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Current Assessment of Stand-Up Forklifts' Underride Accidents

By Richard M. Ziernicki, PhD, PE, DFE (NAFE 308F) and Ricky Nguyen, PE, DFE (NAFE 1223M)

Abstract

Stand-up forklift collisions with storage racks are a known hazard in the material-handling industry. When the height of the first rack beam from the floor is close to or above the height of the forklift's operator compartment — and is at a height that is lower than the forklift's overhead guard — the rack beam can intrude into the forklift's operator compartment. These collisions are typically referred to as "horizontal intrusion incidents," also known as "underride" incidents. When the forklift is not equipped with horizontal intrusion guarding, these occurrences often lead to serious (if not fatal) injuries. This paper presents physical testing and analysis of one major forklift manufacturer's accident database records, which show rear-mounted posts are effective guards in reducing or preventing the consequences of horizontal intrusion incidents. Further, this paper shows these rear post guards met and exceeded design requirements of the material-handling industry standards.

Keywords

Forklifts, horizontal intrusion, under-ride, stand-up forklifts, guarding, safety, forensic engineering

Introduction

In the material-handling industry, stand-up forklifts are commonly used to handle materials within a storage facility, such as in an outdoor yard or indoor warehouse. Even though stand-up forklifts come in various sizes, they are smaller than an average gasoline-powered sedan. However, they are heavy pieces of machinery that commonly weigh as much as three times the weight of an average sedan — upward of 9,000 pounds or more without loads. They can also carry loads as heavy as 4,000 pounds, and some can travel as fast as 9 mph. This may not seem fast on public roads, but these forklifts are commonly used in warehouses with narrow aisle storage racks (some less than 10 feet wide) with workers walking around the warehouse floor. In addition, unlike a vehicle and sit-down forklifts, stand-up forklifts are operated from a standing position and controlled by the throttle controls with one hand and the steering controls with the other. These machines can be operated with forward or reverse (also known as "forks-trailing") steering setups.

The operator compartment structure for a stand-up forklift typically consists of four walls with an opening to allow operators to ingress and egress from the compartment. The walls at the end of the forklift (opposite the forks) typically extend up to a height of approximately 4.5 feet tall off the floor. Stand-up forklifts are also equipped with overhead guards that are at a height of typically 7 feet to 8 feet off the floor (**Figure 1**).

Research has shown the most common form of injury occurrences involving stand-up forklifts are collisions[1,2,4]. Since stand-up forklifts are commonly used in storage warehouses, colliding into storage racks has been known and documented for decades. Depending on the forklift and storage rack configuration — when the height of the first rack beam from the floor is close to or above the height of the forklift's operator compartment and is at a height that is lower than the forklift's overhead guard (see **Figure 2**) — the rack beam can intrude into the forklift's operator compartment when forklifts are traveling in reverse toward a rack.

Underride incidents are serious — many times even deadly — when there is a lack of horizontal intrusion guarding to prevent or mitigate the adverse effects of the collision. **Figure 3** and **Figure 4** are 3D graphics that depict the result of a stand-up forklift override incident the authors investigated and reconstructed.

Horizontal Intrusion Guarding

The authors' experience includes investigating

Richard M. Ziernicki, PhD, PE, 7185 S. Tucson Way, Centennial, CO 80112, (303) 925-1900, rziernicki@knottlab.com

Figure 1
A stand-up forklift (green arrows added to outline the walls around the operator compartment). Blue arrow added to show overhead guard.

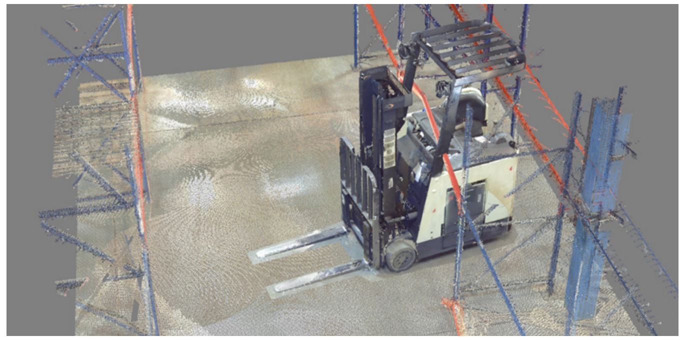

Figure 3
3D graphic of a rack beam that had intruded into a stand-up forklift's occupant compartment.

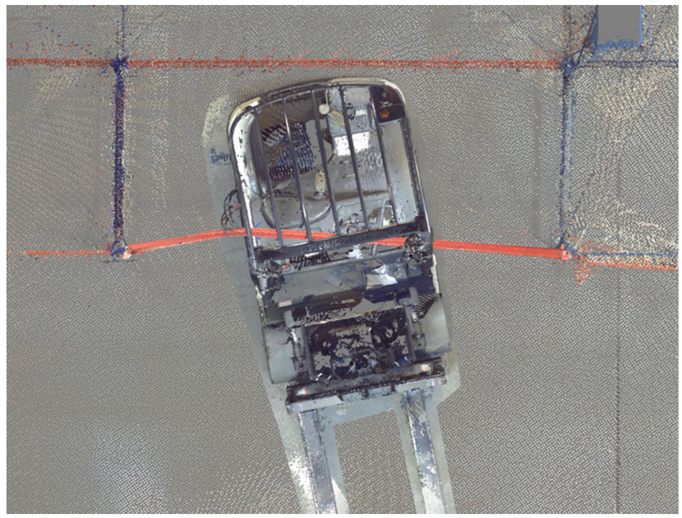

Figure 4
3D graphic of a rack beam that had intruded into a stand-up forklift's occupant compartment (from a top-down view).

Figure 2
Storage racking system.

numerous stand-up forklift underride incidents, which include inspections of more than two dozen stand-up forklifts and storage rack systems. Based on the authors' experience, most stand-up forklifts have operator compartment heights at about 4.5 feet, and first level beams are also typically configured above that height, such as around 5 feet (as seen in home improvement stores). This mismatch of operator compartment height and first level rack beam is commonly seen in warehouses.

Two well-known methods to safeguard against horizontal intrusions are:

1. Have a forklift equipped with guarding, such as a third corner post, to prevent/minimize horizontal beam intrusion into the occupant compartment. A third corner post is a vertical upright (usually fabricated out of common steel) that is installed between the forklift's main power unit and

overhead guard at the rear left corner the forklift (with the front of the forklift being where the forklift's forks are pointing toward), hence the "third-corner" designation (**Figure 6**). This post needs to be provided by the forklift manufacturer due to Occupational Safety and Health Administration's (OSHA) regulations that state any modifications to the forklift must be approved by the forklift's manufacturer (Title 29, 1910.178(a)(4)). Furthermore, when forklifts are equipped with horizontal intrusion guarding systems, the system must meet performance requirements outlined by the American National Standards Institute (ANSI)/ Industrial Truck Standards Development Foundation's (ITSDF) B56.1 "Safety Standard for Low Lift and High Lift Trucks" for the manufacturer of forklifts.

Some manufacturers do equip or have a post available for the forklift's fourth corner (or the rear right corner) to provide additional horizontal intrusion protection (**Figure 5**). However, others have equipped their stand-up forklifts with a fourth corner extension to provide horizontal intrusion protection instead (**Figure 6**). These extensions are typically either a weldment to the forklift's outer wall plate metal or was formed with the plate metal that surrounds the operator compartment. However, unlike a post that extends from the walls of the operator compartment to the overhead guard, these extensions do not extend to the operator guard — and typically extend to only about a height of 5 to 6 inches above the height of the operator compartment walls.

Aftermarket rear posts manufactured by third-party vendors can be purchased and installed on stand-up forklifts that originally did not come with rear posts. From the authors' communication with the manufacturers, these aftermarket posts have been third-party tested, and the results

Figure 5
A stand-up forklift equipped with a third corner post and fourth corner post as a standard feature.

