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Educating – safety

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ABSTRACT: The concept of, and the need for, industrial safety goes back somewhat over a hundred years. There are, of course, some exceptions to that generalised statement, but when looking at industrial history, one gains an impression that *getting results* was more important than *protecting the workers*, or, indeed, protecting the community from the results of errors and accidents. We now have a different view of this matter, partly due to government intervention by legislation, partly by union pressure, partly by community pressure, partly by media publicity of injuries and fatalities, and … who knows what else? The last century has shown an increase in industrial safety, yet accidents, with their attendant damage to property and environment, and injuries and fatalities to people, continue to occur, and that leads to the question often posed by a visiting American academic: *Why is it so?* There is no simple, straightforward, all-in-one-piece, response to that question; there is a multitude of answers giving reasons for unsatisfactory levels of safety that lead to accidents which cause those consequences and, in this paper, the author suggests a cause of today's lack of a desired level of industrial safety. Is it possible that one cause is embedded in the professional engineers' learning?

INTRODUCTION

There is, always, a reluctance to bring out one's *dirty washing*, or to discuss the behaviour of the *black sheep* of one's family. Similarly, the engineering profession very rarely comes forth with one of the reasons why industrial safety is imperfect: it is that engineers can – and do – design, and build or manufacture, and operate *things* that can injure and kill people. Sometimes, in parallel, these *things* also damage property and the environment.

By using the word *things*, we pool together the products and processes of our technological systems. Such items go back well before the hundred-or-so years mentioned above; Egypt and Rome of more than ten times that time into the past had technology capable of causing problems. As an example, one can refer to Rome's use of lead for town water piping, which led to lead poisoning, some acute, some mild, of the city's inhabitants.

There are more modern examples that relate to the efforts of today's professional engineers and one will be used to come to a redefinition of an aspect of safety.

But before progressing in the directions outlined above, some background needs to be presented, much of which is taken from relatively old references – quite deliberately – in order to show how long some of these ideas have been around.

SAFETY

The word, *safety*, can be interpreted in many ways. The *Oxford Dictionary* defines it as *freedom from danger or risks* [1]. This is essentially a definition used by Roland and Moriarty, who stated: *the condition of being free from undergoing or causing hurt, injury, or loss* [2]. An eminent guru of safety in one industry, Kletz also used a very similar wording [3].

A search, made about 15 years ago through seven references in the safety literature failed to locate a definition more generally appropriate to industrial situations, which is being considered here [4-10]. Brown took pains to define the word *system* and how that applied to safety, but did not define safety itself [11].

The closest approximation to a general definition for industrial safety was provided by the joint ILO/WHO Committee on Occupational Health, as quoted by Williams:

1. *The promotion and maintenance of the highest degree of physical, mental, and social well being of workers in all occupations;*
2. *The prevention among workers of departures from health caused by their working conditions;*
3. *The protection of workers in their employment from diseases resulting from factors adverse to health;*
4. *The placing and maintenance of the worker in an occupational environment adapted to his physiological and psychological equipment* [12].

This implies that the worker should have an accident-free workplace. However, it does not connect *industrial safety* with members of the community other than the workers.

A more general definition was taken by Rodgers from a US Department of Defence document, as follows: *Safety: Freedom from those conditions that can cause injury or death to personnel, damage to or loss of equipment or property* [13].

However, Rodgers considered that inadequate and provided his version, as follows:

> *The surety that the environment that personnel or items are subjected to is free from inadvertent or*

unexpected events which may result in injury to personnel or damage to the items exposed [13].

TWO ASPECTS OF SAFETY IN PRACTICE

One runs into a problem in progressing from basic definitions to actual safety practice in industry, because two aspects of safety can be recognised, namely: *occupational safety* and *technical safety*.

Occupational safety is, literally, *personnel safety*: protecting the well-being of the employees. However, industry generally, and the chemical industry in particular, recognised some years ago the distinction between *occupational safety* and *technical safety* (UK) or *process safety* (USA), which is ensuring that the equipment staff use is reliable and will not cause damage or injury by failing in service [14]. The two terms, *technical safety* and *process safety*, are used interchangeably in safety literature.

The general term, *safety*, as used in industry, has acquired these two sub-definitions: *occupational safety* and *technical safety*.

OCCUPATIONAL SAFETY

As a simple illustration of the first of the above two sub-definitions, occupational safety is concerned with the human-work environment interface and how that affects employee health [12]. For example, that concern covers prevention and treatment of physical injuries ranging from minor matters, such as small cuts and bruises, to serious injuries like damaged backs. Such injuries occur *relatively* frequently and are almost predictable on an annual basis from statistics.

