ISSN 1041-9489

SAFETY BRIEF

June, 1985
Reprinted August, 2005

V.3 N.2 Revised

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Safety Hierarchy

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Abstract

Outside of the judicial oath, the most popular litany heard in a product liability trial is "the safety hierarchy." It is associated with a number of misconceptions which are explored in this paper. First, there is no such thing as ***the*** *safety hierarchy; there are many hierarchies. Second, "it" is not a scientific law but rather a useful rule of thumb whose genesis is consensus. Finally, its complete form is broader than reported in any single reference.*

I. Introduction

The past four decades have witnessed the emergence of various safety hierarchies which safety practitioners have embraced in their approach to accident prevention. The hierarchies do not arise from a research base, but rather they reflect the experience of safety professionals and safety organizations. An examination of the literature reveals enough similarities among the hierarchies to suggest the existence of a consensus. This paper views the whole collection of hierarchies which yields a broader hierarchy than previously proposed.

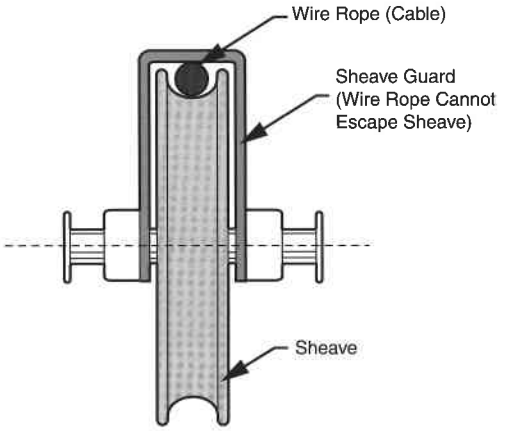
II. The Present Posture

The safety hierarchy shown in Table I represents the current consensus reflected in the literature which is presented in Section III of this paper.

Table I - Safety Hierarchy - 1985

First Priority	Eliminate the hazard and/ or risk
Second Priority	Apply safeguarding technology
Third Priority	Use Warning Signs
Fourth Priority	Train and Instruct
Fifth Priority	Prescribe personal protection

The first priority is the elimination of danger. The word danger is taken as a function or combination of hazard and risk. Here, a hazard is an injury-producing agent whose magnitude is referred to as severity. Risk, which has a multitude of meanings, is used here as a measure of the frequency with which a hazard produces injury. Elimination of the hazard was attempted in the design of lawn mowers by removing the metal blade and substituting a whirling nylon string. An example of risk removal is the use of wire rope retainers on crane sheaves to eliminate the task of reinserting jumped cables at dangerous locations such as boom tips and crane cab roofs.



▲ *Figure 1. Sheave Guard*

This research was conducted for Triodyne Inc. by the Institute for Advanced Safety Studies.

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No Charge

"Safeguarding technology," the second priority, includes all safety concepts except warning, training, and personal protection. These safety concepts not only include guards and safety devices, but more abstract notions such as structural safety factors and proof testing, e.g., overspeeding grinding wheels by fifty percent to eliminate the weaker wheels.

The third priority deals strictly with placing warning signs and placards on and about machinery. Verbal and written warnings which appear in instruction manuals and the like fall into the fourth priority which encompasses the full range of teaching techniques. Personal protective devices, the fifth priority, include such things as eye protection, hearing protection, and environmental garments.

III. Analysis of Safety Literature

Examples of safety hierarchies culled from the classical and popular safety literature are summarized in Table II. The categories used by the sources studied head each column. Synonymous categories have been grouped together in the chart under the five broader headings from the hierarchy in Table I: Eliminate Danger, Safeguarding Technology, Warn, Train, Guard Person.

The fractions across from each source indicate the categories which were included in that source's hierarchy. The numerator denotes the source's ranking of the category and the denominator denotes the total number of categories in the hierarchy. The ranking of categories by the various sources represents such a high level of unanimity that a consensus ranking falls out of Table II without recourse to prioritization techniques. For the reader's convenience, the number of the citation of each source in the bibliography appended to this paper is listed in the last column of the Table.

