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Energy damage and the 10 countermeasure strategies

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This paper is the first in a series of Injury Classic. Our goal is to reprint one such paper in each issue to initiate newcomers to the field to these old, often quoted, and important contributions. As many are difficult to find, it should help all of us to have a copy at hand. Your suggestions about future articles are welcome. Write to the editor with details of your favourite, most quoted paper.

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An important landmark is reached in the evolution of a scientific field when classification of its subject matter is based on the relevant, fundamental processes involved rather than on descriptions of the appearances of the phenomena of interest. In illustration, a fundamental turning point was reached when the debilitation and progressive susceptibility to bruising of shipboard scurvy could for the first time be classified as the process resulting from a deficiency of consumption of something variously present in fruits and vegetables (much later identified as ascorbic acid, vitamin C). In fact, such transition from classifications consisting essentially only of a description of appearances to those based on fundamental processes is basic to scientific progress generally; hence, examples abound from the full gamut of scientific concerns.

Additional illustrations, among the many, include the classificatory and conceptual transitions that followed recognition:

a. That rocks could be grouped on the basis of the processes involved in their formation – as sedimentary, igneous, metamorphic.

b. That the variations among the Galapagos finches studied by Darwin were the result of differential ecologic processes.

c. That earthquakes were one aspect of tectonic processes.

d. That the epidemic disease of the young which could for decades be described only as 'infantile paralysis' was a rare variant of a commonplace process initiated by infection with one of several similar and previously unknown viruses.

e. That plague was a process in which a specific pathogen, *Pasteurella pestis*, rats, fleas, and people interacted.

Extrarational explanations in the absence of process knowledge

Before such conceptual and hence classification advance, lacking an understanding of process, and therefore of the possibility of human intervention or avoidance, phenomena of concern to people have commonly been attributed to extrarational factors. 'Luck', 'chance', 'accident', 'fate' and similar terms are the hallmarks of such ignorance, and perhaps of a human necessity for explaining it away.[8] The distinction between the way in which people tend to deal with the understood as opposed to the merely known-about is illustrated nicely by the renowned anthropologist Malinowski. He found that Trobriand natives viewed the hazards outside the reef, which they did not understand, in ways more supernatural than they viewed those inside the reef, which they did understand. As he wrote, 'It is most significant that in the lagoon fishing, where man can rely completely upon his knowledge and skill, magic does not exist, while in the open-sea fishing, full of danger and uncertainty, there is extensive magical ritual to secure safety and good results'.[16]

Divine punishment as an explanation in the absence of process understanding

The Book of Job epitomizes another commonplace aspect of human response to undersirable happenings not yet understood – and therefore not yet categorized – in process terms. The events are explained as divine retribution for shortcomings. The suffering of oneself, someone else, or some group occurs because it is divine and well-deserved punishment. Therefore, unless the sin can be expiated by appropriate change in behavior, it may be 'too bad', but there is nothing else to be done to ameliorate the personally or societally undesirable happening unless it is an increase in efforts at human reform.

Expanded classificatory sets and different sets

The transition to understanding of underlying, relevant processes commonly results in more than just a relabeling of past groupings.[8] Usually the phenomena previously recognized have been 'the tip of the iceberg', and the recognition of underlying process adds much more. Thus, in the case of what was originally termed 'infantile paralysis', it was found that the infectious process routinely involved hundreds of individuals subclinically for each person ill enough to be diagnosed. Moreover, parallel illustrations are legion, not only from medicine but also widely from other sciences.

For example, understanding the actual nature of earthquakes is to classify them conceptually as one aspect of a far broader range of tectonic processes; and understanding the origins of a butterfly or a clam is to identify it in terms of its life cycle, a process classification. Understanding the process involved in eclipses is to classify them as one aspect of celestial mechanics.