Figure 6
Stand-up forklift equipped with a third corner post (arrow "1") and a fourth corner extension (arrow "2").

showed their design met the requirements of the ANSI/ITSDF B56.1 standard. The authors had not verified the test results at the time of this paper, but evaluations/verifications of these test results could be performed as part of a future study. The aftermarket post manufacturer further stated that forklift manufacturers do not endorse or provide approval to install these aftermarket posts on their forklifts to meet the 1910.178 regulation regarding forklift modification. Furthermore, the aftermarket posts manufacturer mentioned that end-users have petitioned OSHA to allow them to install these aftermarket posts on their forklifts without approval from the forklift manufacturer.

2. The other method to safeguard against horizontal intrusions is to have a rack system with horizontal rack beams placed at specific heights or add structures, such as a curb, to prevent the occurrence of forklifts under-riding the beams. This needs to be done by the warehouse owner/designer.

   Unless the racking system was initially designed or configured to prevent horizontal intrusion incidents, the existing racking system would need to be modified or retrofitted to provide underride guarding for the forklifts with too low of a fourth corner extension and lack of a third corner post. A common issue with modifying or retrofitting an existing rack system is that the changes can affect the volume and load capacity of the rack system for an entire warehouse, which can be physically and financially impractical.

   The alternative, mounting a post to one or both corners of the forklift, is less of a financial burden (a few hundred dollars for parts and installation) and does not depend on the various configurations of rack systems to be effective.

Forklift Industry Regulations, Standards, and Literature Regarding Rear Posts Guards

In July 2009, OSHA published a Safety and Health Information Bulletin (SHIB) titled "Standup Forklift Under-Ride Hazards." In the bulletin, one of the recommendations OSHA makes was: "*Purchase, where appropriate, standup forklifts that have corner posts, extended backrest, rear post guards, or other features to prevent an under-ride from occurring*"[5].

In August 2004, the National Institute of Occupational Health and Safety (NIOSH) published a Fatality Assessment and Control Evaluation (FACE) report regarding a horizontal intrusion incident that occurred in Iowa in 2003. As a result of the incident, NIOSH recommended: "*manufacturers of stand-up reach forklifts should include vertical framing or post at the rear corners of their machines, from the operator's console to the overhead guard, to protect the operator from horizontal components entering the operator's station*"[6].

Since the early 1990s, the ANSI/ITDSF B56.1, "Safety Standard for Low Lift and High Lift Trucks," contains language that allows manufacturers to equip forklifts with means to protect the operator from the intrusion of horizontal beams, such as rear posts[7]. Further, the standard provides test methodologies and performance criteria for horizontal intrusion guards.

The Industrial Truck Association (ITA) has an engineering committee that included representatives from forklift manufacturers in the industry. In the early to mid-1980s, one of the specific hazards that the committee addressed was the hazard of horizontal intrusion. By 1989, the ITA adopted a recommended practice regarding horizontal intrusion that was similar to the ANSI/ITDSF B56.1 standard's language regarding a means to protect the operator from the intrusion of horizontal beams[8].

Methodology

To analyze the effectiveness and increased safety benefits of equipping stand-up forklifts with rear posts in preventing/minimizing the consequences of horizontal intrusion incidents, the authors analyzed one major forklift manufacturer's accident database to determine if there was a decreasing trend in serious and fatal injuries caused by horizontal intrusion incidents, after the manufacturer equipped their stand-up forklift with a third corner post. The authors then addressed the issues of manufacturers not having these vertical posts as standard equipment on their stand-up forklifts by evaluating their decision with accepted safety engineering practices. Physical testing was also reviewed to analyze the performance of rear posts with criteria outlined in the ANSI/ITDSF B56.1 standard.

Analysis

Manufacturer Statistics

In older studies, Manufacturer A's forklift accident database, consisting of more than 3,000 stand-up forklift accidents, was analyzed. The data indicated there were 250 horizontal intrusion accidents, which resulted in more than 12 fatalities and 100 serious injuries from 1977 to 2005[1]. The database has since been updated, with records of more than 5,000 accidents that occurred up to the year 2017. **Figure 7** through **Figure 10** are graphs created with information from the updated database.

The updated database showed that by the year 2017, the number of reported horizontal intrusion accidents increased to 303. Furthermore, the number of accidents resulting in fatal injuries increased to 15, and the number of accidents resulting in serious injuries increased to 130.

Analysis of the data showed that the rate of annual horizontal intrusion occurrences started to rapidly decline in the year 1999 and then leveled out to a steady rate starting in the year 2009. The decline in horizontal intrusion occurrences could be attributed to changes in operator training requirements in the 1910.178 regulations for powered industrial trucks. However, the annual rate for the combined number of serious and fatal injuries in horizontal intrusion accidents did not have the same rapid decline (four to eight occurrences per year) until the year 2008 (less than four occurrences per year), as shown in **Figure 11**. It is also worth mentioning that there has been zero reported deaths since the year 2007.

The decline in serious and fatal accidents starting in the year 2008 coincides with the manufacturer's decision to make a third corner post a standard feature on all its stand-up forklifts, starting in 2007. From review of the updated database, the authors also found zero horizontal intrusion accidents that resulted in serious or fatal injuries involving their stand-up forklifts that were equipped with a third corner post as a standard feature. Although there are still reported occurrences of horizontal intrusion accidents that resulted in serious injuries since 2007, the data showed these accidents involved older model forklifts that were not equipped with a third corner post as a