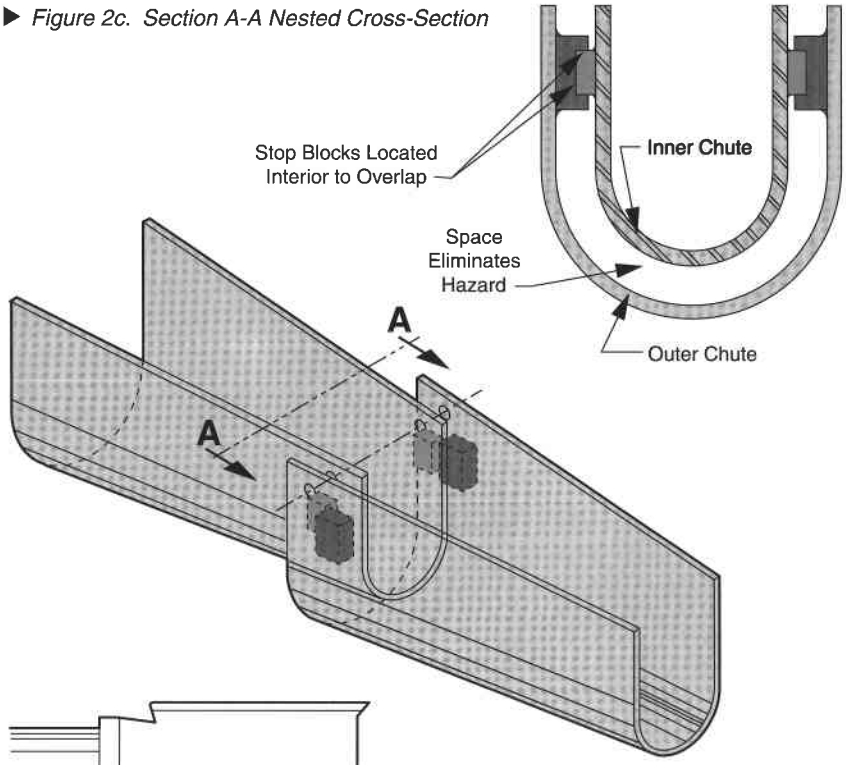
IV. A Good Servant, But a Bad Master

A. Rule of Thumb

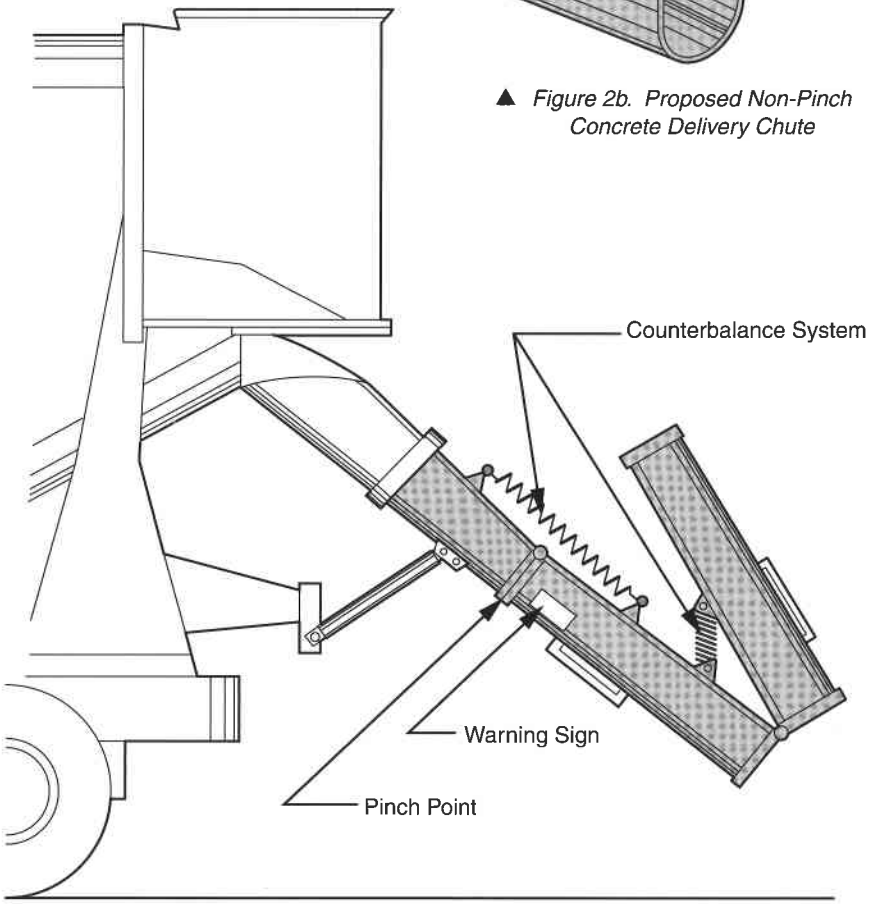
A safety hierarchy such as the one in Table I provides a guideline for designers endeavoring to improve the safety of physical systems. Its use may be illustrated by a few examples.