Another frequent result of transition to process-based understanding is regrouping of phenomena not merely in expanded sets, but in new sets that do not bear a one-to-one correlation with the old. Figure 1 illustrates this. As process (or, to use a related [medical] term, etiologic) understanding advanced, the set of phenomena formerly referred to as 'wasting' was, in effect, parcelled out to such process-defined sets as tuberculosis, amebiasis, protein deficiency, and a host of others.[8]

More relevant here is to view the process in reverse; that is, from the standpoint of the etiologic or process sets in picking up pieces of many pre-existing descriptive sets, as illustrated in figure 2.[8]

Thus syphilis, the etiologic set based on the infectious agent, *Treponema pallidum*, picked up parts of previous descriptive sets, such as paresis, gummas, penile lesions, rashes, certain gastric lesions, certain abnormalities of the growing ends of bone, and many others, but not all of those in any one of the earlier descriptive

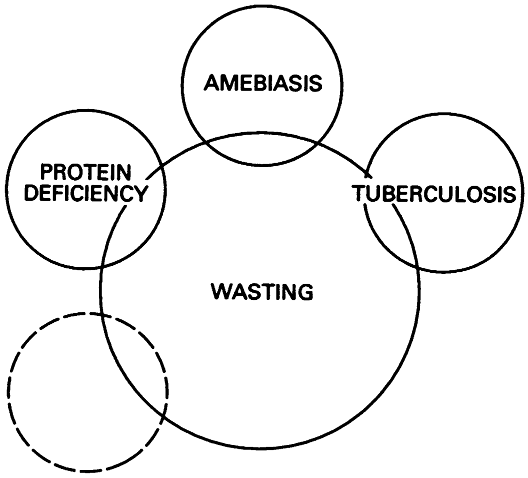

Figure 1 An illustration of the parcelling out to etiologically defined sets of the components of a descriptively defined set of pathology.

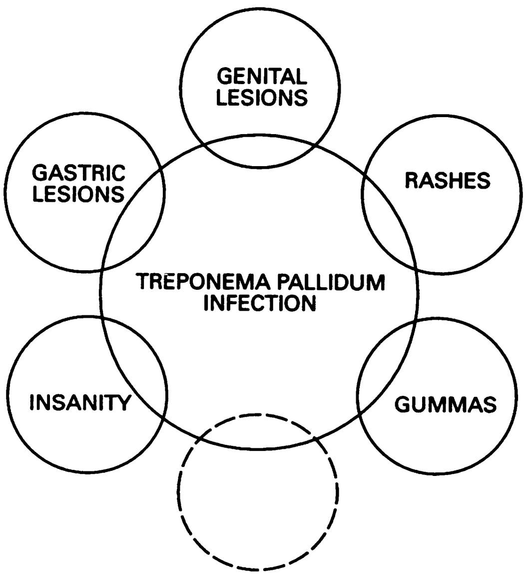

Figure 2 An illustration of the incorporation of portions of various descriptively defined sets of pathology into an etiologically defined set.

sets. Again, an important point is that there is usually not in such transitions, a one-to-one relationship between the earlier, descriptive ways of looking at the phenomena and those process-based which are substituted for them.[8]

The foregoing is brief background for that which follows, an introduction to the classification of certain widespread, important phenomena defined and grouped in terms of a small number of closely parallel processes. Most of the included phenomena are not yet regarded in process terms by the implicit and explicit classifications still appplied to them by most professionals and laymen. Yet there is widespread, implicit, and at least qualitative recognition of the processes themselves, because cultures, past and present, abound in actions directed at changing the outcome of these processes through interventions at specific points in their sequences.

Energy damage processes

The phenomena of concern are those involved when energy is transferred in such ways and amounts, and at such rates, that inanimate or animate structures are damaged.[1 6–8 10 14] (Much of the remainder of this paper closely follows reference 10.) The harmful interactions with people and property of hurricanes, earthquakes, projectiles, moving vehicles, ionizing radiation, lightning, conflagrations, and the cuts and bruises of daily life illustrate this class.

10 Strategies for reducing these losses

Several strategies, in one mix or another, are available for reducing the human and economic losses that make this class of phenomena of social concern. In their logical sequence, they are as follows:

The *first* strategy is to prevent the marshalling of the form of energy in the first place: preventing the generation of thermal, kinetic, or electrical energy, or ionizing radiation; the manufacture of gunpowder; the concentration of U-235; the build-up of hurricanes, tornadoes, or tectonic stresses; the accumulation of snow where avalanches are possible; the elevating of skiers; the raising of babies above the floor, as to cribs and chairs from which they may fall; the starting and movement of vehicles; and so on, in the richness and variety of ecologic circumstances.

The *second* strategy is to reduce the amount of energy marshalled: reducing the amounts and concentrations of high school chemistry reagents, the size of bombs or firecrackers, the height of divers above swimming pools, or the speed of vehicles.