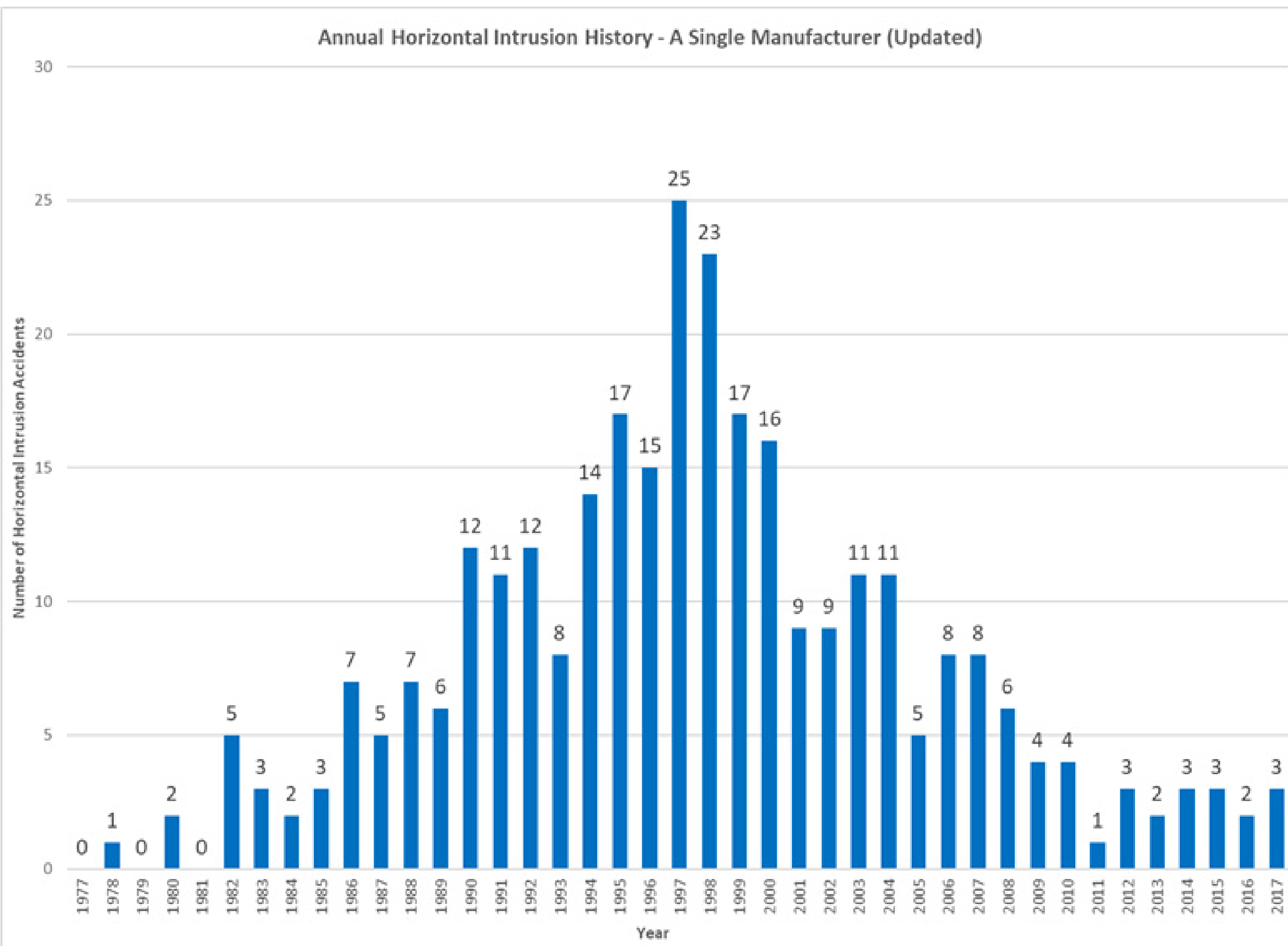

Figure 7
Graph showing the annual number of horizontal intrusion accidents from Manufacturer A's updated database.

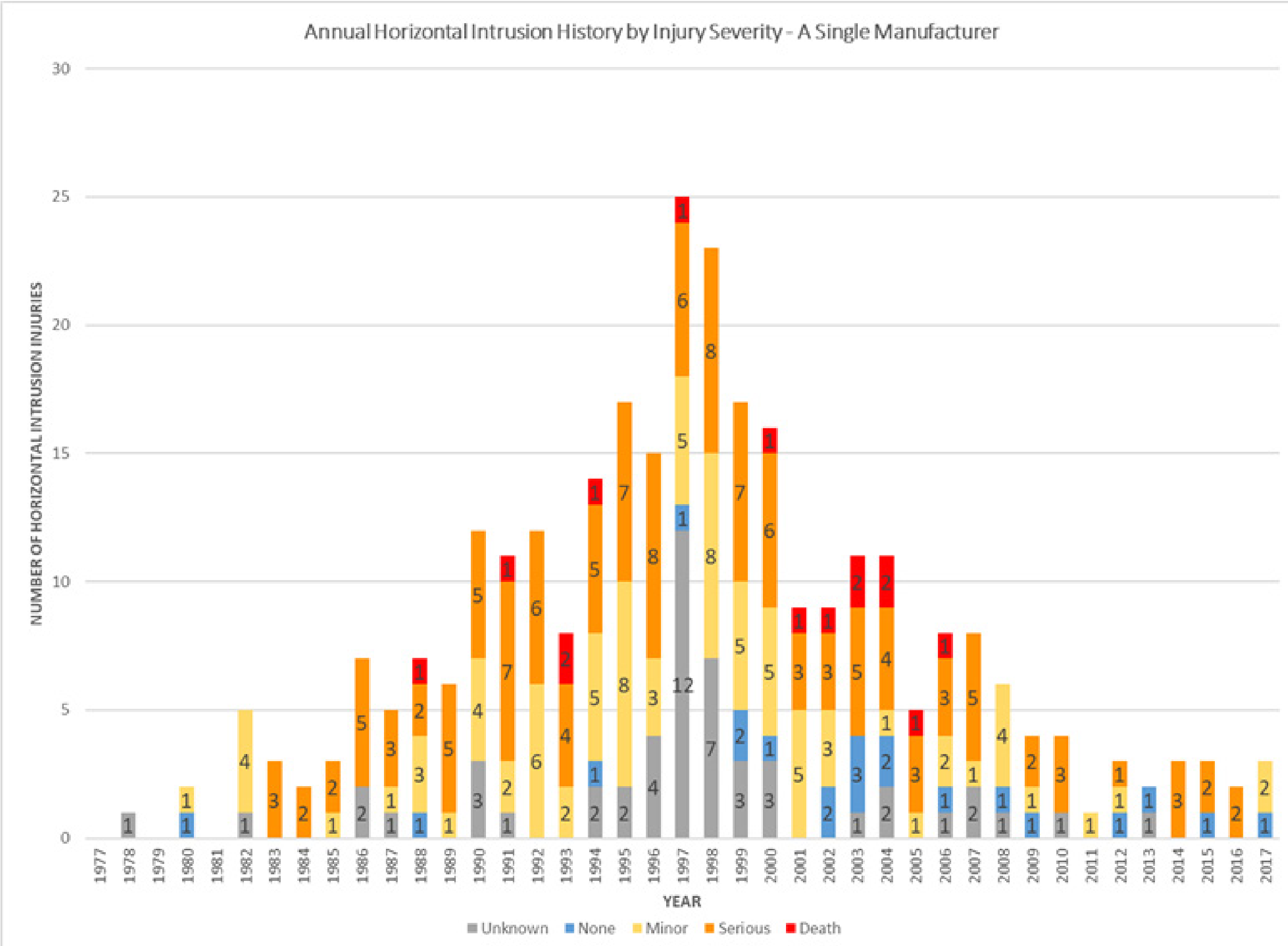

Figure 8
Graph showing the number of annual horizontal intrusion accidents, categorized by injury severity from Manufacturer A's updated database.

standard feature (pre-2007). Therefore, it could be inferred from the accident data that the significant reduction/elimination of serious/fatal horizontal intrusion injury occurrences was due to the addition of the third corner post on modern stand-up forklifts.

Although rear posts have been known to protect operators from the hazard of intruding horizontal beams for decades (and more manufacturers are adopting single or multiple rear posts as a standard feature on their forklifts), some still choose to not make rear posts a standard feature on their stand-up forklifts. Even though the manufacturers may offer one or two rear posts on the forklifts as an optional feature, making the post an optional feature requires the customer to make the decision to add the post for an additional cost. The manufacturers even list some claimed negative considerations associated with rears post in promotional material, further discouraging customers from purchasing the rear post additions. For example, the negative considerations associated with the third corner post that Manufacturer A listed in brochures included the following:

- Doesn't protect in all cases
- Pinch/crush point
- Post may shear/break, striking the operator
- Operator may use post as a bumper
- May create false sense of security with operator

The authors acknowledge that the presence of a third corner post potentially introduces hazards associated with the above negative considerations. However, review of Manufacturer A's accident database from 1977 through 2017 showed the number of serious or fatal injuries (18