- Concrete delivery chute
  Figure 2a illustrates a typical delivery chute used with a truck mounted concrete mixer. The pinch points formed between the hinged chute sections are safeguarded by a counterbalance system and chute handles (second priority). In addition, warning signs which identify the hazard and instruct in its control are located near the pinch points (third priority). Applying the safety hierarchy in Table I, one can eliminate the pinch hazard by applying concepts developed for hinged joints in baby's cribs and garden furniture. Figures 2b and 2c illustrate overlapping chute joints where the space between the inner and outer chutes precludes entrapment of a hand (approximately 3 inches). The stop blocks shown can be remotely located from the edge of the external chute. This hinged joint is compatible with the counterweight and handhold devices.

▶ *Figure 2c. Section A-A Nested Cross-Section*



▲ *Figure 2b. Proposed Non-Pinch Concrete Delivery Chute*

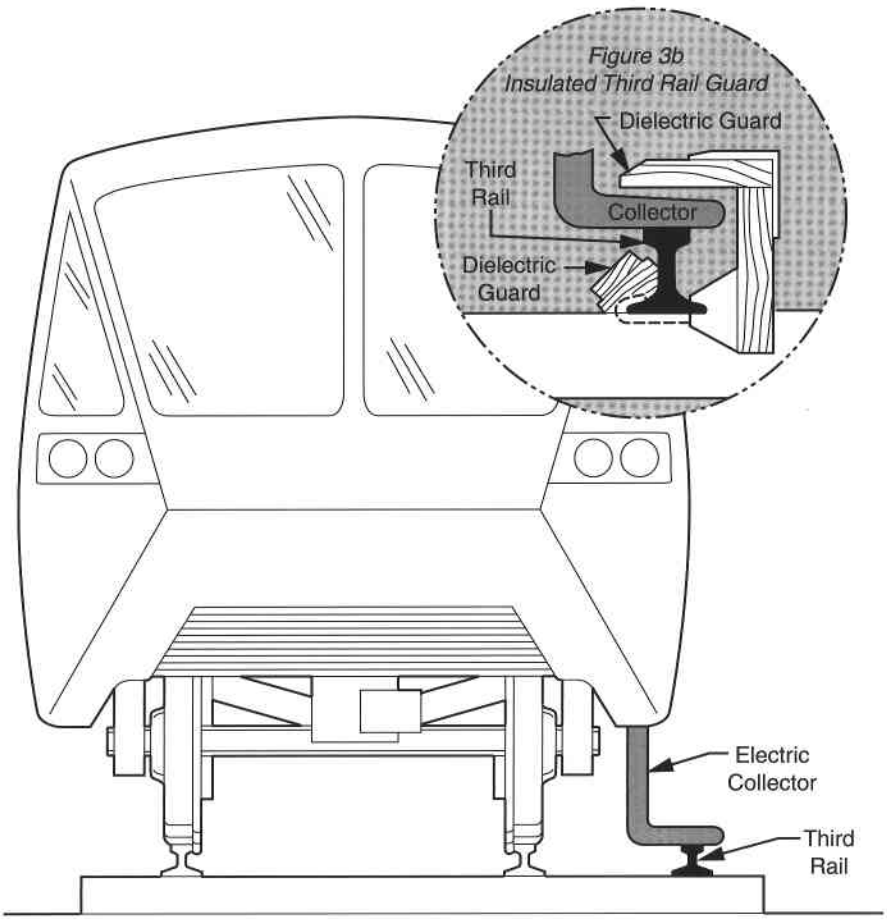


▲ *Figure 2a. Conventional Concrete Delivery Chute*

Table II - Safety Hierarchy - Historical Perspective

Year	Source	Eliminate Danger		Safeguarding Technology								Warn	Train		Guard Person	Bibliography Number
		Eliminate Hazard	Eliminate Danger	Guard Hazard	Isolate Hazard	Protect Against Hazard	Minimize Exposure To Hazard	Reduce Severity	Safeguard	Safeguard Danger	Reduce Danger	Warn	Educate	Train	Guard Person	Bibliography Number
1984	ANSI B11.15	1/3		2/3								3/3				1
1984	ANSI B11.6	1/3				2/3						3/3				2