The *third* strategy is to prevent the release of the energy: preventing the discharge of nuclear devices, armed crossbows, gunpowder, or electricity; the descent of skiers; the fall of elevators; the jumping of would-be suicides; the undermining of cliffs; or the escape of tigers. An Old Testament writer illustrated this strategy in the context both of the architecture of his area and of the moral imperatives of this entire field: 'When you build a new house, you shall make a parapet for your roof, that you may not bring the guilt of blood upon your house, if any one fall from it'.[3] This biblical position, incidentally, is fundamentally at variance with that of those who, by conditioned reflex, regard harmful interactions between man and his environment as problems requiring reforming imperfect man rather than suitably modifying his environment.

The *fourth* strategy is to modify the rate of spatial distribution of release of the energy from its source: slowing the burning rate of explosives, reducing the slopes of ski trails for beginners, and choosing the re-entry speed and trajectory of space capsules. The third strategy is the limiting case of such release reduction, but is identified separately because in the real world it commonly involves substantially different circumstances and tactics.

The *fifth* strategy is to separate, in space or time, the energy being released from the susceptible structure, whether living or inanimate: the evacuation of the Bikini islanders and test personnel, the use of sidewalks and the phasing of pedestrian and vehicular traffic, the elimination of vehicles and their pathways from community areas commonly used by children and adults, the use of lightning rods, and the placing of electric power lines out of reach. This strategy, in a sense also concerned with rate-of-release modification, has as its hallmark the elimination of intersections of energy and susceptible structure – a common and important approach.

The very important *sixth* strategy uses not separation in time and space but separation by interposition of a material 'barrier': the use of electrical and thermal insulation, shoes, safety glasses, shin guards, helmets, shields, armor plate, torpedo nets, antiballistic missiles, lead aprons, buzz-saw guards, and boxing gloves. Note that some 'barriers', such as crash padding and ionizing radiation shields, attenuate or lessen but do not totally block the energy from reaching the structure to be protected. This strategy, although also a variety of rate-of-release modification, is also separately identified because the tactics involved comprise a large, and usually clearly discrete, category.

The *seventh* strategy, into which the sixth blends, is also very important – to modify appropriately the contact surface, subsurface, or basic structure, as in eliminating, rounding, and softening corners, edges, and points with which people can, and therefore sooner or later do, come in contact. This strategy is widely overlooked in architecture, with many minor and serious injuries the result. It is, however, increasingly reflected in automobile design, and in such everyday measures as making lollipop sticks of cardboard and making some toys less harmful for children in impact. Despite the still only spotty application of such principles, the two basic requisites, large radius of curvature and softness, have been known since at least about 400 BC, when the author of the treatise on head injury attributed to Hippocrates wrote: 'Of those who are wounded in the parts about the bone, or in the bone itself, by a fall, he who falls from a very high place upon a very hard and blunt object is in most danger of sustaining a fracture and contusion of the bone, and of having it depressed from its natural position; whereas he that falls upon more level ground, and upon a softer object, is likely to suffer less injury in the bone, or it may not be injured at all . . . '.[15]

The *eighth* strategy in reducing losses in people and property is to strengthen the structure, living or nonliving, that might otherwise be damaged by the entry transfer. Common tactics, often expensively underapplied, include tougher codes for earthquake, fire, and hurricane resistance, and for ship and motor vehicle impact resistance. The training of athletes and soldiers has a similar purpose, among others, as does the treatment of hemophiliacs to reduce the results of subsequent mechanical insults. A successful therapeutic approach to reduce the osteoporosis of many postmenopausal women would also illustrate this strategy, as would a drug to increase resistance to ionizing radiation in civilian or military experience. (Vaccines, such as those for polio, yellow fever, and smallpox, are analogous strategies in the closely parallel set to reduce losses from infectious agents.)

The *ninth* strategy in loss reduction applies to the damage not prevented by measures under the eight preceding – to move rapidly in detection and evaluation of damage that has occurred or is occurring, and to counter its continuation and extension. The generation of a signal that response is required; the signal's transfer, receipt, and evaluation; the decision and follow-through, are all elements here – whether the issue be an urban fire or wounds on the battlefield or highway. Sprinkler and other suppressor responses, firedoors, MAYDAY and SOS calls, fire alarms, emergency medical care, emergency transport, and related tactics all illustrate this countermeasure strategy. (Such tactics have close paralleles in many earlier stages of the sequence discussed here, as, for example, storm and tsunami warnings.)