Occupational safety is also concerned with preventing or treating less visible injuries, such as breathing and blood contamination from materials, and the rehabilitation of people who have been injured. Attention is also given to psychological and psychiatric treatment of trauma caused by injury, or by observation of the injury. Many of these occupational injuries can be prevented – and have been – by education, training and legislation (each of which impinges on management action).

TECHNICAL OR PROCESS SAFETY

Technical safety was obliquely defined by Kuhlmann as a *science*, as follows:

> *The science of safety is concerned with the safety from possible dangers connected with the utilization of technology … technical safety must be regarded as an integral part of human life.*
>
> *The peculiar function of the science of safety … is the acquisition and summarization of knowledge regarding the conditions and design of safety in handling technical systems …* [15].

Process safety has been defined in a manner which overlaps the above:

> Process safety *refers to the protection of people and property from episodic and catastrophic incidents that may results from unplanned or unexpected deviations in process conditions* [16].

The combination of process safety and management has been referred to as *process safety management* (a term that generally appears in the American literature), as follows:

> *Process safety management is the application of management principles and systems to the identification, understanding, and control of process hazards to prevent process-related injuries and accidents* [17].

A failure of technical or process safety commonly results in a *loss of containment*. That is, some chemical material is released to atmosphere from the vessel, pipeline or other containment in which it was being held [18]. The material released by a loss of containment may be flammable, explosive or toxic, or even all three, possibly followed by a fire or an explosion, or the spread of a toxic liquid or gas. These possible downstream results are not necessarily mutually exclusive. All may cause damage to property and fatalities.

Accidents from the failure of technical safety and process safety management are *relatively* rare and are fairly, if not almost, unpredictable except in a gross manner. Kletz pointed out that in any year ahead, there are certain events that are highly likely to occur, although it is not possible to say when, where and to whom they will occur [19]. They are preventable by appropriate design, operations and maintenance activities (which are also management-related).

Such serious equipment failures, which cause accidents, injuries and damage, have been relatively common on a worldwide basis. However, these have been fortunately rare in Australia, at least until recent times.

The chemical industry features in this aspect of safety because it is more heavily mechanised and automated, and less labour-intensive than many other industries, and, therefore, has fewer occupational injuries from manual work than many other industries [8].

THE CONNECTION BETWEEN OCCUPATIONAL SAFETY AND TECHNICAL SAFETY

The connection between occupational safety and technical safety is that a breach of *technical or process safety*, which leads to equipment failure, *may* well in turn, in addition, lead to a breach of *occupational safety* by injuring personnel.

There is, without known exception, a one-way connection between these: equipment failure may cause harm to employees, but personnel injury causing equipment failure is far more unlikely. No cases of the latter have been found in the literature. This uni-directional connection between process safety and personnel safety has not been noted in the literature but was pointed out in this author's doctoral thesis [20].

ACCIDENTS AND SAFETY

To err may be human, but much of technology is far from divine by being very unforgiving when an accident occurs. This leads to the questions: what is an accident? And why do accidents occur?

Before defining *accident*, the word *incident* needs to be considered. *Incident* is often synonymous with the word *occurrence*. The *Oxford Dictionary* gives the following definition: *subordinate or accessory event; event, occurrence; detached event attracting general attention* [1]. Following from that to *event*, the *Oxford Dictionary* gives this: *fact of a thing's happening; thing that happens; any of several possible but mutually exclusive occurrences* [1]. Further, for *happening*, the *Oxford* gives no precise definition but the phrase *chance, have the fortune to* is given.

Thus, in the unfortunately imprecise general English language usage, an *incident* and *occurrence*, or an *event*, is *anything that happens*. Both *incident* and *occurrence* are often used in the context of a *minor* event of a potentially serious nature. As such, an *event* is regarded as being less significant than an *accident*. This is a fine distinction generally observed in industry, that an *incident* is not necessarily an *accident*. Bamber has pointed that the following:

> *All accidents are incidents.*
> *All incidents are not accidents.*
> *All injuries result from accidents.*
> *All accidents do not result in injury* [21].

Now to the second question: why do accidents occur? In general, it is because we are surrounded by *hazards*, some minor (with which we live) and some extreme (which we try to control or avoid), as well as many in between.

A hazard, in itself, only has a *potential* for harm, and only causes a damaging or injuring event if the hazard is *realised* by the event occurring, hence a hazard will not *necessarily* cause harm. *Potential* means there is only a *possibility* of harm and is defined as *capable of coming into being or action* [1].