1983	Blundell	1/3		2/3								3/3				3
1983	Roland						1/4		2/4			3/4		4/4		4
1983	ANSI B11.14	1/3							2/3			3/3				5
1983	ANSI B11.4, B11.8 B11.12, B11.13	1/3				2/3						3/3				6, 7, 8, 9
1982	Marshall	1/4			2/4								3/4		4/4	10
1982	ANSI B151.11	1/3				2/3						3/3				11
1982	ANSI B11.1	1/3				2/3						3/3				12
1981	NSC	1/4							2/4					3/4	4/4	13
1981	Philo		1/3								2/3	3/3				14
1981	Cunitz	1/3					2/3					3/3				15
1980	Buchele	1/3		2/3								3/3				16
1980	Klein	1/3		2/3				3/3								17
1980	FMC	1/3					2/3					3/3				18
1979	NSC	1/2							2/2							19
1979	ASAE Paper No. MC 79-903	1/3		2/3								3/3				20
1979	ANSI B155.1	1/3				2/3						3/3				21
1979	ANSI Z53.1	1/2										2/2				22
1976	Hammer	1/3			2/3							3/3				23
1975	Strong	1/3		2/3									3/3			24
1975	BS 5304		1/2							2/2						25
1975	ANSI B56.1	1/2												2/2		26
1975	ANSI B11.5, B11.6, B11.9, B11.13	1/3				2/3						3/3				27, 28, 29, 30
1975	NSC	1/4		2/4										3/4	4/4	31
1974	ANSI B11 .8	1/3				2/3						3/3				32
1973	ANSI B11 .4	1/3				2/3						3/3				33
1973	ANSI B155.1	1/3				2/3						3/3				34
1972	Hammer	1/3			2/3							3/3				35
1972	ANSI Z35.1	1/2										2/2				36
1971	ANSI Z53.1	1/2										2/2				37
1969	NSC	1/4		2/4										3/4	4/4	38
1968	Leahy	1/4		2/4			3/4						4/4			39
1968	USAS Z35.1	1/2										2/2				40
1967	USAS Z53.1	1/2										2/2				41
1964	NSC	1/4		2/4										3/4	4/4	42
1959	NSC	1/3		2/3											3/3	43
1955	NSC	1/3		2/3											3/3	44
1953	ASA Z53.1	1/2										2/2				45