The *tenth* strategy encompasses all the measures between the emergency period following the damaging energy exchange and the final stabilization of the process after appropriate intermediate and long-term reparative and rehabilitative measures. These may involve return to the pre-event status or stabilization in structurally or functionally altered states.

Separation of loss reduction and causation

There are, of course, many real-world variations on the main theme. These include those unique to each particular form of energy and those determined by the geometry and other characteristics of the energy's path and the point or area and characteristics of the structure on which it impinges – whether a BB hits the forehead or the center of the cornea.

One point, however, is of overriding importance: subject to qualifications as noted subsequently, there is no logical reason why the rank order (or priority) of loss-reduction countermeasures generally considered must parallel the sequence, or rank order, of causes contributing to the result of damaged people or property. One can eliminate losses in broken teacups by packaging them properly (the sixth strategy), even though they be placed in motion in the hands of the postal service, vibrated, dropped, piled on, or otherwise abused. Similarly, a vehicle crash, per se, need necessitate no injury, nor a hurricane housing damage.

Failure to understand this point in the context of measures to reduce highway losses underlies the common statement: 'If it's the driver, why talk about the vehicle?' This confuses the rank or sequence of causes, on the one hand, with that of a loss-reduction countermeasure – in this case 'crash packaging' – on the other.

There are, nonetheless, practical limits in physics, biology, and strategy potentials. One final limit is operative at the boundary between the objectives of the eighth and ninth strategies. Once appreciable injury to man or to other living structure occurs, complete elimination of undesirable end results is often impossible, though appreciable reduction is commonly achievable. (This is often also true for inanimate structures, for example, teacups.) When lethal damage has occurred, the subsequent strategies, except as far as the strictly secondary salvage of parts is concerned, have no application.

There is another fundamental constraint. Generally speaking, the larger the amounts of energy involved in relation to the resistance to damage of the structures at risk, the earlier in the countermeasure sequence must be strategy lie. In the ultimate case, that of a potential energy release of proportions that could not be countered to any satisfactory extent by any known means, the prevention of marshalling or of release, or both, becomes the only approach available. Furthermore, in such an ultimate case, if there is a finite probability of release, prevention of marshalling (and dismantling of stockpiles of energy already marshalled) becomes the only, and essential, strategy to assure that the undesirable end result cannot occur.

For each strategy an analogous opposite

Although the concern here is the reduction of damage produced by energy transfer, it is noteworthy that to each strategy there is an opposite focused on increasing damage. The latter are most commonly seen in collective and individual violence – as in war, homicide, and arson. Various of them are also seen in manufacturing, mining, machining, hunting, and some medical and other activities in which structural damage, often of a very specific nature, is sought. (A medical illustration would be the destruction of the anterior pituitary with a beam of ionizing radiation as a measure to eliminate pathologic hyperactivity.) For example, a marker of motor vehicles or of aircraft landing-gear struts – a product predictably subject to energy insults – could make his product more delicate, both to increase labor and sales of parts and materials, and to shorten its average useful life by decreasing the age at which commonplace amounts of damage increasingly exceed in cost the depreciating value of the product in use. The manufacturer might also design for difficulty of repair by using complex exterior sheet metal surfaces, making components difficult to get at, and other means.

The type of categorization outlined here is similar to those useful for dealing systematically with other environmental problems and their ecology. In brief illustration, various species of toxic and environment-damaging atoms (such as lead), molecules (eg DDT and heroin), and mixtures (garbage and some air pollutants, among others) are marshalled, go through series of physical states and situations, interact with structures and systems of various characteristics, and produce damage in sequences leading to the final, stable results.

Similar comments can be made concerning the ecology of some of the viral, unicellular, and metazoan organisms that attack animate and inanimate structures; their hosts; and the types of stages of damage they produce. Actual and potential birth control and related strategies and tactics can be somewhat similarly categorized. Thus, in brief, beginning on the male line: preventing the marshalling of viable sperm (by castration or certain pharmacological agents); reducing the amount of sperm produced; preventing the release of semen (or of one of its necessary components, eg, by vasectomy); modifying the rate of spatial distribution of release of semen (as in hypospadias, a usually developmental or traumatic condition in which the urethra opens on the underside of the penis, sometimes near its base); separating semen release in space or time from the susceptible ovum (eg continence, limiting intercourse to presumably nonfertile periods, coitus interruptus, and preventing a fertile ovum from being present when sperm arrive); separation by interposition of a material barrier (eg, condoms, spermicidal creams, foams, jellies); increasing resistance of the ovum to penetration; making the ovum infertile, even if penetrated; prevention of implantation of the fertilized egg; abortion; and infanticide.