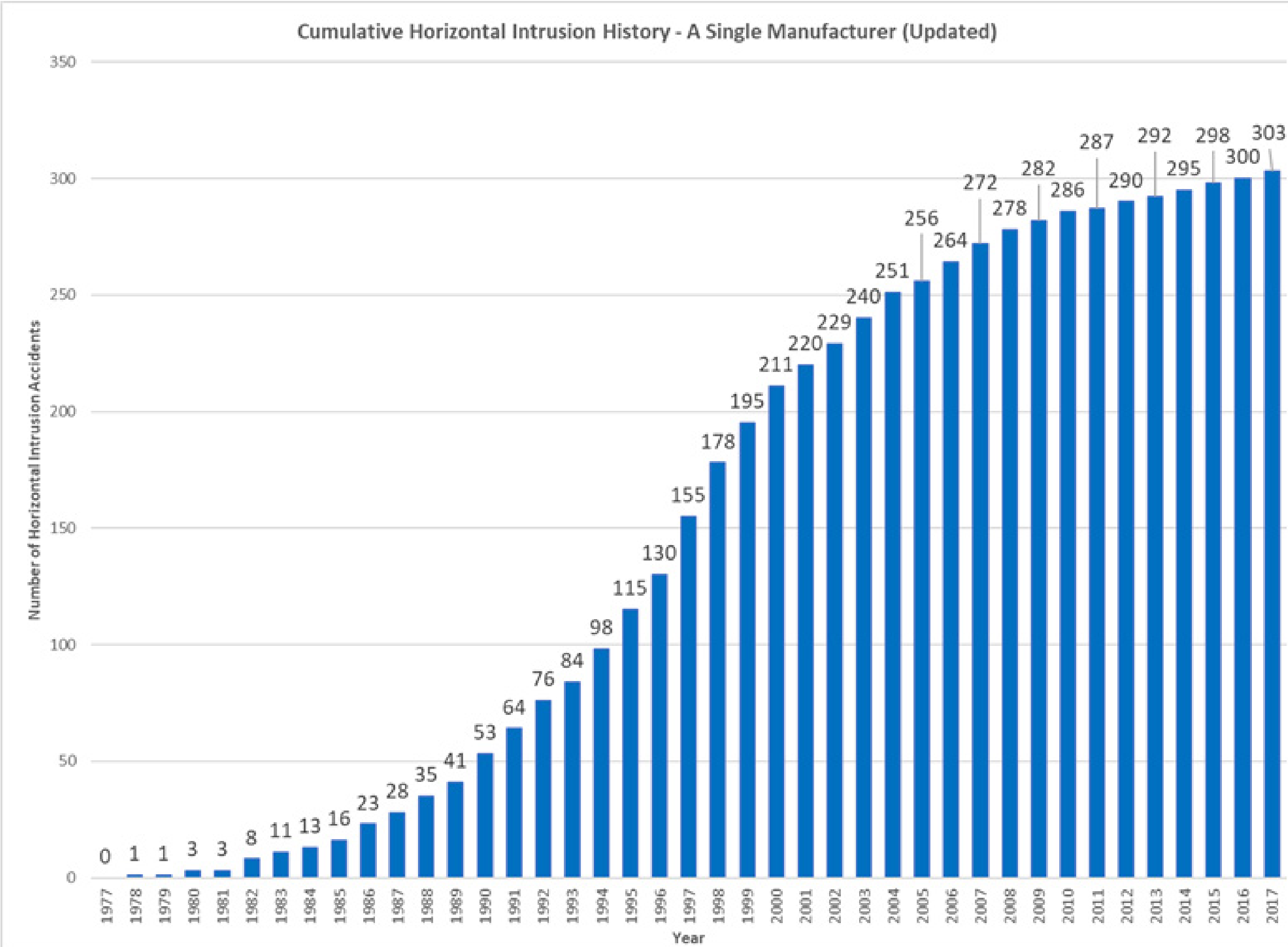

Figure 9

Graph showing the cumulative number of horizontal intrusion accidents from Manufacturer A's updated database.

accidents) that were reportedly caused by claimed hazards associated with the third corner post was an order of magnitude less than the occurrence of serious or fatal horizontal intrusion accidents (more than 140 accidents from 1977 through 2017). The data would indicate that the likelihood of serious/fatal injury caused by the claimed hazards associated with the posts are low compared to the likelihood of injury caused by the lack of post on a forklift. Therefore, the data would also indicate the third corner post's safety benefits outweigh the claimed negative considerations with the post, and the post does provide an overall increase in safety to stand-up forklifts.

Regardless of Manufacturers A's claimed negative considerations, the manufacturer eventually changed its stance on third corner posts being an optional feature, and made them standard on all of its stand-up forklifts since 2007. From information obtained through legal investigations, the reason the manufacturer decided to make the post a standard feature stemmed from the manufacturer's engineers. After reviewing the accident data collected over the last few decades, they subsequently made the determination that the posts did increase the overall safety of the forklift.

In addition to making rear posts an optional feature and inadequately explaining the safety benefits of the rear posts, charging the customer to add the rear posts indicates to the user that this is an unnecessary feature and further discourages the buyer from equipping their forklifts with rear posts. Forklift buyers are also unaware of the safety benefits of rear posts — or even the existence of the posts at all — as the information discussing safety benefits of the posts is relegated to a few brochures or must be explained to the user by the forklift dealer.

Furthermore, the decision to make rear posts a standard feature has been historically divisive in the industry.

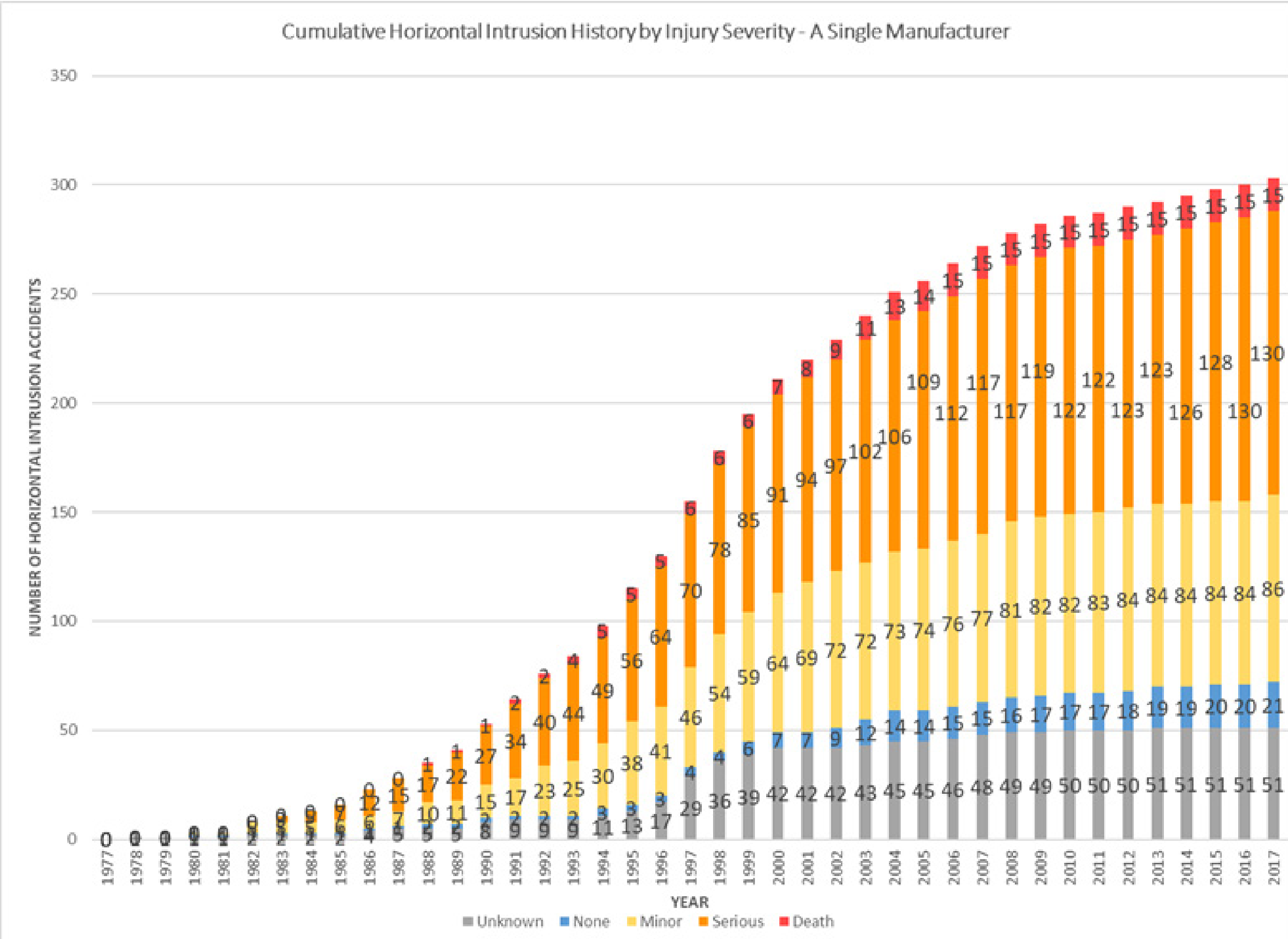

Figure 10

Graph showing cumulative number of horizontal intrusion accidents, categorized by injury severity from Manufacturer A's updated database.

