, allowing the webbing to extend slightly.

Variable impedance fibre webbing

Variable impedance fibre webbing acts as a load limiter on impact, in a three-step reaction. First, the high-resistance fibres restrain the passenger in place. Then the fibres relax and extend just enough to limit the load applied to the occupant's chest and damp the body's movement when it comes in contact with the airbag. Lastly, the fibres keep the passenger from striking the steering wheel or dashboard when the airbag inflates.

Pre-pretensioner

Some pre-pretensioners decrease the load on the occupant's chest in an accident by means of a high-velocity electric motor that tightens the seat belt about a tenth of second before impact, using the vehicle's electronic system, such as stability sensors, panic-braking sensors or pre-impact radar.

Slack starts being removed earlier than with seat belts without a pretensioner or with a conventional pretensioner. This reduces the force applied to the occupant's chest. The pre-pretensioner system is reversible; it can activate as a precaution and tighten the belt if it is difficult to determine whether or not an accident will occur. A pre-pretensioner system can also work as an alarm, for instance, by making the seat belt vibrate when a driver takes a curve too fast.

Webbing lock

A webbing lock is a mechanism installed at the retractor opening that clamps down and locks the webbing during accidents. With a retractor, locking occurs at the spool, while with a webbing lock, locking occurs at the retractor opening. Moving the locking site in this way reduces the risk of withdrawal if the belt is wound too loosely around the spool. When the spool is locked by the retractor, if the webbing is not rewound tightly enough, following impact, it will release and move the occupant by an unknown distance during the collision.

Belt-integrated airbag

Like airbags on dashboards, steering wheels or vehicle corners, a belt-integrated airbag deploys on impact by means of pyrotechnic loads placed, for example, inside the belt buckle. This type of seat belt acts as a pretensioner by inflating, as well as potentially decreasing the risk of the head striking the vehicle door.

Comfort adjuster

Comfort adjusters can be used to adjust the webbing length on shoulder belts by preventing the webbing from retracting. The advantage is that the user can adjust the belt comfortably and prevent it from tightening too much on his body. This product is designed, among others, for truck drivers using suspension seats. It relieves the discomfort caused when the webbing locks or chafes on the shoulder and allows a greater range of motion. If the vehicle suddenly decelerates, the system disengages and the seat belt can retract sufficiently to restrain the occupant. With this system, the webbing can be kept at a specific length, but this may reduce the seat belt's effectiveness.

Annexe C. Other types of seat belts

Three-point seat belt

A three-point seat belt consists of a lap belt and a shoulder belt that runs diagonally over the thorax, from the hip to the shoulder on the opposite side. It has two anchorages in the floor or the seat on either side of the user, as well as a third anchorage on one of the vehicle pillars so that the webbing can be passed over the shoulder. This belt attachment may be static or have a retractor or a fourth anchorage lower down on the pillar. In the last case, the retractor is installed on the lower anchorage and a ring guides the webbing to the upper anchorage.

Unlike a lap belt, a three-point belt prevents the abdomen from coming into contact with the steering wheel in a head-on collision. However, it will not totally prevent the head from striking the steering wheel or nearby structures (Smith et al. 2005). In a static or dynamic 90° lateral rollover, a three-point belt restrains the driver’s trunk and head better than a lap belt, as long as the rollover is in the direction of the side of the trunk restrained by the belt (Smith et al. 2005). If the shoulder belt is worn on the opposite side, displacement of the head and trunk is similar to that measured when the occupant is wearing a lap belt. Smith et al.’s study (2005) also noted that in dynamic rollovers, the shoulder belt tended to wrap around the neck and transmit force that was likely to cause injury.

Harness

A harness is the most restrictive seat belt. It can have from four to seven anchorages and is mainly used in race cars and child safety systems. It can be retractorless, or have two or three retractors. A report written by the Health and Safety Executive (Smith et al. 2005) states that a four-point harness is the best restraint system in earth-moving or mining vehicles because it effectively restrains the user in frontal and lateral, static or dynamic rollovers. However, the authors point out that the acceptability of this type of system depends on the tasks performed by operators. A harness is incompatible with tasks requiring the operator to get on and off the vehicle frequently or requiring mobility, for example, to turn around.

Annexe D. Observed conditions

Table D1. Features of the 12 participating operators.

Gender	Male: 12 Female: 0
Seniority as an operator in the company (years)	Median: 12.5 Min.: 2.0 Max.: 37.0
Height (m)	Median: 1.77 Min.: 1.57 Max.: 1.83
Weight (kg)	Median: 88.2 Min.: 68 Max.: 147
BMI: body mass index - man (number of subjects per class)	Healthy weight or overweight: 7 Obese (classes 1, 2, 3): 5
Clothing features	Light clothing, jacket or winter coat With or without gloves With or without tool pouch

Table D2. Experience of the 7 participating supervisors.

Gender	Male: 7 Female: 0
Experience as supervisor in the company (years)	Median: 4.0 Min.: 2.0 Max.: 14.0
Experience as operator in the company or elsewhere (years)	Median: 2,0 Min.: 0.5 Max. : 11.0

Table D3. Characteristics of the 14 lift trucks in the study sample.

Manufacturer	Toyota, Hyster, Yale, Cat
Type of gripping equipment	Clamping, forked, spurred
Type of motor	Propane, electric
Cab	Open and closed
Capacity (including gripping equipment)	From 1,300 kg (3,000 lb) to 7,000 kg (15,000 lbs)

Table D4. Type of seat belt retractor installed on the 14 lift trucks in the study sample.

Type of retractor	Number
Manual	1
ALR (automatic locking retractor)	11
ELR (|emergency locking retractor)	2

Characteristics of seats installed in the 14 lift trucks in the study sample:

- With or without armrests, chest restraints, hip restraints;
- With or without suspension under the seat cushion or backrest; and
- Seat fixed or able to swivel horizontally.

Other features of lift trucks in the study sample:

- Interlock fastening system;
- Fasten seat belt alarm;
- Orange webbing;
- Magnetic key for operator identification;
- Collision data recorder (G-force);
- Speed limiter; and
- Curve speed reducer.