Sufficient differences among systems often exist, however – for example, the ecology of the agents of many anthropod-borne diseases is quite complex, and the life cycles of organisms such as schistosomes require two or more different host species in sequence – to preclude at this time many generalizations useful across the breadth of all environmental hazards and their damaging interactions with other organisms and structures.

A systemic analysis of options

It has not generally been customary for individuals and organizations that influence, or are influenced by, damage due to harmful transfers of energy to analyze systematically their options for loss reduction, the mix of strategies and tactics they might employ, and their cost. Yet is is entirely feasible and not especially difficult to do so, although specific supporting data are still often lacking. In fact, unless such systematic analysis is done routinely and well, it is generally impossible to maximize the pay-offs both of loss-reduction planning and of resource allocations.

Such analysis is also needed to consider properly the problems inherent in the use of given strategies in specific situations. Different strategies to accomplish the same end commonly have different requirements; in kinds and numbers of people, in the disciplines involved, in material resources, in capital investments, and in public and professional education, among others. In the case of some damage-reduction problems, particular strategies may require political and legislative action more than others. And, where the potential or actual hazard exists across national boundaries, correspondingly international action is commonly essential.

The types of concepts outlined in this note are basic to dealing with important aspects of the quality of life, and all of the professions concerned with the environment and with the public health need to understand and apply the principles involved – and not in the haphazard, spotty, and poorly conceptualized fashion now virtually universal. It is the purpose of this brief note to introduce the pathway along which this can be achieved.

1 Baker SP. Injury control, accident prevention and other approaches to reduction of injury. In: Sartwell PE, ed. *Preventive medicine and public health (10th edition)*. Appleton-Century-Crofts, in press. Preprint distributed by Insurance Institute for Highway Safety, 1972.
2 Brown EW. Space-heater hazards. *N Engl J Med* 1961; **265:** 794–5.
3 Deuteronomy 22:8.
4 Exodus 14:21–9.
5 Goggin JE, Haddon W Jr, Hambly GS, *et al.* Incidence of femoral fractures in post-menopausal women before and after water fluoridation. *Public Health Rep* 1965; **80:** 1005–12.
6 Haddon W Jr. A note concerning accident theory and research with special reference to motor vehicle accidents. *Ann NY Acad Sci* 1963; **107:** 635–46.
7 Haddon W Jr. The prevention of accidents. In: Clark DW, MacMahon B, ed. *Textbook of preventive medicine.* Little, Brown & Co, 1967: 591–621.
8 Haddon W Jr. The changing approach to the epidemiology, prevention, and amelioration of trauma: the transition to approaches etiologically rather than descriptively based. *Am J Public Health* 1968; **58:** 1431–8.
9 Haddon W Jr. Approaching the epidemiology of head injury: an introductory note (Editorial). *J Trauma* 1970; **10:** 712–4.
10 Haddon W Jr. On the escape of tigers: an ecologic note. (Strategy options in reducing losses in energy-damaged people and property). *Technol Rev* (MIT) 1970; **72:** 44–53.
11 Haddon W Jr. A logical framework for categorizing highway safety phenomena and activity. *J Trauma* 1972; **12:** 193–207.
12 Haddon W Jr. Exploring the options. In: *Conference on research directions towards the reduction of injury in the young and the old* (Sponsored by The National Institute of Child Health and Human Development, May 12–14, 1971). US Government Printing Office, in press, 1973.
13 Haddon W Jr, Goddard JL. An analysis of highway safety strategies. In: *Passenger care design and highway safety: proceedings of a conference on research.* Association for the Aid of Crippled Children and Consumers Union of the US, 1962. 6–11.
14 Haddon W Jr, Suchman EA, Klein D. *Accident research, methods and approaches.* Harper & Row, 1964.
15 Hippocrates. On injuries of the head. In: Adams F (tr). *The genuine works of Hippocrates.* Baltimore: The Williams & Wilkins Co, 1939.
16 Malinowsky B. *Magic, science and religion, and other essays.* Garden City, NY: Doubleday Anchor Books, 1948.
17 Waller JA. Tic-tac-toe burns — the hazard of exposed floor-type room heaters. *N Engl J Med* 1961; **265:** 1256–7.