ITA has an engineering committee that included representatives from forklift manufacturers. Although the committee has adopted practices regarding performance requirements of horizontal intrusion guards, they chose to not make effective horizontal intrusion guards (such as rear posts) a required feature on stand-up forklifts. One committee member, a representative from one of the forklift manufacturers (henceforth, will be referred to as "Manufacturer C"), has been critical of the committee's decision to not make the guards a standard feature[15]. Manufacturer C has made rear posts a standard feature on its stand-up forklifts since the 1950s[16].

In conclusion, based on review of Manufacturer A's accident database, it is the authors' opinion that the third corner post should be installed as a standard feature on all-stand-up forklifts rather than an optional feature. If the customer/end-user determines that the third corner post are impractical with their specific application, forklift manufacturers and the B56.1 standard do allow the customer/end-user to request the third corner post to be removed by the forklift manufacturer.

Safeguarding Hierarchy

There are numerous publications that provide methodologies for reducing or eliminating safety hazards. The following are examples of well-known and accepted methodologies that engineers use to design out or reduce hazards associated with products.

International Organization for Standardization (ISO) 12100-1:1992 "Safety of Machinery – Basic Concepts, General Principles for Design" outlines a clear hierarchy to be followed during the design of a product[10]. *"The designer shall, in all circumstances, in the following order:*

- *specify the limits of the machine.*

- *identify the hazards and asses the risks.*
- *remove the hazards or limit the risks as much as possible.*
- *inform and warn the user about any residual risks.*
- *consider any additional precaution."*

The *Mechanical Design Process* by D. Ullman, 1992[11], states:

"There are three ways to institute product safety. The first way is to design safety into the product. This means that the device poses no inherent danger during normal operation or in case of failure. If inherent safety is impossible, as it is with most rotating machinery and vehicles, then the second way to design in safety is to add protective devices to the product."

"The third, and weakest, form of designing for safety is the use of a warning to point out dangers inherent in the use of a product."

"Safety Through Design," published by the National Safety Council, 1999[12], identifies an order of design precedence:

1. *Design for minimum risk.*
2. *Incorporate safety devices.*
3. *Provide warning devices.*
4. *Develop and institute operating procedures and practices.*

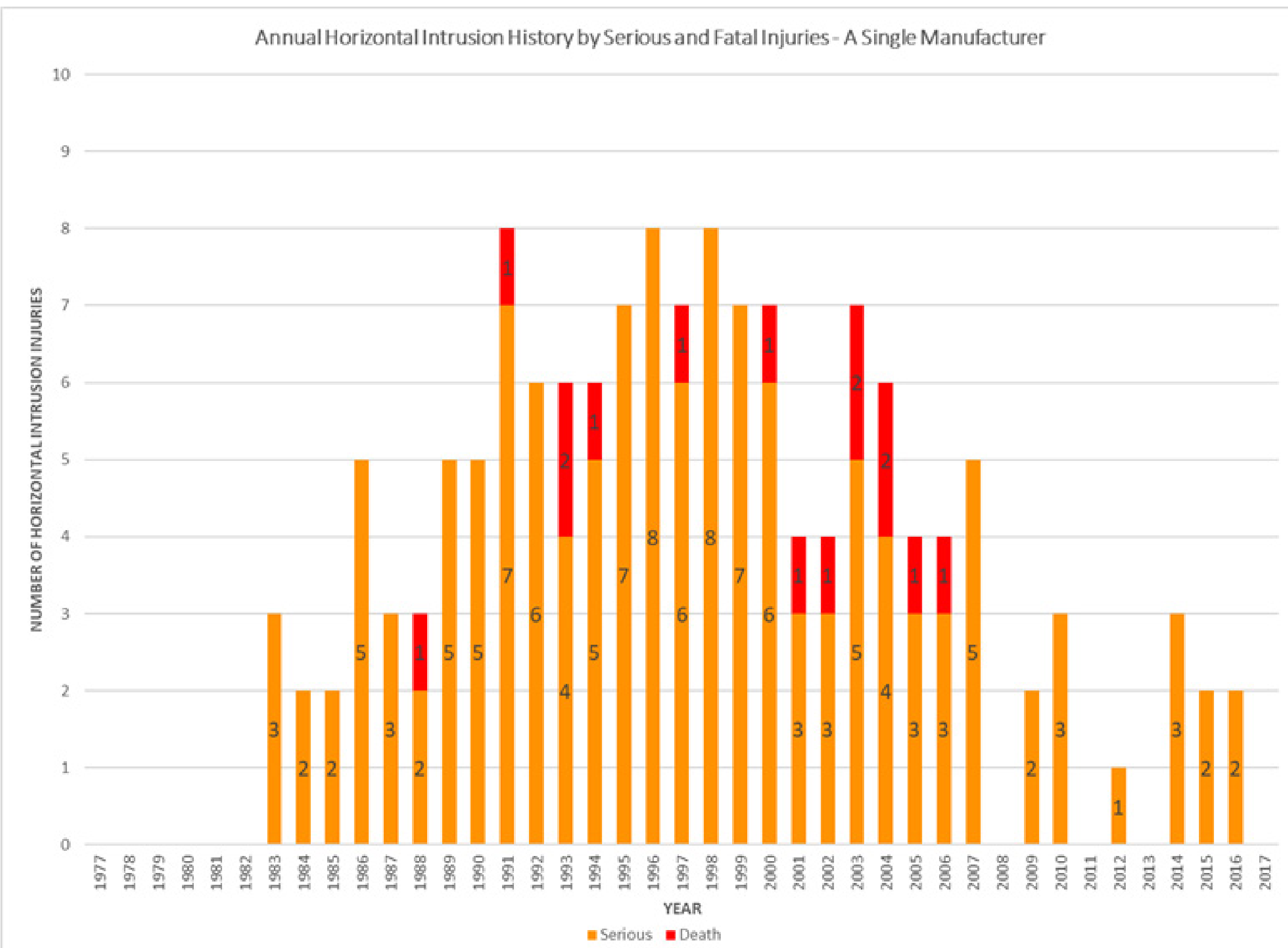

Figure 11
Graph showing annual number horizontal intrusion accidents, categorized by serious and fatal injuries from Manufacturer A's updated database.

It further states, *"Do not choose a lower level of priority until practical applications of the preceding level or levels are exhausted. First and second priorities are more effective because they reduce the risk by design measures that eliminate or adequately control hazards."*

In summary, the recurring theme in safety literature is that when hazard associated with product is recognized, the hazard shall be eliminated or reduced through a hierarchy of design, guard, and warn.

Since the hazard of stand-up forklift collisions cannot be eliminated, the next step in the hierarchy is to guard or incorporate devices to reduce the likelihood and consequences of the underride hazard. Manufacturers have been aware of the hazards associated with horizontal intrusion for decades, have put warnings on their forklifts, and instructed operators about the hazard in the operator's manual. However, manufacturers not equipping third corner posts as a standard feature on forklifts is a violation of well-known and accepted methods to safeguard against hazard of horizontal intrusion.