Hazards may be considered to have other properties. *Casual* or *transient* hazards, those that only appear at rare intervals, are possible. There may be *latent* hazards that are hidden in a system and surface long after they were placed there. Some may be *permanent* hazards. It is also possible to consider *coincident* hazards, each of which are items or features of low concern alone, but which are much more serious when they occur together. There are also *initiating* hazards that are usually inadequacies of control or containment [8].

Major hazard is a term which is a logical development. *Major hazards* only occur, generally, in the *process industries*, which include the chemical and nuclear industries, where they exist due to the properties of the materials used and the nature of the processes operated. The magnitude of a *major hazard* depends on the specific qualities of the materials and processes. For example, if a company decides to manufacture trinitrotoluene, then there is no alternative but to accept the related inherent hazard of the raw materials, the processes and, most particularly, the finished product.

ENGINEERS' INVOLVEMENT

We are now at the stage of the need to show where engineers are involved in the above, the two types of safety and accidents.

In the current industrialised society, engineers are involved in the design of plant, machinery and equipment, as well as in operations, that is, in the manufacture of such capital-based items and the manufacture of consumables using those production utilities. A previous paper gave many examples of injuries that resulted from design errors and/or deficiencies and concluded with the rather gloomy prediction that injury-causing accidents will continue to occur [22]. However, that paper did not mention a way in which such events could at least be reduced.

Engineers relate to another aspect of those involvements by education and the educating of future ranks of professional engineers. The author has formed the opinion that not enough is being undertaken in the tertiary education system to teach safety so that future engineers working in design and operations act to reduce accidents by increasing safety.

There is a major problem with that hope in that engineers often, indeed, it is probably safe to say usually, are not in positions to manage what they understand but have to follow directions from others who do not understand what they manage. So what results from that state of affairs? A couple of illustrations demonstrate what can follow. A large-scale example of that has recently become available to the author, but before giving that, a smaller, but equally true, example from personal knowledge is offered.

A SMALL-SCALE ILLUSTRATION

A student in the author's class worked in the production area of company that manufactured women's shoes. He remarked that designs often came from the *design department*, people who specialised in the style of shoe that would sell well, would often be of a shape likely to cause the wearer to experience at least discomfort and possibly injury, but there was nothing he could do; he had to produce to the style-designs given to him.

A LARGE SCALE ILLUSTRATION

It is now several years since the *B-1* bomber's shape and capabilities were released to the public. It is, certainly, a remarkable aircraft, and the story of its design and development given in a book written by one who has flown them and published in 1997 shows, in principle, the same problem as the above. The following quotes directly from Major Stewart's book:

> *But designing and building the aircraft had not been an easy task. For fifteen years the aircraft's designers had wrestled with one engineering problem after another. Many times they had been tempted to quit, for it seemed that they had been given an impossible job. The pieces just didn't fit together. There were simply too many mutually exclusive criteria to bring together in one single aircraft.*
>
> *To begin with, they had been told to design an aircraft that could penetrate the world's most advanced air defences and attack a heavily defended target. The aircraft would be required to go against the best surface and airborne threats that the enemy had to offer.*
>
> *"Okay," the engineers said. "We can do that. We'll build a small and nimble fighter. We'll make it capable of pulling twelve Gs. We'll make it light and extremely maneuverable. And very small. If we are going to send this aircraft far behind enemy lines, we want it to be as tiny as possible. That will give the enemy a much smaller target to shoot at."*

> *But then the engineers were told that the B-1 had to be able to carry up to 50,000 pounds of weapons. In addition to that, it had to have an intercontinental range, which meant it had to carry enormous amounts of jet fuel.*
>
> *So much for developing a small and nimble fighter. The B-1 would have to be huge – maybe half as big as a football field – to carry such a load of weapons and fuel.*
>
> *The engineers also discovered the new aircraft had to be an accurate bomber. Very accurate. It couldn't just scatter a cluster of bombs in any random pattern, hoping a bomb or two would hit the target. Surgical strikes required much more than that. Even dropping a bomb within a few yards of its target wasn't good enough. It had to fall within a few feet. In some cases even inches.*
>
> *"Okay, we can do that," the engineers muttered as sweat started to bead on their brows.*
>
> *Then the designers were given the bombshell.*
>
> *"We want the aircraft to be nearly invisible," they were told. "We want its radar cross section to be one thousandth of the aircraft's actual size. Make this aircraft look like nothing more than a flock of birds that are cluttering up the enemies' radar."*
>
> *The engineers spent many nights pondering how to make a 400,000 pound aircraft look like nothing but a bunch of speedy seagulls?*
>
> *Hey, this will be easy, they used to joke. We can make an aircraft that will do all that. The only problem is, when we are finished, the sucker certainly will never fly.*
>
> *As the designers wrestled with the problems, they began to realise two important facts that were core to the design of the new aircraft.*
>
> *First, the new bomber would have to be able to fly incredibly low to avoid being detected by the enemy's radar.*
>
> *In addition to a low-level penetration capability, the aircraft needed speed. The aircraft was too big to play with the fighters. It needed speed so it could run away.*
>
> *For fifteen years the engineers worked on the bomber. And when they were finished they had produced the most sophisticated aircraft in the world* [23].