Example: *In 1980, Klein proposed a three-category hierarchy (denominator = 3). His first priority was "eliminate the hazard" (numerator = 1). His second priority was "guard the hazard" (numerator = 2). His third priority was "reduce the severity" (numerator = 3). Klein's hierarchy can be found in reference number 17 in bibliography.* <u>*How to Avoid Products Liability: A Management Guide.*</u>



▲ *Figure 3a. Unprotected Third Rail*

- Electrified third rails
  A typical third rail application for an electrified commuter train is shown in Figure 3a. In those places where overhead lines are not feasible, one cannot eliminate the electrocution hazard posed by a third rail which is required to electrify the train; however, most municipalities have utilized insulated guards which fit into the second priority (see Figure 3b).

- Snowblower augers
  The rotating augers located on the front of a snowblower represent a serious amputation hazard which cannot be eliminated because of the augers' snow-collecting function. Frontal guarding would make it impossible for snow to get to the augers. Here, the third priority of the safety hierarchy can be invoked by warning operators not to make physical contact with the rotating augers.

- Revolver
  Most of the accidental shooting scenarios associated with police revolvers cannot be addressed by eliminating the danger or safeguarding the gun. Warnings do not enhance the understanding of gun users who are fully aware of the potential for tragedy. In this situation, training and instruction provide the most effective safety profile.

- Grinding
  Grinding removes small particles of hot material from both the workpiece and the grinding wheel. This so-called swarf cannot be eliminated or fully guarded against. Furthermore, neither warning nor training provides effective information on controlling the danger of serious eye injury. Grinding requires application of the fifth priority of the safety hierarchy, personal protection. Operators and bystanders are protected from the swarf by donning safety eyewear.

B. Safety Theorem

In spite of the fact that the safety hierarchy in Table I constitutes an important tool for improving safety, it does not rise to the level of a mathematical theorem or a scientific law. This safety hierarchy was born out of consensus, not research, and its general validity can be disproved by numerous counterexamples. For example, on complicated machines such as automobiles and aircraft, there are hundreds of hazards that cannot be eliminated or technically safeguarded. Even if it is possible to invoke the third priority and produce suitable warnings for these individual hazards, the sheer number of warnings destroys their effectiveness. The majority of the population can recall only five to nine written items in a series. In communication theory this is called the "rule of seven plus or minus two."[46] Where large quantities of safety information must be communicated, warning signs cannot be used and one must resort to training. Thus, in complex situations, training is more effective than warning, which disproves the safety hierarchy.

Another provocative counterexample is unwittingly supplied by Harry Philo in the Lawyer's Desk Reference in which he states that a grade crossing hazard associated with train-vehicle collisions can be eliminated by substituting an overpass.[47] Does this necessarily mean that the grade crossing with its bells, lights, and gate is always more dangerous than the overpass? Consider some of the following overpass accident scenarios:

- Missiles dropping from the overpass impact the locomotive's windshield.
- Bridge surfaces ice up even when ordinary road surfaces do not, creating a skidding hazard.
- Oncoming traffic impacts the structures located on the sides of the overpass.
- Passing becomes hazardous because of the visibility problems caused by the overpass. (Recall safety signs that admonish not to pass on hills.)
- Reckless children climb on and fall from the overpass.
- Railway lading which is too tall to pass beneath the overpass crashes into it.
- Errant vehicles drive off the overpass through or over the guardrails.

There is no engineering reason why the combined mayhem associated with the overpass should not exceed the dangers associated with a fully-guarded grade crossing. In such circumstances, the safety hierarchy fails to provide the proper guidance as the second priority may indeed be more desirable than the first priority.

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SAFETY BRIEF

June, 1985 – Volume 3, No. 2

Editor: Paula L. Barnett
Illustrated and Produced by
Triodyne Graphic Communications