Although warnings and instructions can reduce the probability of horizontal intrusion incidents from occurring, operators are still getting seriously or fatally injured in horizontal intrusion accidents when there is a lack of effective horizontal intrusion guarding. Warnings and instructions are less effective than physical guards at preventing or mitigating the consequences associated with the incidents, which are usually serious or fatal injuries. In contrast, it is known that rear posts are passive safety devices that can guard an operator from injury when they are involved in an underride incident. The above pattern is further exemplified in Manufacturer A's accident database (previously discussed), where the data shows the rate of combined serious and fatal injuries did not rapidly decrease until after the forklift manufacturer made the third corner post a standard feature on its standup forklifts.

Furthermore, it is foreseeable that operators can unintendedly drive forklifts into racks. Following are examples of literature that state how designers/manufacturers need to consider foreseeable misuse when designing products.

ISO 12100-1 states[10]:

"With regard to foreseeable misuse, the following behavior should be particularly taken into account in the risk assessment — the foreseeable incorrect behaviors resulting from normal carelessness."

"Handbook of System and Product Safety" by Willie Hammer, P.E., 1972[16], states:

"The designer may not only commit errors but be guilty of omissions in failing to incorporate desirable features as safeguards that would have prevented accidents or protected personnel. When a designer cannot eliminate a hazard or the possibility of an accident completely, he must attempt to minimize the possibilities that other personnel will commit errors generating mishaps. In effect, the designer, through foreseeability, must attempt to make the system "idiot-proof," although he knows he will always be subject to the inevitability of Murphy's Law."

"Occupational Safety Management and Engineering" by Willie Hammer, P.E., 1981[15], states:

"Almost every mishap can be traced ultimately to a personnel error. It may not have been an error on the part of the person immediately involved in the mishap, but it may have been one committed by a designer, a worker manufacturing the equipment, a maintenance man, or almost anyone other than the person present when the accident occurred. A mistake by an operator may have no adverse effect with a safely designed piece of equipment. A similar mistake with one that is poorly designed may result in a disaster. It is evident that if a human error apparently caused an accident, other conditions must also have existed which contributed to its possibility."

"Modern safety practice, therefore, is to provide: 1) equipment and procedures that will minimize the possibilities of errors by operators; 2) designs that will eliminate or minimize the possibilities of accidents if an operator does make an error; and 3) designs and safeguards that will prevent injury if an accident does occur."

"Safety Through Design," published by the National Safety Council, 1999[14], states:

"The theme of this book is that it is difficult for engineers to change human nature and therefore, instead of trying to persuade people not to make mistakes, we should accept people as we find them and try to remove opportunities for error by changing the work situation, that is, the plant or equipment design or the method of working. Alternatively, we can mitigate the consequences of error or provide opportunities for recovery."

In summary, the recurring theme in safety literature and standards is designers/manufacturers need to consider reasonably foreseeable human error/misuse in designing their products and prevent/minimize injury if accidents do occur.

In conclusion, since the hazard of horizontal intrusion has been recognized for decades, the first and foremost responsibility of the engineering designer is to guard against the hazard for foreseeable use and misuse. Further, warnings and training are superseded by safe design and guarding in the safeguarding hierarchy; warnings and instruction are an insufficient safeguard to the horizontal intrusion hazard. Therefore, based on the above, it is the authors' opinion that forklift manufacturers need to equip their forklifts with effective horizontal intrusion guards, such as the third corner post, as a standard feature.

Physical Testing of the Rear Posts

The ANSI/ITSDF B56.1 standard outlines impact performance criterion for horizontal intrusion guards. The year 2020 revision of the standard states:

"The means and its mounting shall be strong enough to withstand the impact of a load simulating the collision between a truck carrying a full rated load and traveling at 1.6 km/h (1 mph) and a horizontal rigid barrier simulating a rack beam with a 75 mm (3 in.) vertical dimension.

After impact, there shall be no separation of parts or permanent deflection in excess of 100 mm (3.9 in) in the horizontal plane."

Even though the standard does provide a protocol and impact performance criteria for manufacturers to design rear posts for forklift travel impact speeds of 1 mph, forklifts can impact horizontal rack beams at speeds much higher than the 1 mph impact speed required by the standard. Although the authors of this paper are aware Manufacturer A impact tested their post design at forklift travel speeds of up to 3 mph (nine times the kinetic energy), not every manufacturer tests their third post beyond the requirements of the ANSI standard.

One study published in 2015 evaluated the effectiveness of rear posts in guarding against horizontal intrusion at higher travel impact speeds than what is required by the ANSI/ITSDF B56.1 standard[3]. In the 2015 study, another major manufacturer's (henceforth, will be referred to as "Manufacturer B") forklift equipped with a third corner post and a fourth corner post system was tested. The rear posts had a 1.5-inch by 2.5-inch rectangular tube cross-section with a wall thickness of 0.19 inches. The posts had a length of 41 inches and were made out of mild steel.

Manufacturer B's forklift, while carrying its rated load capacity, collided into a section of typical warehouse racking in a perpendicular manner four separate times at speeds of up to 3.4 mph. The portions of the posts that made contact with the rack beam were approximately 5 to 10 inches from the bottom of the 41-inch-long post.

During the tests, both posts contacted a horizontal beam, with the fourth corner post contacting the beam first because the position of the post on the forklift was a few inches further rearward than the third corner post. The test results showed the maximum permanent deformation of the posts was 0.229 inches — a fraction of the 3.9-inch maximum allowed by the B56.1 standard (a factor of safety of approximately 17 in these type of collisions). Further, the test results showed there was up to 9.5 inches of deformation to the impacted rack beam or significantly more than the deformation to the post (**Figure 12** and **Figure 13**).

The study concluded that the rear posts system from Manufacturer B met and exceeded the B56.1 standard and provided operator protection in the event of a horizontal intrusion incident. Furthermore, based on the minimal deflection of the post and the fact that the rack beam did not significantly intrude into forklift operator compartment, the test results showed the rear corner posts had a significant factor of safety and would have been effective in operator protection at higher collision speeds than the tested 3.4 mph speed.

Case Study: Manufacturer's Testing

A horizontal intrusion incident involving a stand-up forklift and a storage rack that resulted in serious injury was investigated and reconstructed (**Figure 1**, **2**, **3**, and **4**). The horizontal rack beam, which had intruded into the forklift and crushed the operator, was 96 inches long with a C-channel profile that was 3 inches tall, 1.4 inches wide, and ¼ inches thick. The beam was made out of A992 steel. The forklift involved in the incident was not originally equipped with a third corner post but was equipped with the fourth corner extension. However, the third corner post was offered by Manufacturer A as an optional feature when the forklift was originally sold. As part of the incident reconstruction, it was determined that the forklift (with no load) traveled into the rack at a speed of up to 6.1 mph.

Figure 12
Photograph showing the results of the physical testing performed from the 2015 study[3].

As part of the investigation, the manufacturer of the forklift performed testing with a surrogate stand-up forklift that was equipped with a third corner post. Based on the manufacturer's specifications, the third corner post was a 49-inch-long steel tube with a circular cross section profile with an outer diameter of 2.5 inches and a wall thickness of 0.31 inches. The third corner post was made from 1018 carbon steel. The manufacturer performed impact testing with racking systems that were like the one involved in the case. The manufacturer performed its test with an impact speed of approximately 6 mph (**Figure 14** and **Figure 15)**.

The authors were only provided videos of the testing

Figure 13
Photograph showing the results of the physical testing performed from the 2015 study (view showing the operator compartment and the deformed beam)[3].

that was performed by the manufacturer and were not given any written reports or photographs that could be reviewed to quantitatively determine the deflection and deformations observed to the post and the rack system. However, the test videos showed that after the impact the post exhibited minimal to no deformation. The test also showed that the impact caused the rack beam to significantly deform and deflect away from the operator compartment. The testing further showed the bolts that held the beam onto the rack's vertical uprights had sheared off at one end of the beam so the beam acted more like a cantilevered beam instead of a simply supported beam (and allowed the beam to deflect further away from the forklift's occupant compartment). The test also showed the vertical uprights had deformed and deflected significantly.