So the US Air Force were delivered an aircraft that is extremely good at performing a main task, but cannot defend itself. It can only run while hiding behind radar-obscuring clouds of foil.

REFLECTIONS ON THE ABOVE

These examples illustrate what engineers too commonly face. In the first, the engineer worked on products that he/she knew were, strictly speaking, not suitable for use. In the second, the engineers were given a problem with so many contradictory and confusing criteria that the final product was more like a camel than a horse.

What is common in these? It is the engineer's inherent need to solve a problem by using the knowledge he/she has gained and the resources available. Indeed, engineers love solving problems. Of course, engineers are not alone in that; a surgeon given an *impossible* case will attempt an operation, and lawyers have been known to defend a client *known* to be guilty. It is all part of the *fun* of being good at one's profession.

Furthermore, one can be reasonable sure that in each of those cases, the engineer was being instructed by someone who was managing what he/she did not understand in the sense that the problem was given to an engineer because the one delivering the specification could not carry out the detailed engineering work.

In order to improve the delivery of instructions and specifications coming to engineers, and in order to overcome confusion and the contradictions, engineers need to move into those management positions. However, for that to happen, there needs to be more emphasis placed in engineering education on that movement, even if it is at the expense of reducing technical subjects so that people with engineering knowledge (and understanding) are involved in higher-level decision-making and the delivery of instructions.

Neither of those examples relate directly to safety, so lest this author be accused of straying from the intended path, one must now move back to what can be connected with the principal theme of this article.

REMEMBER THE WESTGATE BRIDGE?

At 11.50 am on 15 October 1970, a span of the under-construction West Gate Bridge over the Yarra River in Melbourne, Australia, buckled. One end slipped off the supporting concrete column and the 112 metre length fell 50 metres to the ground, killing 35 workers.

The bridge spans were steel box sections of what was, then, over 30 years ago, a somewhat innovative design, selected because crossing the river required a main span length of 336 metres. When the section between columns 10 and 11 was placed in position, it was found to have considerably more camber than intended, and concrete blocks were placed on the span to reduce the camber. The engineer in charge of this part of the work had several internal bolts removed to allow movement, and that appears to have contributed to the failure.

What went wrong? The report of the Royal Commission referred to a sequence of errors, the first of which was, probably, the selected design and its details. The concept of having a West Gate bridge dated back to the early 1960s and would have to span the river at the height needed for river traffic. That was a very real problem, quite irresistible to engineers, and taken up by Freeman Fox.

The final error was trying to overcome one introduced in the fabrication by deforming the structure while in position. Was that a safe action to be taken? No. Should the engineer on the job have recognised that? Yes. Should his superiors have recognised it, and directed a different approach? Yes. Why was it undertaken? Because the alternatives would have cost more and delayed progress. So the engineer was instructed to act as he did, which raises this question: why did he follow instructions?

It can only be deduced that, even though he had the conventional education in engineering subjects, his education had not included how to distinguish between reasonably safe and unreasonably hazardous acts and situations. He also may not have been impressed with the *failsafe* philosophy, simply that if whatever is being carried out fails, it should fail in a safe mode.

REDEFINING TECHNICAL SAFETY

Now to tie together the collection of thoughts from the literature, definitions of safety, engineers' involvement and engineering education.

As remarked above, the term *technical safety* is usually used as being synonymous with *process safety* and in the chemical industry. However, it now submitted that all engineering activity should come under that term, *technical safety*, because all engineering activities involve technology. As such, failure, one way or another, must be a *technical failure* of *technical safety*.

A possible connection between engineers and this redefinition of technical safety is through *human error*, from which engineers are not exempt. Errors involving technology can be committed in many ways, directly, indirectly and by omission. These can all lead to possible reduced occupational safety, as well as possible property damage.

CONCLUSION

What is needed is the inclusion in undergraduate engineering curricula of more on the aspects of safety for which an engineer should be responsible. Whether included in another subject, perhaps design, or in an individual unit is not important; what is needed is to impress students with the need for technical safety.

Avoiding mishaps, such as the West Gate Bridge, depends on an awareness of what has happened in the past and what can happen in their futures, without thinking of safety and acting safely. Perhaps students need to learn, or at least to respect, if not even fear, that their work can cause unintended results, as well as achieve successes.

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