Therefore, the manufacturer's testing further exemplifies the common trend that when a post-equipped forklift collides with a racking system, there would be minimal to no deformation to the post, there would be significant deformation and deflection of the racking system instead, and the operator compartment space would have been maintained. The results of the analysis can be applied to impacts with similar rack systems and collision configurations.

Furthermore, like the 2015 test, this third corner post system design also exhibited a significant factor of safety and would have been effective in operator protection at

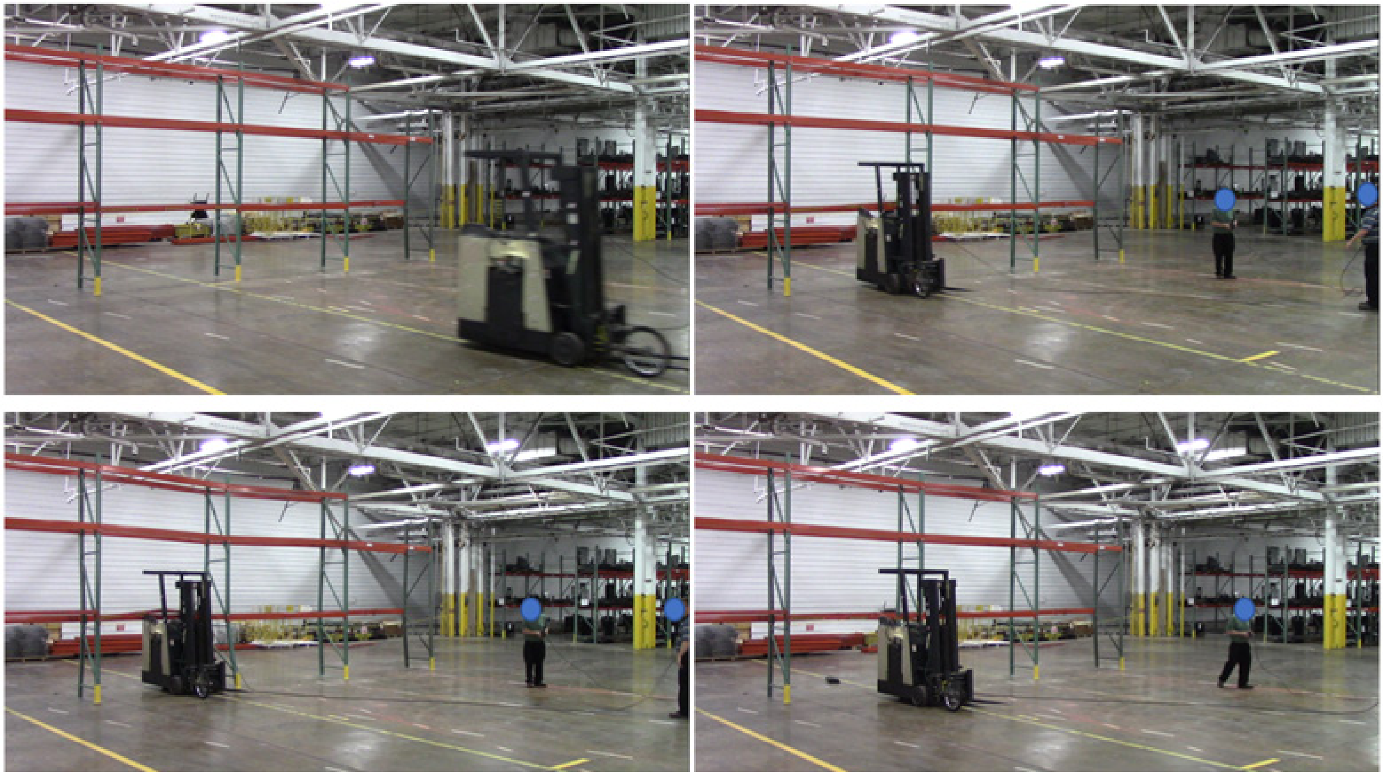

Figure 14
Screenshots from Manufacturer A's testing of a forklift striking a racking system at 6 mph, before impact (top left), at impact (top right), the forklift's maximum intrusion into the rack (bottom left), and the forklift at rest (bottom right).

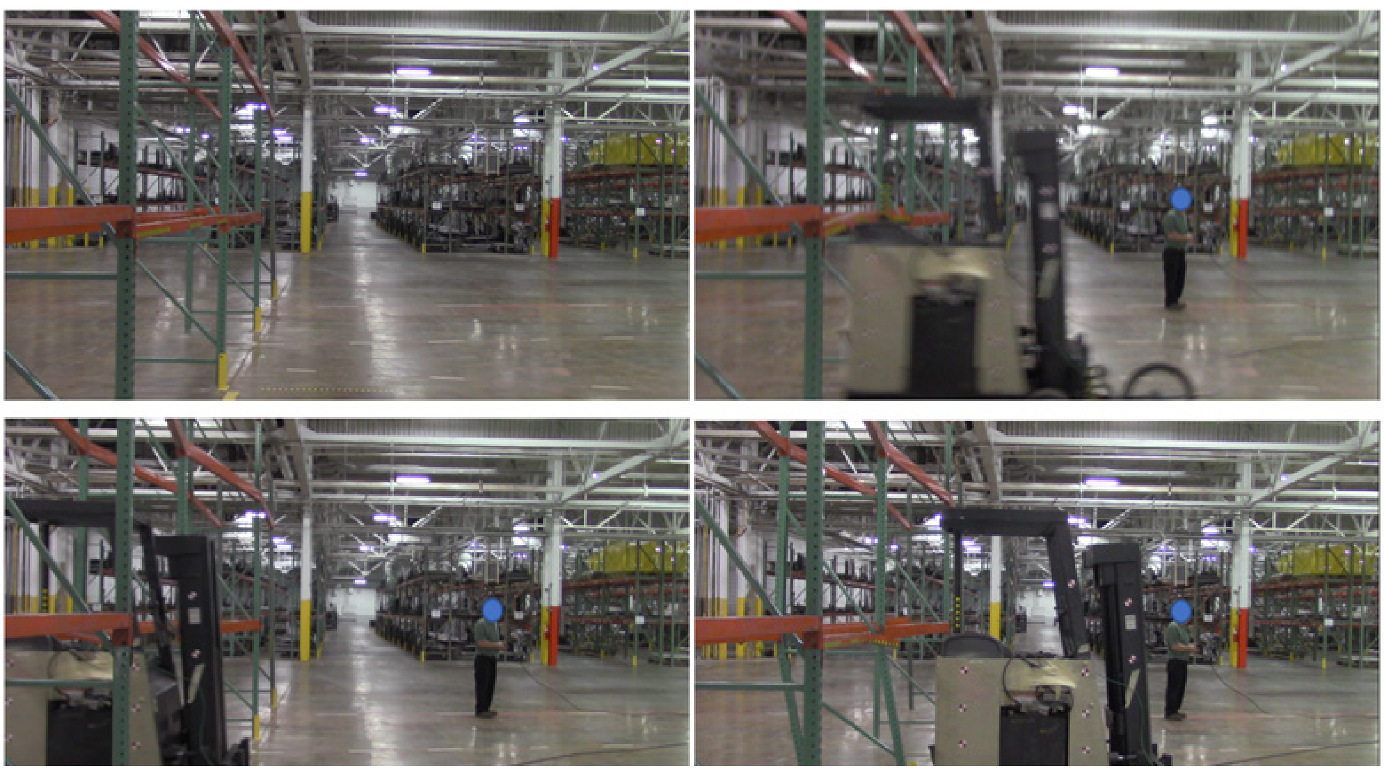

Figure 15
Screenshots from Manufacturer A's testing of a forklift striking a racking system at 6 mph, same test as shown from **Figure 14** but from a side view. Screenshots showing before impact (top left), at impact (top right), the forklift's maximum intrusion into the rack (bottom left), and the forklift at rest (bottom right).

higher collision speeds than the tested 6 mph speed. Future analysis and studies could be performed with different impact configurations that was not presented in this paper, such as impacts with stiffer and more rigid beams, the forklift carrying its full-rated load, higher forklift impact speeds, and different impact points to the rack beam and/or the third corner post.

Fourth Corner Extension and Fourth Corner Post

In the past, some manufacturers chose to forgo equipping third corner post as a standard feature and solely relied on fourth corner extensions for horizontal intrusion protection. Over time, more manufacturers have adopted the third corner post as a standard equipment[9] in addition to the fourth corner extension. However, some manufacturers still choose to solely rely on fourth corner extensions for horizontal intrusion protection.

Although the fourth corner extension does offer some horizontal intrusion protection, these extensions have been shown to have significant deficiencies when compared to a full vertical post. Since these extensions require overlap of the rack beam and the fourth corner for the extensions to be effective in preventing horizontal intrusion of rack beams, these extensions are only effective in certain rack configurations and forklift travel directions. The forklift in the previously discussed case study, was equipped with a fourth corner extension (**Figure 16**). Physical evidence showed the extension did contact the rack beam, and there was an overlap of approximately 4 inches between the rack beam and the fourth corner extension. However, due to the extension's "horseshoe" profile, the rack beam had deformed upward from impact. The beam overrode the extension, and the beam still significantly intruded into the operator compartment, crushing the operator. Therefore, the case study showed these extensions have deficiency in horizontal intrusion protection in certain impact configurations.

Adding a fourth corner post, in some cases, would be more effective than a fourth corner extension in preventing horizontal intrusion injury because the post extends to the overhead guard and provide protection when the horizontal beams intrude toward the fourth corner of the forklift. However, most manufacturers have chosen to not adopt the fourth corner post and some have outright denied customer request for them. Manufacturers justify their position by arguing that since the location of the fourth corner post is much closer to the proximity of the operators' head than a third corner post, the fourth corner post has more associated hazards than a third corner post, such as reduced operator visibility and an increase in the probability of a head or arm injuries. At the time of this paper, there is insufficient data to conclusively determine whether a fourth corner post's safety benefits would outweigh their negative considerations and would therefore make the forklift safer overall. However, there are manufacturers who have chosen to equip their stand-up forklifts with third and fourth corner post as standard features.

Deflection of Racking System vs Post(s)

The referenced physical testing in 2015 and Manufacturer A's testing in the case study have shown that when rear corner post(s) has been designed with stiffness greater than the rack beam, the beam deflects significantly more than the forklift's rear post(s). The rack beam deforming significantly more than the post at impact is to be expected as the post is stiffer because they are typically formed with a stronger and stiffer cross-section (area moment of inertia). The significant deformation to the horizontal beam also aids in maintaining the forklift's occupant space as the significant deformation of the beam starts to wrap around the forklift and prevents intrusion

Figure 16
Stand-up forklift equipped with a horseshoe-shaped fourth corner extension feature (arrow #2).

into the occupant space. Further, the 2015 physical testing and Manufacturer A's testing of rear posts impacting racking systems has shown that as the horizontal beam gets further deflected into the rack, the rack's vertical uprights start to also deflect and/or the bolts fastening the beam to the rack begin to shear off. The bolts shearing off would make the beam cantilevered and no longer simply supported, which would further deflect the beam away from the occupant compartment, improving operator safety.

As previously mentioned, the ANSI/ITDSF B56.1 testing of horizontal intrusion guards requires the guard to be impact tested into a rigid barrier simulating horizontal rack beam with a 3-inch vertical height with a forklift travel speed of 1 mph. Although the B56.1 standard does not define what a "rigid" barrier is, from the authors' experience with inspecting more than two dozen storage rack systems during investigation of forklift underride incidents, the rack systems and beams used in the physical testing in 2015 (and the manufacturer's testing presented in this paper) are consistent with rack systems and beams commonly used in a warehouse.

Requirements of the ANSI/ITSDF B56.1 Standard

Although horizontal intrusion guards for stand-up forklifts have been developed and implemented for decades, the ANSI/ITSDF B56.1, to this day, has not required manufacturers to equip horizontal intrusion guards on stand-up forklifts. Instead, the B56.1 standard still uses suggestive language regarding manufacturer's equipping their stand-up forklifts with horizontal intrusion protection.

The analysis presented in this paper has shown third corner posts are effective guards against horizontal intrusion, and the post increases the overall safety of the forklift. An increasing number of manufacturers have made third corner posts a standard feature on their stand-up forklift[17]. The analyses presented showed stand-up forklifts are safer when they are equipped with standard third corner post than without, because without a third corner post (in certain collision configurations) the operator's body is directly exposed to impact with the rack beams during underride collisions. Furthermore, the accident database from a major forklift manufacturer showed the safety benefits with a third corner post outweigh negative considerations, and the posts increases the overall safety of stand-up forklifts.

Further, the ANSI/ITSDF performance criteria for horizontal intrusion guard have not changed for decades. Forklifts are designed to typically travel well above 1 mph, and rear post systems have been developed for decades by various manufacturers. This paper has shown at least two designs are effective in guarding against horizontal intrusion at impact speeds well above 1 mph. This shows the current design of rear posts are meeting and have exceeded the standard with significant safety margin.

Future evaluations and/or testing could be performed to determine whether the current rear post designs can withstand impacts at above 6 mph. However, based on the testing presented in this paper, the current single and two rear post designs exhibit significant factor of safety when they collide with racking/shelving systems typically seen in storage warehouses. Therefore, the authors expect these rear post designs should be able to withstand and be able to provide operator protection at impact speeds above 6 mph.

Based on the above, it is the authors' opinion that it would be wise for the ANSI/ITSDF committee to revise and update their B56.1 standard, make third corner post a standard feature, and require horizontal intrusion guarding (such as rear posts) to be effective at forklift travel speeds higher than 1 mph.

The authors do not have specific knowledge to why the ANSI/ITSDF committee chose the 3.9-inch of maximum permanent deflection criteria for horizontal intrusion guard testing — because, depending on the shape and size of the forklift's operator compartment, the authors expect survivable operator compartment spacing could still be maintained if a horizontal intrusion guard deflects more than 3.9 inches. Future analysis could be performed to determine whether the 3.9-inch maximum permanent deflection may be too conservative, and the B56.1 standard should be updated to allow more permanent deflection of horizontal intrusion guarding when they are impact tested.

Conclusion

This paper has presented an analysis of Manufacturer A's empirical data of horizontal intrusion incidents before and after they made third corner posts a standard feature on stand-up forklifts, physical testing of Manufacturer A's and Manufacturer B's single and two rear post systems. The analyses presented have all shown that modern rear post systems are effective at preventing intrusion of horizontal rack beams into the operator compartment when the forklift strikes typical warehouse shelving and in the impact configurations presented.

This paper evaluates the deficiency of manufacturers choosing to not make the economically and technologically feasible third corner post system a standard feature on their stand-up forklifts. It is the authors' opinion that by making the third post system an optional feature, forklift manufacturers are violating the safety engineering hierarchy and have failed to guard against the foreseeable consequences associated with horizontal intrusion incidents.

Based on the increased safety benefits of forklifts equipped with third corner posts, it is the authors' opinion that it would be wise for the ANSI/ITSDF committee to revise and update their B56.1 standard and make third corner post a standard feature. In addition, current designs of third corner posts are meeting and have exceeded the standard and have shown to be effective in providing operator protection when forklifts strike shelving/racking systems at up to 6 mph impact speeds. Therefore, the committee should also revise the standard to require horizontal intrusion guards to be effective at impact speeds well above 1 mph.

Once sufficient information and data is available, future evaluations could be performed to determine whether a fourth corner post would increase the overall safety of stand-up forklifts and should also be equipped on stand-up forklifts as a standard feature.

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